VAAGESWARI COLLEGE OF ENGINEERING

(Sponsored by SREE VAAGESWARI EDUCATIONAL SOCIETY)

Accredited by NAAC with A+ Grade

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ARTIFICIAL INTELLIGENCE

MCA II YEAR I SEMESTER

NOTES PREPARED BY

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DEPARTMENT OF MASTER OF COMPUTER APPLICATIONS

(Affiliated to JNTUH, Hyderabad, Approved by AICTE - Accredited by NAAC – 'A+' Grade)

Beside LMD Police Station,Ramakrisha Colony,Thimmapur,karimnagar, Telangana State, India

UNIT - I

Problem Solving by Search-I: Introduction to AI, Intelligent Agents Problem Solving by Search –II: Problem-Solving Agents, Searching for Solutions, Uninformed Search Strategies: Breadth-first search, Uniform cost search, Depth-first search, Iterative deepening Depth-first search, Bidirectional search, Informed (Heuristic) Search Strategies: Greedy best-first search, A* search, Heuristic Functions, Beyond Classical Search: Hill-climbing search, Simulated annealing search, Local Search in Continuous Spaces, Searching with Non-Deterministic Actions, Searching with Partial Observations, Online Search Agents and Unknown Environment .

UNIT-II

Problem Solving by Search-II and Propositional Logic .Adversarial Search: Games, Optimal Decisions in Games, Alpha–Beta Pruning, Imperfect Real-Time Decisions.

Constraint Satisfaction Problems: Defining Constraint Satisfaction Problems, Constraint Propagation, Backtracking Search for CSPs, Local Search for CSPs, The Structure of Problems.

UNIT-III

Propositional Logic: Knowledge-Based Agents, The Wumpus World, Logic, Propositional Logic, Propositional Theorem Proving: Inference and proofs, Proof by resolution, Horn clauses and definite clauses, Forward and backward chaining, Effective Propositional Model Checking, Agents Based onPropositional Logic.

Logic and Knowledge Representation

First-Order Logic: Representation, Syntax and Semantics of First-Order Logic, Using FirstOrder Logic, Knowledge Engineering in First-Order Logic.

Inference in First-Order Logic: Propositional vs. First-Order Inference, Unification and Lifting, Forward Chaining, Backward Chaining, Resolution.

UNIT-IV

Knowledge Representation: Ontological Engineering, Categories and Objects, Events. Mental Events and Mental Objects, Reasoning Systems for Categories, Reasoning with Default Information.

Planning

Classical Planning: Definition of Classical Planning, Algorithms for Planning with StateSpace Search, Planning Graphs, other Classical Planning Approaches, Analysis of Planning approaches.

Planning and Acting in the Real World: Time, Schedules, and Resources, Hierarchical Planning, Planning and Acting in Nondeterministic Domains, Multi agent Planning.

UNIT-V

Learning: Forms of Learning, Supervised Learning, Learning Decision Trees.Knowledge in Learning: Logical Formulation of Learning,

Knowledge in Learning, Explanation-Based Learning, Learning Using Relevance Information, Inductive Logic Programming.

TEXT BOOKS

1. Artificial Intelligence A Modern Approach, Third Edition, Stuart Russell and Peter Norvig, Pearson Education.

REFERENCES:

1. Artificial Intelligence, 3rd Edn., E. Rich and K. Knight (TMH)
2. Artificial Intelligence, 3rd Edn., Patrick Henny Winston, Pearson Education.
3. Artificial Intelligence, Shivani Goel, Pearson Education.
4. Artificial Intelligence and Expert systems – Patterson, Pearson Education.

Artificial Intelligence Will Reach Human Levels By Around 2029. Follow That Out Further To, Say, 2045, We Will Have Multiplied The Intelligence, The Human Biological Machine Intelligence Of Our Civilization A Billion-Fold."

Note: These notes are not enough, For more learning refer the above Text book and Reference Books

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UNIT I:

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VAAGESWARI COLLEGE OF ENGINEERING-DEPARTMENT OF MCA

Introduction:

- Artificial Intelligence is concerned with the design of intelligence in an artificial device. The term was coined by John McCarthy in 1956.
- Intelligence is the ability to acquire, understand and apply the knowledge to achieve goals in the world.
- AI is the study of the mental faculties through the use of computational models
- AI is the study of intellectual/mental processes as computational processes.
- AI program will demonstrate a high level of intelligence to a degree that equals or exceeds the intelligence required of a human in performing some task.
- AI is unique, sharing borders with Mathematics, Computer Science, Philosophy, Psychology, Biology, Cognitive Science and many others.
- Although there is no clear definition of AI or even Intelligence, it can be described as an attempt to build machines that like humans can think and act, able to learn and use knowledge to solve problems on their own.

History of AI:

Important research that laid the groundwork for AI:

- In 1931, Goedel layed the foundation of Theoretical Computer Science**1920-30s**:

  He published the first universal formal language and showed that math itself is either flawed or allows for unprovable but true statements.

- In 1936, Turing reformulated Goedel's result and church's extension thereof.

- In 1956, John McCarthy coined the term "Artificial Intelligence" as the topic of the **Dartmouth Conference**, the first conference devoted to the subject.

- In 1957, The **General Problem Solver (GPS)** demonstrated by Newell, Shaw & Simon
- In 1958, John McCarthy (MIT) invented the Lisp language.
- In 1959, Arthur Samuel (IBM) wrote the first game-playing program, for checkers, to achieve sufficient skill to challenge a world champion.
- In 1963, Ivan Sutherland's MIT dissertation on Sketchpad introduced the idea of interactive graphics into computing.
- In 1966, Ross Quillian (PhD dissertation, Carnegie Inst. of Technology; now CMU) demonstrated semantic nets
- In 1967, Dendral program (Edward Feigenbaum, Joshua Lederberg, Bruce Buchanan, Georgia Sutherland at Stanford) demonstrated to interpret mass spectra on organic chemical compounds. First successful knowledge-based program for scientific reasoning.
- In 1967, Doug Engelbart invented the mouse at SRI
- In 1968, Marvin Minsky & Seymour Papert publish Perceptrons, demonstrating limits of simple neural nets.
- In 1972, Prolog developed by Alain Colmerauer.
- In Mid 80's, Neural Networks become widely used with the Backpropagation algorithm (first described by Werbos in 1974).
- 1990, Major advances in all areas of AI, with significant demonstrations in machine learning, intelligent tutoring, case-based reasoning, multi-agent planning, scheduling, uncertain reasoning, data mining, natural language understanding and translation, vision, virtual reality, games, and other topics.
- In 1997, Deep Blue beats the World Chess Champion Kasparov
- In 2002,iRobot, founded by researchers at the MIT Artificial Intelligence Lab, introduced **Roomba**, a vacuum cleaning robot. By 2006, two million had been sold.

Foundations of Artificial Intelligence:

- **Philosophy**

  e.g., foundational issues (can a machine think?), issues of knowledge and believe, mutual knowledge

- **Psychology and Cognitive Science**

  e.g., problem solving skills
- **Neuro-Science**

  e.g., brain architecture
- **Computer Science And Engineering**

  e.g., complexity theory, algorithms, logic and inference, programming languages, and system building.
- **Mathematics and Physics**

  e.g., statistical modeling, continuous mathematics,
- **Statistical Physics, and Complex Systems**.

SUB AREAS OF AI:

1) **Game Playing**

   Deep Blue Chess program beat world champion Gary Kasparov
2) **Speech Recognition**

   PEGASUS spoken language interface to American Airlines' EAASY SABRE reseration system, which allows users to obtain flight information and make reservations over the telephone. The 1990s has seen significant advances in speech recognition so that limited systems are now successful.
3) **Computer Vision**

   Face recognition programs in use by banks, government, etc. The ALVINN system from CMU autonomously drove a van from Washington, D.C. to San Diego (all but 52 of 2,849 miles), averaging 63 mph day and night, and in all weather conditions. Handwriting recognition, electronics and manufacturing inspection, photo interpretation, baggage inspection, reverse engineering to automatically construct a 3D geometric model.
4) **Expert Systems**

   Application-specific systems that rely on obtaining the knowledge of human experts in an area and programming that knowledge into a system.

   a. **Diagnostic Systems** : MYCIN system for diagnosing bacterial infections of the blood and suggesting treatments. Intellipath pathology diagnosis system (AMA approved). Pathfinder medical diagnosis system, which suggests tests and makes diagnoses. Whirlpool customer assistance center.

b. **System Configuration**

DEC's XCON system for custom hardware configuration. Radiotherapy treatment planning.

c. **Financial Decision Making**

Credit card companies, mortgage companies, banks, and the U.S. government employ AI systems to detect fraud and expedite financial transactions. For example, AMEX credit check.

d. **Classification Systems**

Put information into one of a fixed set of categories using several sources of information. E.g., financial decision making systems. NASA developed a system for classifying very faint areas in astronomical images into either stars or galaxies with very high accuracy by learning from human experts' classifications.

5) **Mathematical Theorem Proving**

Use inference methods to prove new theorems.

6) **Natural Language Understanding**

AltaVista's translation of web pages. Translation of Catepillar Truck manuals into 20 languages.

7) **Scheduling and Planning**

Automatic scheduling for manufacturing. DARPA's DART system used in Desert Storm and Desert Shield operations to plan logistics of people and supplies. American Airlines rerouting contingency planner. European space agency planning and scheduling of spacecraft assembly, integration and verification.

8) **Artificial Neural Networks:**

9) **Machine Learning**

APPLICATION OF AI:

AI algorithms have attracted close attention of researchers and have also been applied successfully to solve problems in engineering. Nevertheless, for large and complex problems, AI algorithms consume considerable computation time due to stochastic feature of the search approaches

1) Business; financial strategies

2) Engineering: check design, offer suggestions to create new product, expert systems for all engineering problems

3) Manufacturing: assembly, inspection and maintenance

4) Medicine: monitoring, diagnosing

5) Education: in teaching

6) Fraud detection

7) Object identification

8) Information retrieval

9) Space shuttle scheduling

Building AI Systems:

1) Perception

Intelligent biological systems are physically embodied in the world and experience the world through their sensors (senses). For an autonomous vehicle, input might be images from a camera and range information from a rangefinder. For a medical diagnosis system, perception is the set of symptoms and test results that have been obtained and input to the system manually.

2) Reasoning

Inference, decision-making, classification from what is sensed and what the internal "model" is of the world. Might be a neural network, logical deduction system, Hidden Markov Model induction, heuristic searching a problem space, Bayes Network inference, genetic algorithms, etc.

Includes areas of knowledge representation, problem solving, decision theory, planning, game theory, machine learning, uncertainty reasoning, etc.

3) Action

Biological systems interact within their environment by actuation, speech, etc. All behavior is centered around actions in the world. Examples include controlling the steering of a Mars rover or autonomous vehicle, or suggesting tests and making diagnoses for a medical diagnosis system. Includes areas of robot actuation, natural language generation, and speech synthesis.

THE DEFINITIONS OF AI:

a) "The exciting new effort to make computers think . . . *machines with minds,* in the full and literal sense" (Haugeland, 1985) "The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning..."(Bellman, 1978)	b) "The study of mental faculties through the use of computational models" (Charniak and McDermott, 1985) "The study of the computations that make it possible to perceive, reason, and act" (Winston, 1992)
c) "The art of creating machines that perform functions that require intelligence when performed by people" (Kurzweil, 1990) "The study of how to make computers do things at which, at the moment, people are better" (Rich and Knight, 1 99 1)	d) "A field of study that seeks to explain and emulate intelligent behavior in terms of computational processes" (Schalkoff, 1 990) "The branch of computer science that is concerned with the automation of intelligent behavior" (Luger and Stubblefield, 1993)

The definitions on the top, **(a)** and **(b)** are concerned with **reasoning**, whereas those on the bottom**, (c)** and **(d)** address **behavior.**The definitions on the left, **(a)** and **(c)** measure success in terms of human performance, and those on the right, **(b)** and **(d)** measure the ideal concept of intelligence called rationality

INTELLIGENT SYSTEMS:

In order to design intelligent systems, it is important to categorize them into four categories (Luger and Stubberfield 1993), (Russell and Norvig, 2003)

1. Systems that think like humans
2. Systems that think rationally
3. Systems that behave like humans
4. Systems that behave rationally

	Human- Like	**Rationally**
Think:	**Cognitive Science Approach** ***"Machines that think like humans"***	**Laws of thought Approach** ***" Machines that think Rationally"***
Act:	**Turing Test Approach** ***"Machines that behave like humans"***	**Rational Agent Approach** ***"Machines that behave Rationally"***

Scientific Goal: To determine which ideas about knowledge representation, learning, rule systems search, and so on, explain various sorts of real intelligence.

Engineering Goal: To solve real world problems using AI techniques such as Knowledge representation, learning, rule systems, search, and so on.

Traditionally, computer scientists and engineers have been more interested in the engineering goal, while psychologists, philosophers and cognitive scientists have been more interested in the scientific goal.

Cognitive Science: Think Human-Like

a. Requires a model for human cognition. Precise enough models allow simulation by computers.

b. Focus is not just on behavior and I/O, but looks like reasoning process.

c. Goal is not just to produce human-like behavior but to produce a sequence of steps of the reasoning process, similar to the steps followed by a human in solving the same task.

Laws of thought: Think Rationally

a. The study of mental faculties through the use of computational models; that it is, the study of computations that make it possible to perceive reason and act.

b. Focus is on inference mechanisms that are probably correct and guarantee an optimal solution.

c. Goal is to formalize the reasoning process as a system of logical rules and procedures of inference.

d. Develop systems of representation to allow inferences to be like

"*Socrates is a man. All men are mortal. Therefore Socrates is mortal"*

TURING TEST: ACT HUMAN-LIKE

a. The art of creating machines that perform functions requiring intelligence when performed by people; that it is the study of, how to make computers do things which, at the moment, people do better.

b. Focus is on action, and not intelligent behavior centered around the representation of the world

c. Example: Turing Test

- 3 rooms contain: a person, a computer and an interrogator.
- The interrogator can communicate with the other 2 by teletype (to avoid the machine imitate the appearance of voice of the person)

- The interrogator tries to determine which the person is and which the machine is.
- The machine tries to fool the interrogator to believe that it is the human, and the person also tries to convince the interrogator that it is the human.
- If the machine succeeds in fooling the interrogator, then conclude that the machine is intelligent.

Rational agent: Act Rationally

a. Tries to explain and emulate intelligent behavior in terms of computational process; that it is concerned with the automation of the intelligence.

b. Focus is on systems that act sufficiently if not optimally in all situations.

c. Goal is to develop systems that are rational and sufficient

The difference between strong AI and weak AI:

Strong AI makes the bold claim that computers can be made to think on a level (at least) equal to humans.

Weak AI simply states that some "thinking-like" features can be added to computers to make them more useful tools... and this has already started to happen (witness expert systems, drive-by-wire cars and speech recognition software).

AI Problems:

AI problems (speech recognition, NLP, vision, automatic programming, knowledge representation, etc.) can be paired with techniques (NN, search, Bayesian nets, production systems, etc.).AI problems can be classified in two types:

1. Common-place tasks(Mundane Tasks)
2. Expert tasks

Common-Place Tasks:

1. *Recognizing* people, objects.
2. Communicating (through *natural language*).
3. *Navigating* around obstacles on the streets.

These tasks are done matter of factly and routinely by people and some other animals.

Expert tasks:

1. Medical diagnosis.
2. Mathematical problem solving
3. Playing games like chess

These tasks cannot be done by all people, and can only be performed by skilled specialists.

Clearly tasks of the first type are easy for humans to perform, and almost all are able to master them. The second range of tasks requires skill development and/or intelligence and only some specialists can perform them well. However, when we look at what computer systems have been able to achieve to date, we see that their achievements include performing sophisticated tasks like medical diagnosis, performing symbolic integration, proving theorems and playing chess.

1. Intelligent Agent's:

Agents andenvironments:

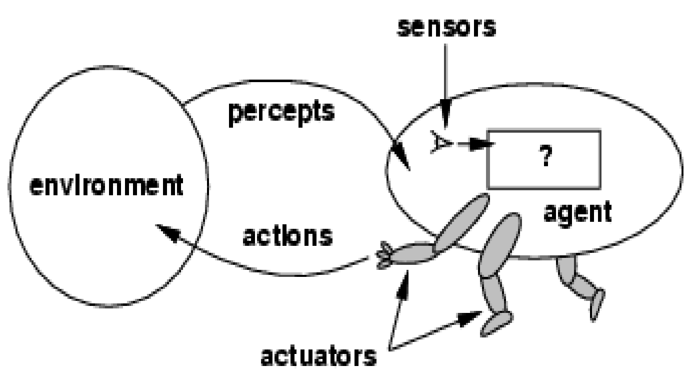


Fig 2.1: Agents and Environments

Agent:

An *Agent* is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators.

- ✓ A *human agent* has eyes, ears, and other organs for sensors and hands, legs, mouth, and other body parts foractuators.
- ✓ A *robotic agent* might have cameras and infrared range finders for sensors and various motors foractuators.
- ✓ A *software agent* receives keystrokes, file contents, and network packets as sensory

inputs and acts on the environment by displaying on the screen, writing files, and sending network packets.

Percept:

We use the term percept to refer to the agent's perceptual inputs at any given instant.

PerceptSequence:

An agent's percept sequence is the complete history of everything the agent has ever perceived.

Agent function:

Mathematically speaking, we say that an agent's behavior is described by the agent function that maps any **given percept sequence to an action**.

Agentprogram

Internally, the agent function for an artificial agent will be implemented by an agent program. It is important to keep these two ideas distinct. The agent function is an abstract mathematical description; the agent program is a concrete implementation, running on the agent architecture.

To illustrate these ideas, we will use a very simple example-the vacuum-cleaner world shown in **Fig 2.1.5**. This particular world has just two locations: squares A and B. The vacuum agent perceives which square it is in and whether there is dirt in the square. It can choose to move left, move right, suck up the dirt, or do nothing. One very simple agent function is the following: if the current square is dirty, then suck, otherwise move to the other square. A partial tabulation of this agent function is shown in **Fig 2.1.6**.

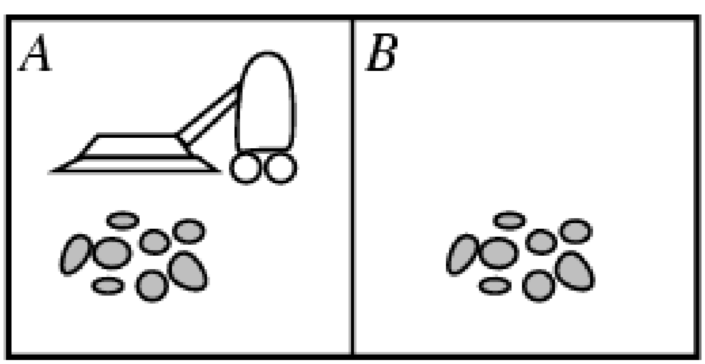


Fig 2.1.5: A vacuum-cleaner world with just two locations.

Agentfunction

Percept Sequence	**Action**
[A, Clean]	Right
[A, Dirty]	Suck
[B, Clean]	Left
[B, Dirty]	Suck
[A, Clean], [A, Clean]	Right
[A, Clean], [A, Dirty]	Suck
…	

Fig 2.1.6: Partial tabulation of a simple agent function for the example: vacuum-cleaner world shown in the **Fig 2.1.5**

```
Function REFLEX-VACCUM-AGENT ([location, status]) returns an action If

status=Dirty then return Suck

else if location = A then return Right

else if location = B then return Left
```

Fig 2.1.6(i): The REFLEX-VACCUM-AGENT program is invoked for each new percept (location, status) and returns **an** action each time

Strategies of Solving Tic-Tac-Toe Game Playing

Tic-Tac-Toe Game Playing:

Tic-Tac-Toe is a simple and yet an interesting board game. Researchers have used various approaches to study the Tic-Tac-Toe game. For example, Fok and Ong and Grim et al. have used artificial neural network based strategies to play it. Citrenbaum and Yakowitz discuss games like Go-Moku, Hex and Bridg-It which share some similarities with Tic-Tac-Toe.

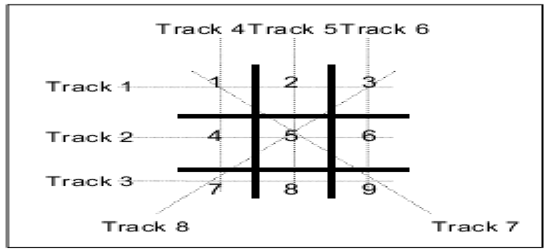


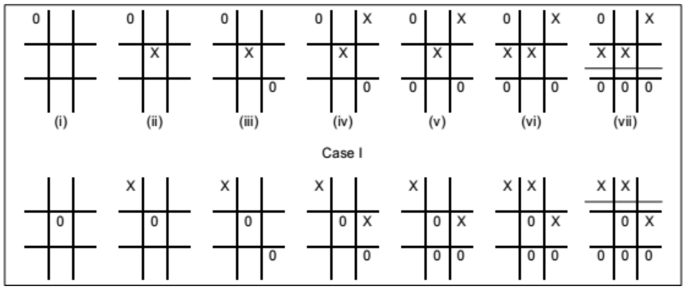
Fig 1.

A Formal Definition of the Game:

The board used to play the Tic-Tac-Toe game consists of 9 cells laid out in the form of a 3x3 matrix (Fig. 1). The game is played by 2 players and either of them can start. Each of the two players is assigned a unique symbol (generally 0 and X). Each player alternately gets a turn to make a move. Making a move is compulsory and cannot be deferred. In each move a player places the symbol assigned to him/her in a hitherto blank cell.

Let a track be defined as any row, column or diagonal on the board. Since the board is a square matrix with 9 cells, all rows, columns and diagonals have exactly 3 cells. It can be easily observed that there are 3 rows, 3 columns and 2 diagonals, and hence a total of 8 tracks on the board (Fig. 1). The goal of the game is to fill all the three cells of any track on the board with the symbol assigned to one before the opponent does the same with the symbol assigned to him/her. At any point of the game, if there exists a track whose all three cells have been marked by the same symbol, then the player to whom that symbol have been assigned wins and the game terminates. If there exist no track whose cells have been marked by the same symbol when there is no more blank cell on the board then the game is drawn.

Let the priority of a cell be defined as the number of tracks passing through it. The priorities of the nine cells on the board according to this definition are tabulated in Table 1. Alternatively, let the priority of a track be defined as the sum of the priorities of its three cells. The priorities of the eight tracks on the board according to this definition are tabulated in Table 2. The prioritization of the cells and the tracks lays the foundation of the heuristics to be used in this study. These heuristics are somewhat similar to those proposed by Rich and Knight.



Strategy 1:

Algorithm:

1. View the vector as a ternary number. Convert it to a decimal number.

2. Use the computed number as an index into Move-Table and access the vector stored there.

3. Set the new board to that vector.

Procedure:

1) Elements of vector:

0: Empty

1: X

2: O

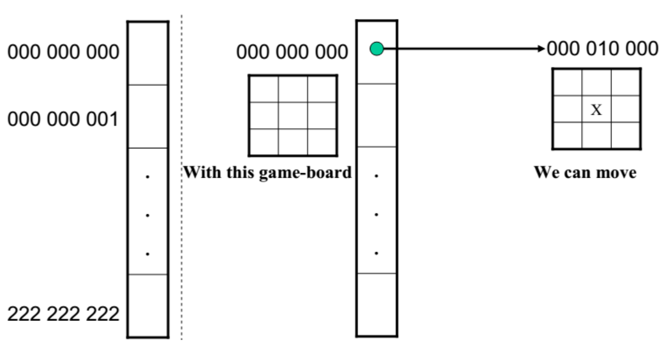
→ the vector is a ternary number

2) Store inside the program a move-table (lookuptable):

a) Elements in the table: 19683 (3^9)

b) Element = A vector which describes the most suitable move from the

❖ Data Structure:



Comments:

1. A lot of space to store the Move-Table.

2. A lot of work to specify all the entries in the Move-Table.

3. Difficult to extend

Explanation of Strategy 2 of solving Tic-tac-toe problem

Stratergy 2:

Data Structure:

1) Use vector, called board, as Solution 1

2) However, elements of the vector:

   2: Empty

   3: X

   5: O

3) Turn of move: indexed by integer

   1,2,3, etc

Function Library:

1.Make2:

a) Return a location on a game-board.

IF (board[5] = 2)

RETURN 5; //the center cell.

ELSE

RETURN any cell that is not at the board's corner;

// (cell: 2,4,6,8)

b) Let P represent for X or O

c) can_win(P) :

P has filled already at least two cells on a straight line (horizontal, vertical, or diagonal)

d) cannot_win(P) = NOT(can_win(P))

2. Posswin(P):

IF (cannot_win(P))

RETURN 0;

ELSE

RETURN index to the empty cell on the line of

can_win(P)

Let odd numbers are turns of X

Let even numbers are turns of O

3. Go(n): make a move

Algorithm:

1. Turn = 1: (X moves)

Go(1) //make a move at the left-top cell

2. Turn = 2: (O moves)

IF board[5] is empty THEN

Go(5)

ELSE

Go(1)

3. Turn = 3: (X moves)

IF board[9] is empty THEN

Go(9)

ELSE

Go(3).

4. Turn = 4: (O moves)

IF Posswin (X) <> 0 THEN

Go (Posswin (X))

//Prevent the opponent to win

ELSE Go (Make2)

5. Turn = 5: (X moves)

IF Posswin(X) <> 0 THEN

Go(Posswin(X))

//Win for X.

ELSE IF Posswin(O) <> THEN

Go(Posswin(O))

//Prevent the opponent to win

ELSE IF board[7] is empty THEN

Go(7)

ELSE Go(3).

Comments:

1. Not efficient in time, as it has to check several conditions before making each move.
2. Easier to understand the program's strategy.
3. Hard to generalize.

Introduction to Problem Solving, General problem solving

Problem solving is a process of generating solutions from observed data.

−a problem is characterized by a set of goals,

−a set of objects, and

−a set of operations.

These could be ill-defined and may evolve during problem solving.

Searching Solutions:

To build a system to solve a problem:

1. Define the problem precisely
2. Analyze the problem
3. Isolate and represent the task knowledge that is necessary to solve the problem
4. Choose the best problem-solving techniques and apply it to the particular problem.

Defining the problem as State Space Search:

The state space representation forms the basis of most of the AI methods.

- Formulate a problem as a **state space search** by showing the legal problem states, the legal operators, and the initial and goal states.
- A **state** is defined by the specification of the values of all attributes of interest in the world
- An **operator** changes one state into the other; it has a precondition which is the value of certain attributes prior to the application of the operator, and a set of effects, which are the attributes altered by the operator
- The **initial state** is where you start
- The **goal state** is the partial description of the solution

Formal Description of the problem:

1. Define a state space that contains all the possible configurations of the relevant objects.
2. Specify one or more states within that space that describe possible situations from which the problem solving process may start **(initial state)**
3. Specify one or more states that would be acceptable as solutions to the problem**. (goal states)**

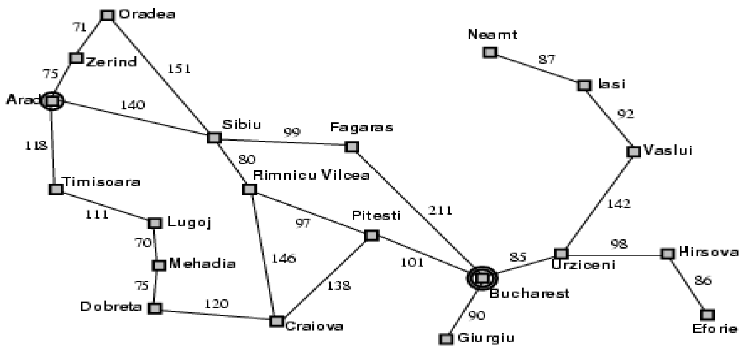
Specify a set of rules that describe the actions **(operations)** available

State-Space Problem Formulation:

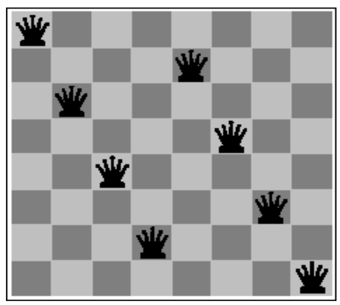
Example: A problem is defined by four items:

1. **initial state** e.g., "at Arad―
2. **actions or successor function** : *S(x)* = set of action–state pairs
   e.g., *S(Arad)* = {*<Arad → Zerind, Zerind>*, … }
3. **goal test (or set of goal states)**
   e.g., *x* = "at Bucharest‖, *Checkmate(x)*
4. **path cost (additive)**
   e.g., sum of distances, number of actions executed, etc.
   $c(x,a,y)$ is the step cost, assumed to be ≥ 0

A solution is a sequence of actions leading from the initial state to a goal state



Example: 8**-queens problem**



1. **Initial State**: Any arrangement of 0 to 8 queens on board.
2. **Operators**: add a queen to any square.
3. **Goal Test**: 8 queens on board, none attacked.
4. **Path cost**: not applicable or Zero (because only the final state counts, search cost might be of interest).

State Spaces versus Search Trees:

- State Space
    - o Set of valid states for a problem
    - o Linked by operators
    - o e.g., 20 valid states (cities) in the Romanian travel problem
- Search Tree
    - – Root node = initial state
    - – Child nodes = states that can be visited from parent
    - – Note that the depth of the tree can be infinite
        - E.g., via repeated states
    - – Partial search tree

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- Portion of tree that has been expanded so far
  - Fringe
    - Leaves of partial search tree, candidates for expansion

Search trees = data structure to search state-space

Properties of Search Algorithms

Which search algorithm one should use will generally depend on the problem domain.
There are four important factors to consider:

1. ***Completeness*** – Is a solution guaranteed to be found if at least one solution exists?

2. ***Optimality*** – Is the solution found guaranteed to be the best (or lowest cost) solution if there exists more than one solution?

3. ***Time Complexity*** – The upper bound on the time required to find a solution, as a function of the complexity of the problem.

4. ***Space Complexity*** – The upper bound on the storage space (memory) required at any point during the search, as a function of the complexity of the problem.

General problem solving, Water-jug problem, 8-puzzle problem

General Problem Solver*:*

The General Problem Solver (GPS) was the first useful AI program, written by Simon, Shaw, and Newell in 1959. As the name implies, it was intended to solve nearly any problem***.***

Newell and Simon defined each problem as a space. At one end of the space is the starting point; on the other side is the goal. The problem-solving procedure itself is conceived as a set of operations to cross that space, to get from the starting point to the goal state, one step at a time.

The General Problem Solver, the program tests various actions (which Newell and Simon called operators) to see which will take it closer to the goal state. An operator is any activity that changes the state of the system. The General Problem Solver always chooses the operation that appears to bring it closer to its goal.

Example: Water Jug Problem

Consider the following problem:

> A Water Jug Problem: You are given two jugs, a 4-gallon one and a 3-gallon one, a pump which has unlimited water which you can use to fill the jug, and the ground on which water may be poured. Neither jug has any measuring markings on it. How can you get exactly 2 gallons of water in the 4-gallon jug?

State Representation and Initial State :

> We will represent a state of the problem as a tuple (x, y) where x represents the amount of water in the 4-gallon jug and y represents the amount of water in the 3-gallon jug. Note 0 ≤x≤ 4, and 0 ≤y ≤3. Our initial state: (0, 0)

Goal Predicate - state = (2, y) where 0≤ y≤ 3.

Operators -we must defi ne a set of operators that will take us from one state to another:

1. Fill 4-gal jug	(x,y) x < 4	→ (4,y)
2. Fill 3-gal jug	(x,y) y < 3	→ (x,3)
3. Empty 4-gal jug on ground	(x,y) x > 0	→ (0,y)
4. Empty 3-gal jug on ground	(x,y) y > 0	→ (x,0)
5. Pour water from 3-gal jug to ll 4-gal jug	(x,y) 0 < x+y 4 and y > 0	→! (4, y - (4 - x))
6. Pour water from 4-gal jug to ll 3-gal-jug	(x,y) 0 < x+y 3 and x > 0	→ (x - (3-y), 3)
7. Pour all of water from 3-gal jug	(x,y)	→ (x+y, 0)

into 4-gal jug	0 < x+y 4 and y 0	
8. Pour all of water from 4-gal jug	(x,y)	→ (0, x+y)
into 3-gal jug	0 < x+y 3 and x 0	

Through Graph Search, the following solution is found :

Gals in 4-gal jug	Gals in 3-gal jug	Rule Applied
0	0	
		1. Fill 4
4	0	
		6. Pour 4 into 3 to ll
1	3	
		4. Empty 3
1	0	
		8. Pour all of 4 into 3
0	1	
		1. Fill 4
4	1	
		6. Pour into 3
2	3	

Second Solution:

Number of Steps	*Rules applied*	*4-g jug*	*3-g jug*
1	**Initial State**	0	0
2	R2 {Fill 3-g jug}	0	3
3	R7{Pour all water from 3 to 4-g jug }	3	0
4	R2 {Fill 3-g jug}	3	3
5	R5 {Pour from 3 to 4-g jug until it is full}	4	2
6	R3 {Empty 4-gallon jug}	0	2
7	R7 {Pour all water from 3 to 4-g jug}	2	0

Goal State

Control strategies

Control Strategies means how to decide which rule to apply next during the process of searching for a solution to a problem.

Requirement for a good Control Strategy

1. **It should cause motion**

   In water jug problem, if we apply a simple control strategy of starting each time from the top of rule list and choose the first applicable one, then we will never move towards solution.

2. **It should explore the solution space in a systematic manner**

   If we choose another control strategy, let us say, choose a rule randomly from the applicable rules then definitely it causes motion and eventually will lead to a solution. But one may arrive to same state several times. This is because control strategy is not systematic.

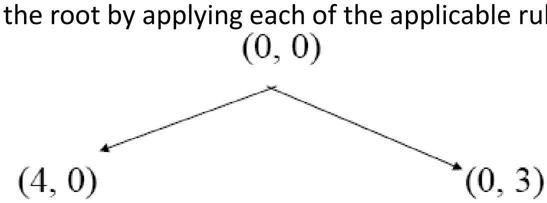
Systematic Control Strategies (Blind searches):

Breadth First Search:

Let us discuss these strategies using water jug problem. These may be applied to any search problem.

Construct a tree with the initial state as its root.

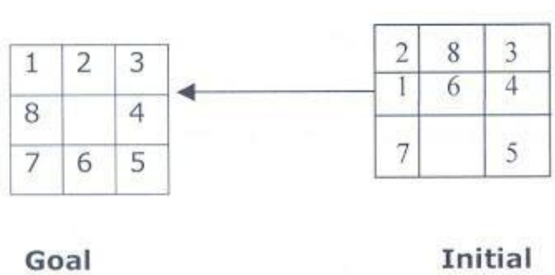
Generate all the offspring of the root by applying each of the applicable rules to the initial state.



Now for each leaf node, generate all its successors by applying all the rules that are appropriate.

8 Puzzle Problem.

The 8 puzzle consists of eight numbered, movable tiles set in a 3x3 frame. One cell of the frame is always empty thus making it possible to move an adjacent numbered tile into the empty cell. Such a puzzle is illustrated in following diagram.



The program is to change the initial configuration into the goal configuration. A solution to the problem is an appropriate sequence of moves, such as "move tiles 5 to the right, move tile 7 to the left, move tile 6 to the down, etc".

Solution:

To solve a problem using a production system, we must specify the global database the rules, and the control strategy. For the 8 puzzle problem that correspond to these three components. These elements are the problem states, moves and goal. In this problem each tile configuration is a state. The set of all configuration in the space of problem states or the problem space, there are only 3, 62,880 different configurations o the 8 tiles and blank space. Once the problem states have been conceptually identified, we must construct a computer representation, or description of them . this description is then used as the database of a production system. For the 8-puzzle, a straight forward description is a 3X3 array of matrix of numbers. The initial global database is this description of the initial problem state. Virtually any kind of data structure can be used to describe states.

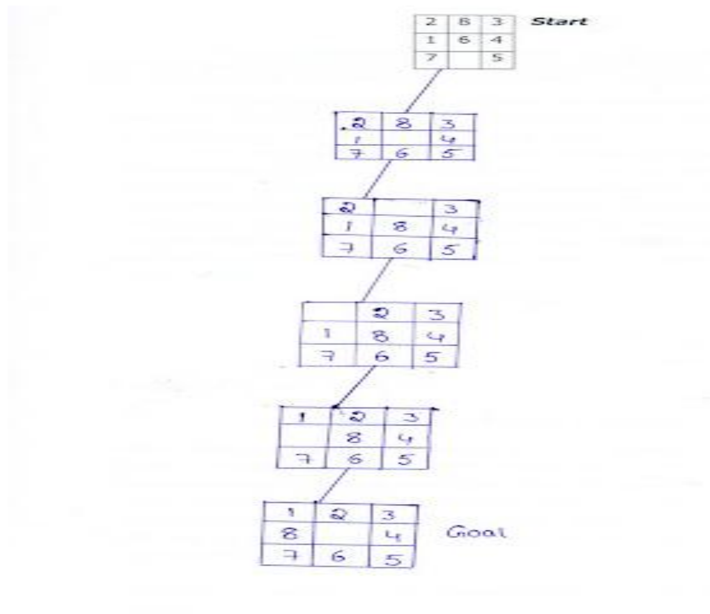
A move transforms one problem state into another state. The 8-puzzle is conveniently interpreted as having the following for moves. Move empty space (blank) to the left, move blank up, move blank to the right and move blank down,. These moves are modeled by production rules that operate on the state descriptions in the appropriate manner.

The rules each have preconditions that must be satisfied by a state description in order for them to be applicable to that state description. Thus the precondition for the rule associated with "move blank up" is derived from the requirement that the blank space must not already be in the top row.

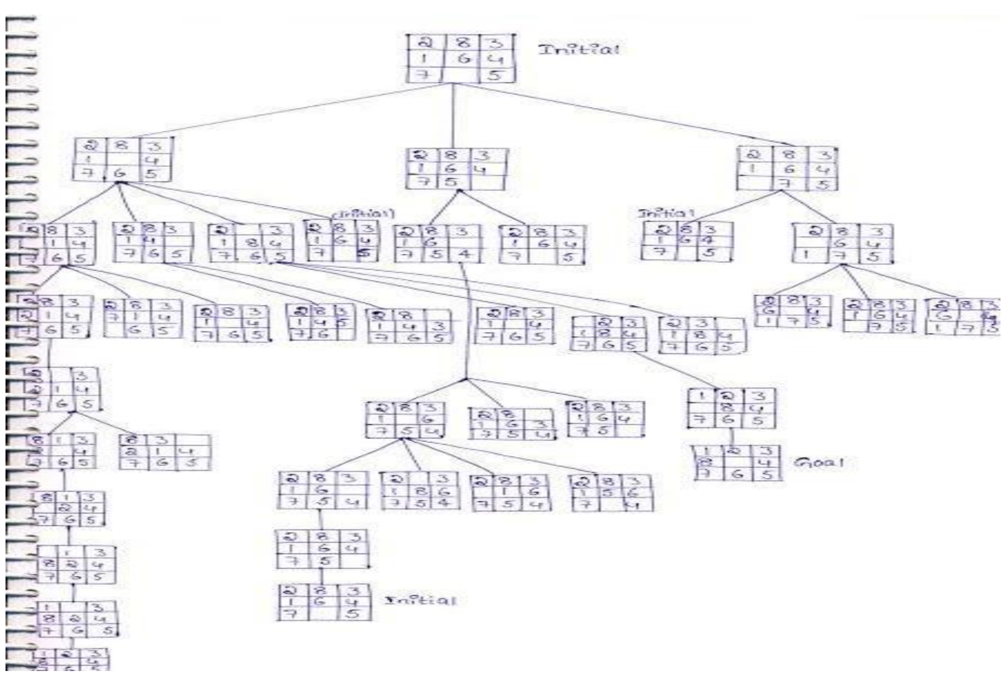
The problem goal condition forms the basis for the termination condition of the production system. The control strategy repeatedly applies rules to state descriptions until a description of a goal state is produced. It also keeps track of rules that have been applied so that it can compose them into sequence representing the problem solution. A solution to the 8-puzzle problem is given in the following figure.

Example:- Depth – First – Search traversal and Breadth - First - Search traversal

for 8 – puzzle problem is shown in following diagrams.



Searrh tree for 8-puzzle



Exhaustive Searches, BFS and DFS

Search is the systematic examination of states to find path from the start/root state to the goal state.

Many traditional search algorithms are used in AI applications. For complex problems, the traditional algorithms are unable to find the solution within some practical time and space limits. Consequently, many special techniques are developed; using heuristic functions. The algorithms that use heuristic functions are called heuristic algorithms. Heuristic algorithms are not really intelligent; they appear to be intelligent because they achieve better performance.

Heuristic algorithms aremore efficient because they take advantage of feedback from the data to direct the search path.

Uninformed search

Also called blind, exhaustive or brute-force search, uses no information about the problem to guide the search and therefore may not be very efficient.

Informed Search:

Also called heuristic or intelligent search, uses information about the problem to guide the search, usually guesses the distance to a goal state and therefore efficient, but the search may not be always possible.

Uninformed Search Methods:

Breadth- First -Search:

Consider the state space of a problem that takes the form of a tree. Now, if we search the goal along each breadth of the tree, starting from the root and continuing up to the largest depth, we call it *breadth first search*.

- **Algorithm:**
    1. Create a variable called NODE-LIST and set it to initial state
    2. Until a goal state is found or NODE-LIST is empty do
        a. Remove the first element from NODE-LIST and call it E. If NODE-LIST was empty, quit
        b. For each way that each rule can match the state described in E do:
            i. Apply the rule to generate a new state
            ii. If the new state is a goal state, quit and return this state
            iii. Otherwise, add the new state to the end of NODE-LIST

BFS illustrated:

Step 1: Initially fringe contains only one node corresponding to the source state A.

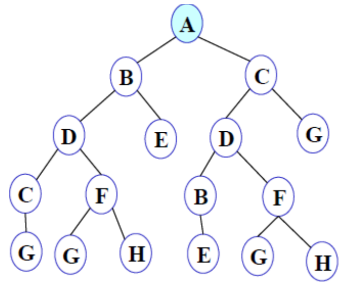


Figure 1

FRINGE: A

Step 2: A is removed from fringe. The node is expanded, and its children B and C are generated. They are placed at the back of fringe.

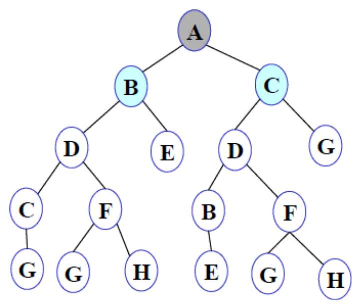


Figure 2

FRINGE: B C

Step 3: Node B is removed from fringe and is expanded. Its children D, E are generated and put at the back of fringe.

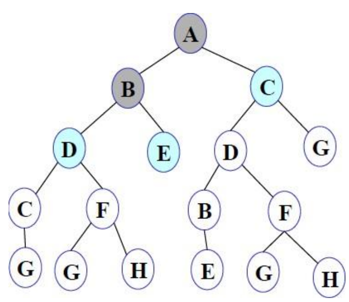


Figure 3

FRINGE: C D E

Step 4: Node C is removed from fringe and is expanded. Its children D and G are added to the back of fringe.

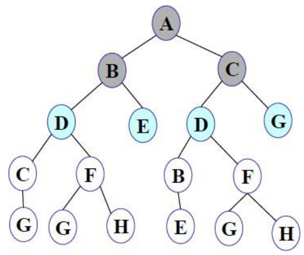


Figure 4

FRINGE: D E D G

Step 5: Node D is removed from fringe. Its children C and F are generated and added to the back of fringe.

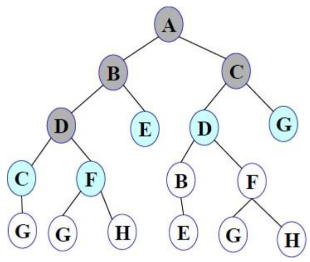


Figure 5

FRINGE: E D G C F

Step 6: Node E is removed from fringe. It has no children.

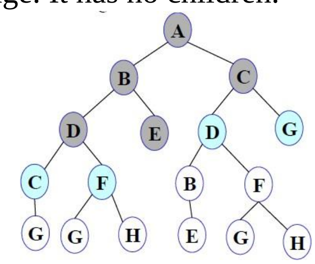


Figure 6

FRINGE: D G C F

Step 7: D is expanded; B and F are put in OPEN.

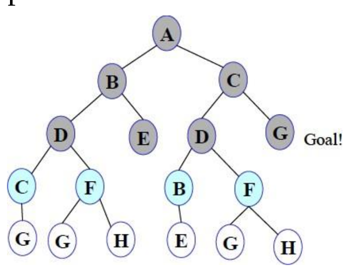


Figure 7

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Vaageswari College of Engineering
KARIMNAGAR-505 527.

FRINGE: G C F B F

Step 8: G is selected for expansion. It is found to be a goal node. So the algorithm returns the path A C G by following the parent pointers of the node corresponding to G. The algorithm terminates.

Breadth first search is:

- One of the simplest search strategies
- Complete. If there is a solution, BFS is guaranteed to find it.
- If there are multiple solutions, then a minimal solution will be found
- The algorithm is optimal (i.e., admissible) if all operators have the same cost. Otherwise, breadth first search finds a solution with the shortest path length.
- **Time complexity** : $O(b^d)$
- **Space complexity** : $O(b^d)$
- **Optimality** :Yes

  b - branching factor(maximum no of successors of any node),

  d – Depth of the shallowest goal node

  Maximum length of any path (m) in search space

Advantages: Finds the path of minimal length to the goal.

Disadvantages:

- Requires the generation and storage of a tree whose size is exponential the depth of the shallowest goal node.
- The breadth first search algorithm cannot be effectively used unless the search space is quite small.

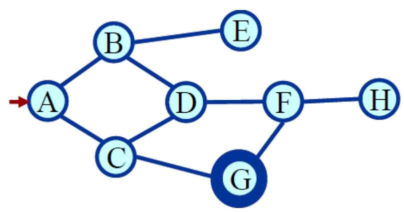
Depth- First- Search.

We may sometimes search the goal along the largest depth of the tree, and move up only when further traversal along the depth is not possible. We then attempt to find alternative offspring of the parent of the node (state) last visited. If we visit the nodes of a tree using the above principles to search the goal, the traversal made is called depth first traversal and consequently the search strategy is called *depth first search*.

- **Algorithm:**
  1. Create a variable called NODE-LIST and set it to initial state

2. Until a goal state is found or NODE-LIST is empty do
    a. Remove the first element from NODE-LIST and call it E. If NODE-LIST was empty, quit
    b. For each way that each rule can match the state described in E do:
        i. Apply the rule to generate a new state
        ii. If the new state is a goal state, quit and return this state
        iii. Otherwise, add the new state in front of NODE-LIST

DFS illustrated:



A State Space Graph

Step 1: Initially fringe contains only the node for A.

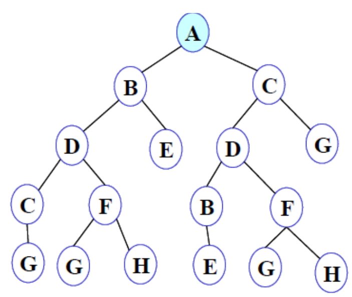


Figure 1

FRINGE: A

Step 2: A is removed from fringe. A is expanded and its children B and C are put in front of fringe.

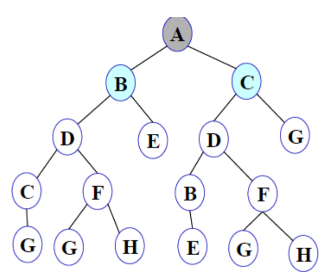


Figure 2

FRINGE: B C

Step 3: Node B is removed from fringe, and its children D and E are pushed in front of fringe.

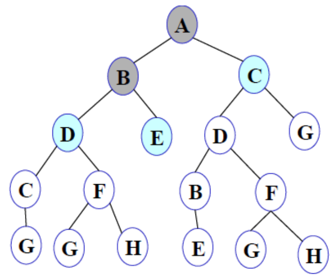


Figure 3

FRINGE: D E C

Step 4: Node D is removed from fringe. C and F are pushed in front of fringe.

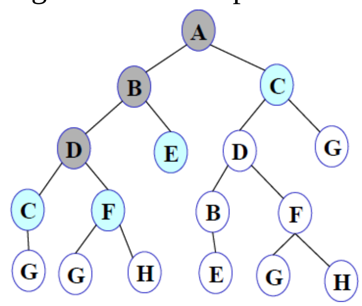


Figure 4

FRINGE: C F E C

Step 5: Node C is removed from fringe. Its child G is pushed in front of fringe.

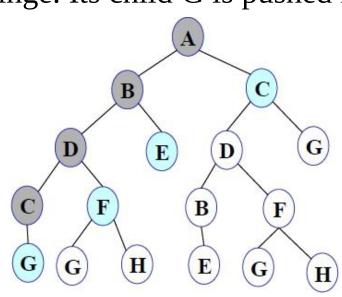


Figure 5

FRINGE: G F E C

Step 6: Node G is expanded and found to be a goal node.

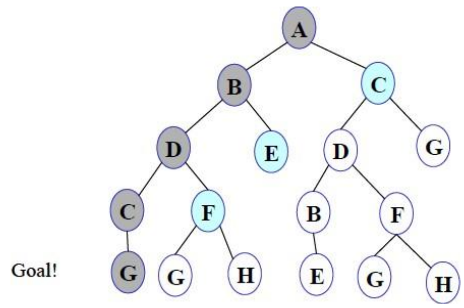


Figure 6

FRINGE: *G* F E C

The solution path A-B-D-C-G is returned and the algorithm terminates.

Depth first searchis:

1. The algorithm takes exponential time.
2. If N is the maximum depth of a node in the search space, in the worst case the algorithm will take time $O(b^d)$.
3. The space taken is linear in the depth of the search tree, O(bN).

Note that the time taken by the algorithm is related to the maximum depth of the search tree. If the search tree has infinite depth, the algorithm may not terminate. This can happen if the search space is infinite. It can also happen if the search space contains cycles. The latter case can be handled by checking for cycles in the algorithm. Thus **Depth First Search is not complete.**

Exhaustive searches- Iterative Deeping DFS

Description:

- It is a search strategy resulting when you combine BFS and DFS, thus combining the advantages of each strategy, taking the completeness and optimality of BFS and the modest memory requirements of DFS.
- IDS works by looking for the best search depth d, thus starting with depth limit 0 and make a BFS and if the search failed it increase the depth limit by 1 and try a BFS again with depth 1 and so on – first d = 0, then 1 then 2 and so on – until a depth d is reached where a goal is found.

Algorithm:

```
procedure IDDFS(root)
for depth from 0 to ∞
    found ← DLS(root, depth)
if found ≠ null
return found

procedure DLS(node, depth)
if depth = 0 and node is a goal
return node
else if depth > 0
foreach child of node
      found ← DLS(child, depth−1)
if found ≠ null
return found
return null
```

Performance Measure:

- Completeness: IDS is like BFS, is complete when the branching factor b is finite.
- Optimality: IDS is also like BFS optimal when the steps are of the same cost.

- Time Complexity:
    - One may find that it is wasteful to generate nodes multiple times, but actually it is not that costly compared to BFS, that is because most of the generated nodes are always in the deepest level reached, consider that we are searching a binary tree and our depth limit reached 4, the nodes generated in last level = $2^4 = 16$, the nodes generated in all nodes before last level = $2^0 + 2^1 + 2^2 + 2^3 = 15$
    - Imagine this scenario, we are performing IDS and the depth limit reached depth d, now if you remember the way IDS expands nodes, you can see that nodes at depth d are generated once, nodes at depth d-1 are generated 2 times, nodes at depth d-2 are generated 3 times and so on, until you reach depth 1 which is generated d times, we can view the total number of generated nodes in the worst case as:
        - $N(IDS) = (b)d + (d – 1)b^2 + (d – 2)b^3 + …. + (2)b^{d-1} + (1)b^d = O(b^d)$

- If this search were to be done with BFS, the total number of generated nodes in the worst case will be like:
  - $N(BFS) = b + b^2 + b^3 + b^4 + \ldots.\ b^d + (b^{d+1} - b) = O(b^{d+1})$
- If we consider a realistic numbers, and use b = 10 and d = 5, then number of generated nodes in BFS and IDS will be like
  - N(IDS) = 50 + 400 + 3000 + 20000 + 100000 = 123450
  - N(BFS) = 10 + 100 + 1000 + 10000 + 100000 + 999990 = 1111100
  - BFS generates like 9 time nodes to those generated with IDS.

- Space Complexity:
  - IDS is like DFS in its space complexity, taking *O*(bd) of memory.

    Weblinks:

    i. *https://www.youtube.com/watch?v=7QcoJjSVT38*

    ii. https://mhesham.wordpress.com/tag/iterative-deepening-depth-first-search

Conclusion:

- We can conclude that IDS is a hybrid search strategy between BFS and DFS inheriting their advantages.
- IDS is faster than BFS and DFS.
- It is said that "IDS is the preferred uniformed search method when there is a large search space and the depth of the solution is not known".

Heuristic Searches:

A Heuristic technique helps in solving problems, even though there is no guarantee that it will never lead in the wrong direction. There are heuristics of every general applicability as well as domain specific. The strategies are general purpose heuristics. In order to use them in a specific domain they are coupler with some domain specific heuristics. There are two major ways in which domain - specific, heuristic information can be incorporated into rule-based search procedure.

A heuristic function is a function that maps from problem state description to measures desirability, usually represented as number weights. The value of a heuristic function at a given node in the search process gives a good estimate of that node being on the desired path to solution.

Greedy Best First Search

Greedy best-first search tries to expand the node that is closest to the goal, on the: grounds that this is likely to lead to a solution quickly. Thus, it evaluates nodes by using just the heuristic function:

$$f(n) = h(n).$$

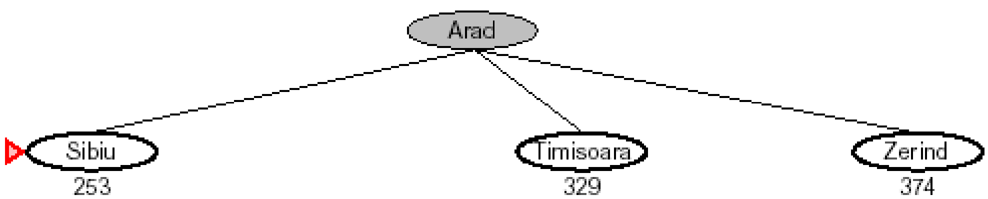
Taking the example of **Route-finding problems** in Romania, the goal is to reach Bucharest starting from the city Arad. We need to know the straight-line distances to Bucharest from various cities as shown in **Figure 8.1**. For example, the initial state is In (Arad), and the straight line distance heuristic h_{SLD} (In (Arad)) is found to be 366. Using the **straight-line distance** heuristic **h_{SLD},** the goal state can be reached faster.

Arad	366	**Mehadia**	241	**Hirsova**	151
Bucharest	0	**Neamt**	234	**Urziceni**	80
Craiova	160	**Oradea**	380	**Iasi**	226
Drobeta	242	**Pitesti**	100	**Vaslui**	199
Eforie	161	**Rimnicu Vilcea**	193	**Lugoj**	244
Fagaras	176	**Sibiu**	253	**Zerind**	374
Giurgiu	77	**Timisoara**	329		

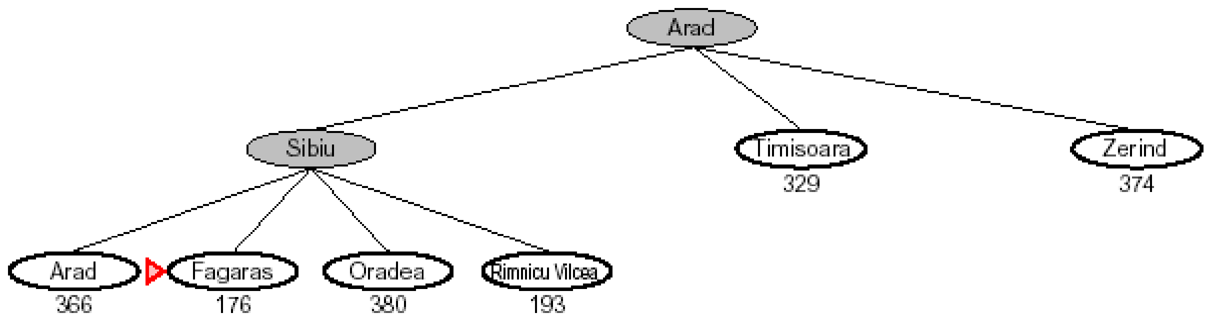
Figure 8.1: Values of h_{SLD}-straight-line distances to B u c h a r e s t.

The Initial State

After Expanding Arad



After Expanding Sibiu



After Expanding Fagaras

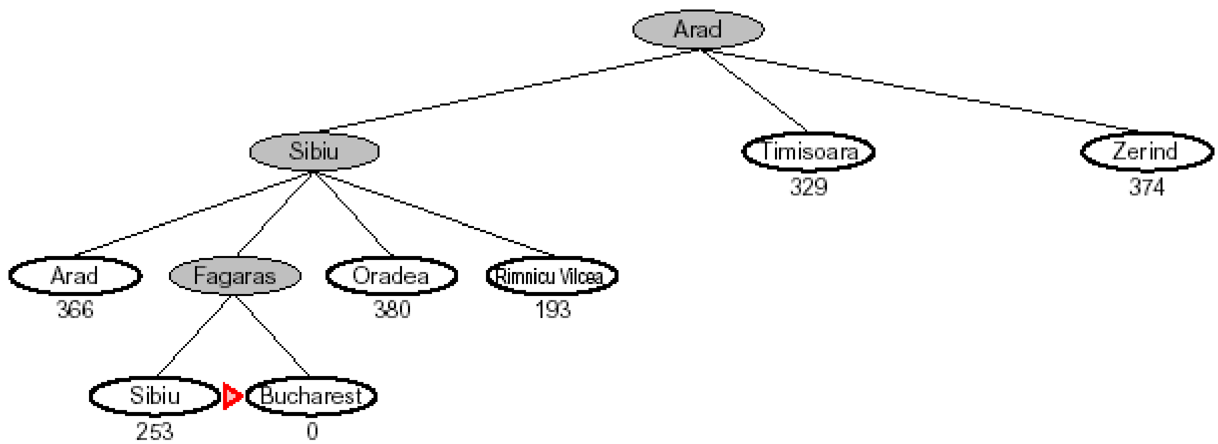


Figure 8.2: Stages in a greedy best-first search for Bucharest using the straight-line distance heuristic h_{SLD}. Nodes are labeled with their h-values.

Figure 8.2 shows the progress of greedy best-first search using h_{SLD} to find a path from Arad to Bucharest. The first node to be expanded from Arad will be Sibiu, because it is closer to Bucharest than either Zerind or Timisoara. The next node to be expanded will be Fagaras, because it is closest.

Fagaras in turn generates Bucharest, which is the goal.

Evaluation Criterion of Greedy Search

- **Complete: NO [can get stuck in loops, e.g., Complete in finite space with repeated-state checking**]
- **Time Complexity: O (bm) [but a good heuristic can give dramatic improvement**]
- **Space Complexity: O (bm) [keeps all nodes in memory**]

- **Optimal: NO**

Greedy best-first search is not optimal, and it is incomplete. The worst-case time and space complexity is **O (b^m),** where m is the maximum depth of the search space.

HILL CLIMBING PROCEDURE:

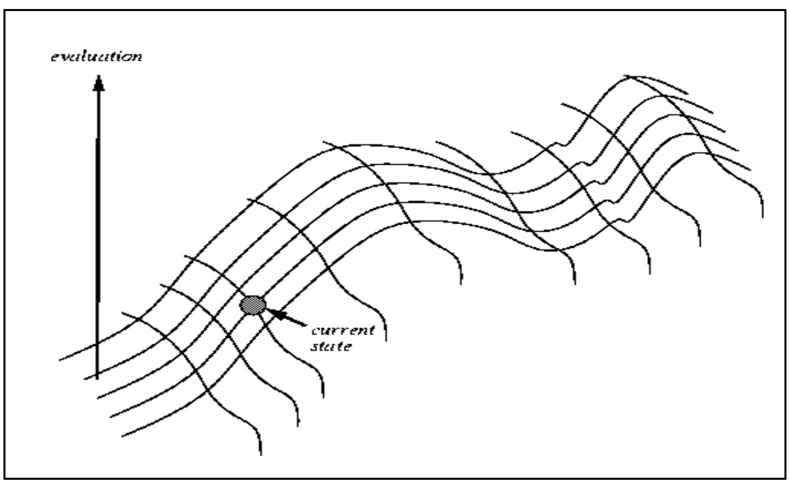
Hill Climbing Algorithm

We will assume we are trying to maximize a function. That is, we are trying to find a point in the search space that is better than all the others. And by "better" we mean that the evaluation is higher. We might also say that the solution is of better quality than all the others.

The idea behind hill climbing is as follows.

1. Pick a random point in the search space.
2. Consider all the neighbors of the current state.
3. Choose the neighbor with the best quality and move to that state.
4. Repeat 2 thru 4 until all the neighboring states are of lower quality.
5. Return the current state as the solution state.

We can also present this algorithm as follows (it is taken from the AIMA book (Russell, 1995) and follows the conventions we have been using on this course when looking at blind and heuristic searches).



Algorithm:

Function HILL-CLIMBING(*Problem*) **returns** a solution state

Inputs: *Problem*, problem

Local variables: *Current*, a node

Next, a node

Current = MAKE-NODE(INITIAL-STATE[*Problem*])

Loop do

Next = a highest-valued successor of *Current*

If VALUE[Next] < VALUE[Current] **then return** *Current*

Current = *Next*

End

Also, if two neighbors have the same evaluation and they are both the best quality, then the algorithm will choose between them at random.

Problems with Hill Climbing

The main problem with hill climbing (which is also sometimes called ***gradient descent***) is that we are not guaranteed to find the best solution. In fact, we are not offered any guarantees about the solution. It could be abysmally bad.

You can see that we will eventually reach a state that has no better neighbours but there are better solutions elsewhere in the search space. The problem we have just described is called a ***local maxima***.

Simulated annealing search

A hill-climbing algorithm that never makes "downhill" moves towards states with lower value (or higher cost) is guaranteed to be incomplete, because it can stuck on a local maximum. In contrast, a purely random walk –that is, moving to a successor chosen uniformly at random from the set of successors – is complete, but extremely inefficient. Simulated annealing is an algorithm that combines hill-climbing with a random walk in some way that yields both efficiency and completeness.

Figure 10.7 shows simulated annealing algorithm. It is quite similar to hill climbing. Instead of picking the best move, however, it picks the random move. If the move improves the situation, it is always accepted. Otherwise, the algorithm accepts the move with some probability less than 1. The probability decreases exponentially with the "badness" of the move – the amount ⮝E by which the evaluation is worsened. The probability also decreases as the "temperature" T goes down: "bad moves are more likely to be allowed at the start when temperature is high, and they become more unlikely as T decreases. One can prove that if the schedule lowers T slowly enough, the algorithm will find a global optimum with probability approaching 1.

Simulated annealing was first used extensively to solve VLSI layout problems. It has been applied widely to factory scheduling and other large-scale optimization tasks.

function ***S I M U L A T E D - A N NEALING****(problem, schedule)* **returns** a **solution state**

inputs: *problem*, a problem

schedule, a mapping from time to "temperature"

local variables: *current*, a node

next, a node

T, a "temperature" controlling the probability of downward steps

current ←**MAKE-NODE(INITIAL-STATE[***problem***])**

for t←l **to** ∞ **do**

T ←*schedule[t]*

if *T* = 0 **then return** *current*

next ←a randomly selected successor of *current*

ΔE←***VALUE****[next]* – ***VALUE****[current]*

if ΔE> 0 **then** *current* ← *next*

else *current* ← *next* only with probability $e^{\Delta E/T}$

LOCAL SEARCH IN CONTINUOUS SPACES

- We have considered algorithms that work only in discrete environments, but real-world environment are continuous.
- Local search amounts to maximizing a continuous objective function in a multi-dimensional vector space.
- This is hard to do in general.
- Can immediately retreat
  - ✓ Discretize the space near each state
  - ✓ Apply a discrete local search strategy (e.g., stochastic hill climbing, simulated annealing)

- Often resists a closed-form solution
    - Fake up an empirical gradient
    - Amounts to greedy hill climbing in discretized state space
- Can employ Newton-Raphson Method to find maxima.
- Continuous problems have similar problems: plateaus, ridges, local maxima, etc.

Best First Search:

- A combination of depth first and breadth first searches.
- Depth first is good because a solution can be found without computing all nodes and breadth first is good because it does not get trapped in dead ends.
- The best first search allows us to switch between paths thus gaining the benefit of both approaches. At each step the most promising node is chosen. If one of the nodes chosen generates nodes that are less promising it is possible to choose another at the same level and in effect the search changes from depth to breadth. If on analysis these are no better than this previously unexpanded node and branch is not forgotten and the search method reverts to the

OPEN is a priorityqueue of nodes that have been evaluated by the heuristic function but which have not yet been expanded into successors. The most promising nodes are at the front.

CLOSED are nodes that have already been generated and these nodes must be stored because a graph is being used in preference to a tree.

Algorithm:

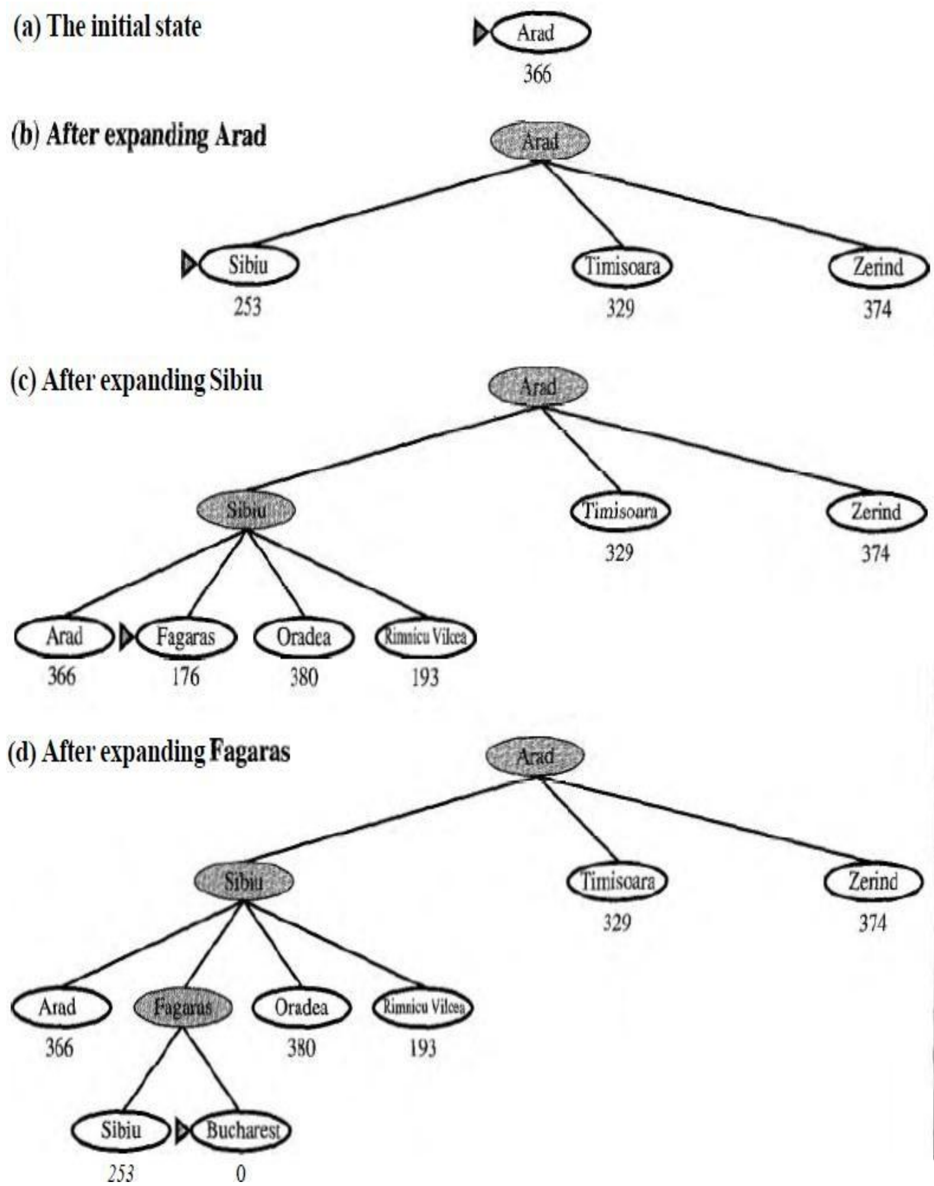
1. Start with OPEN holding the initial state
2. Until a goal is found or there are no nodes left on open do.

    - Pick the best node on OPEN
    - Generate its successors
    - For each successor Do
        - If it has not been generated before ,evaluate it ,add it to OPEN and record its parent

- If it has been generated before change the parent if this new path is better and in that case update the cost of getting to any successor nodes.

3. If a goal is found or no more nodes left in OPEN, quit, else return to 2.

Example:



1. It is not optimal.
2. It is incomplete because it can start down an infinite path and never return to try other possibilities.

3. The worst-case time complexity for greedy search is *O* (b^m), where *m* is the maximum depth of the search space.
4. Because greedy search retains all nodes in memory, its space complexity is the same as its time complexity

A* Algorithm

The Best First algorithm is a simplified form of the *A** algorithm.

The **A* search algorithm** (pronounced "Ay-star") is a tree search algorithm that finds a path from a given initial node to a given goal node (or one passing a given goal test). It employs a "heuristic estimate" which ranks each node by an estimate of the best route that goes through that node. It visits the nodes in order of this heuristic estimate.

Similar to greedy best-first search but is more accurate because A* takes into account the nodes that have already been traversed.

From *A** we note that ***f* = *g* + *h*** where

g is a measure of the distance/cost to go from the initial node to the current node

his an estimate of the distance/cost to solution from the current node.

Thus ***f***is an estimate of how long it takes to go from the initial node to the solution

Algorithm:

1. Initialize	**:**	**Set OPEN = (S); CLOSED = ( )**
		g(s)= 0, f(s)=h(s)
2. Fail	**:**	**If OPEN = ( ), Terminate and fail.**
3. Select	**:**	**select the minimum cost state, n, from OPEN,**
		save n in CLOSED
4. Terminate	**:**	**If n €G, Terminate with success and return f(n)**
5. Expand	**:**	**for each successor, m, of n**

a) If m € *OPEN U CLOSED+

Set g(m) = g(n) + c(n , m)

Set f(m) = g(m) + h(m)

Insert m in OPEN

b) If m € *OPEN U CLOSED+

Set g(m) = min { g(m) , g(n) + c(n , m)}

Set f(m) = g(m) + h(m)

If f(m) has decreased and m € CLOSED

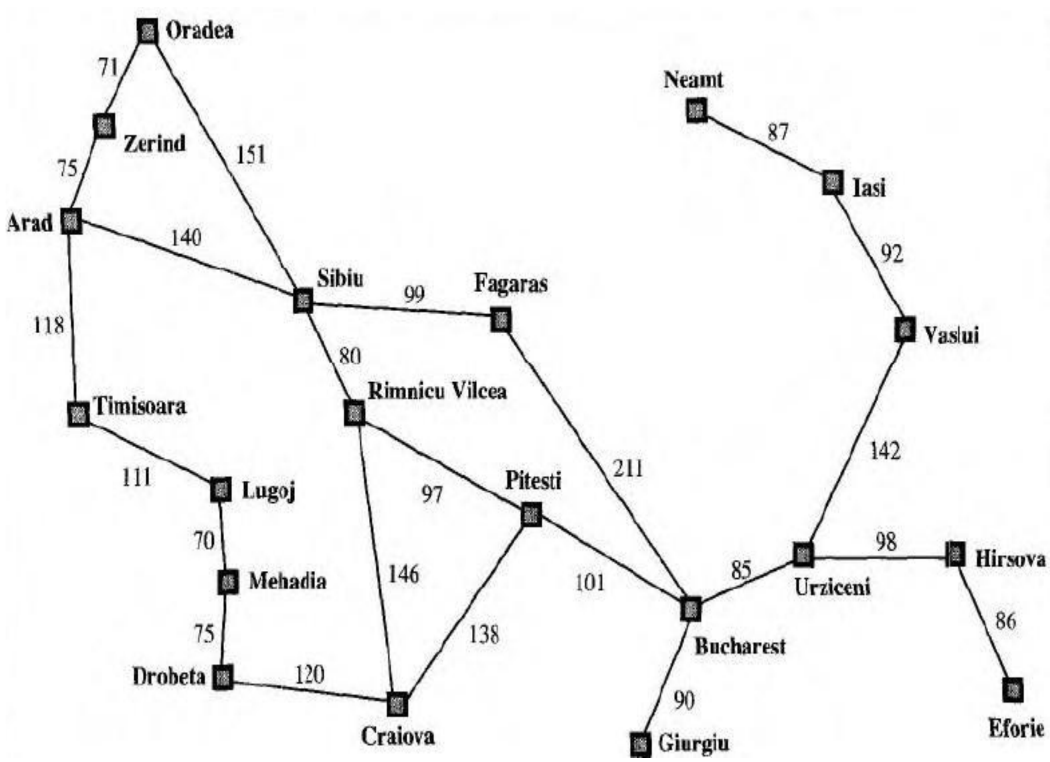
Move m to OPEN.

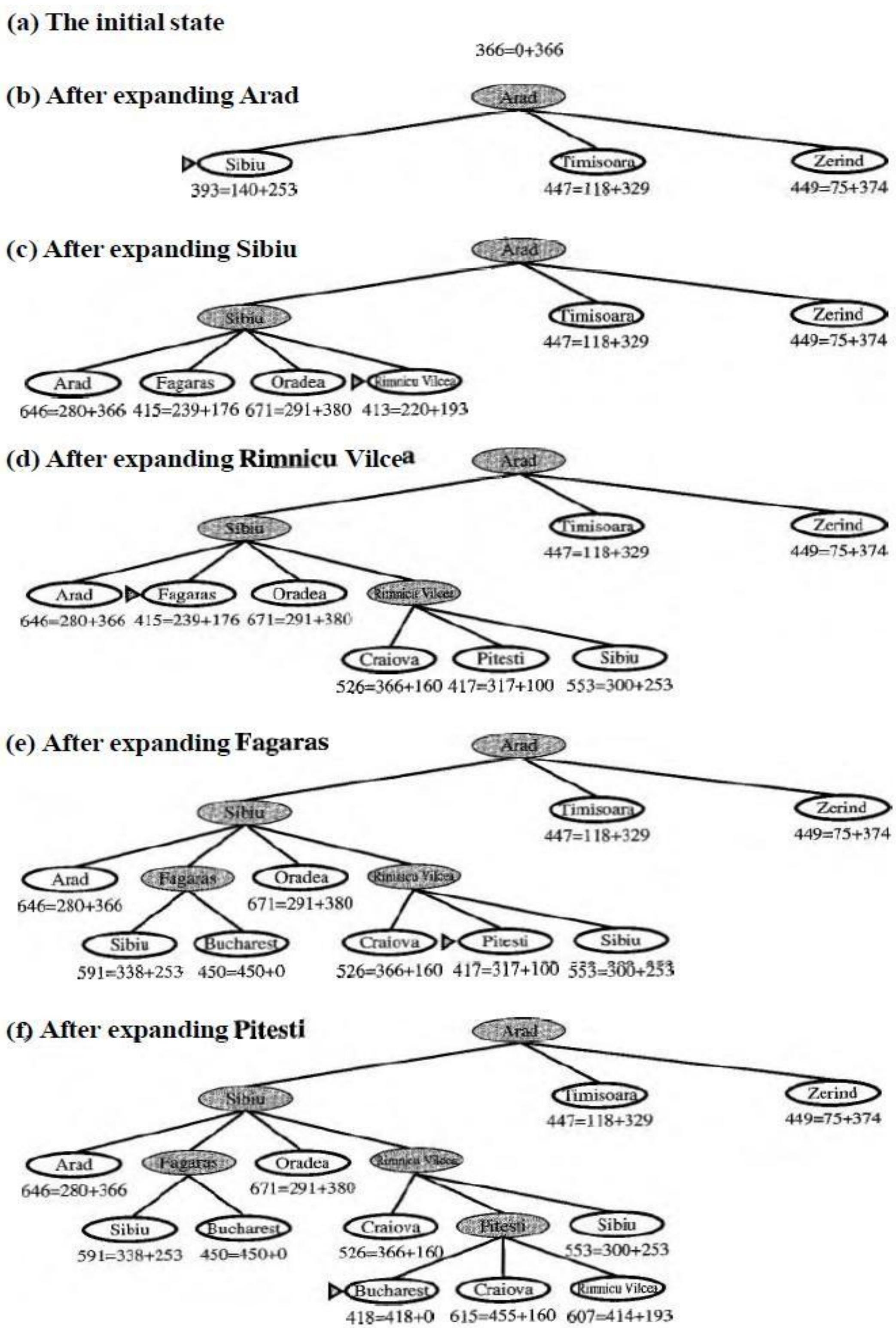
Description:

- A* begins at a selected node. Applied to this node is the "cost" of entering this node (usually zero for the initial node). A* then estimates the distance to the goal node from the current node. This estimate and the cost added together are the heuristic which is assigned to the path leading to this node. The node is then added to a priority queue, often called "open".
- The algorithm then removes the next node from the priority queue (because of the way a priority queue works, the node removed will have the lowest heuristic). If the queue is empty, there is no path from the initial node to the goal node and the algorithm stops. If the node is the goal node, A* constructs and outputs the successful path and stops.
- If the node is not the goal node, new nodes are created for all admissible adjoining nodes; the exact way of doing this depends on the problem at hand. For each successive node, A* calculates the "cost" of entering the node and saves it with the node. This cost is calculated from the cumulative sum of costs stored with its ancestors, plus the cost of the operation which reached this new node.
- The algorithm also maintains a 'closed' list of nodes whose adjoining nodes have been checked. If a newly generated node is already in this list with an equal or lower cost, no further processing is done on that node or with the path associated with it. If a node in the closed list matches the new one, but has been stored with a *higher* cost, it is removed from the closed list, and processing continues on the new node.

- Next, an estimate of the new node's distance to the goal is added to the cost to form the heuristic for that node. This is then added to the 'open' priority queue, unless an identical node is found there.
- Once the above three steps have been repeated for each new adjoining node, the original node taken from the priority queue is added to the 'closed' list. The next node is then popped from the priority queue and the process is repeated. **The heuristic costs from each city to Bucharest:**

Arad	366	Mehadia	241
Bucharest	0	Neamt	234
Craiova	160	Oradea	380
Drobeta	242	Pitesti	100
Eforie	161	Rimnicu Vilcea	193
Fagaras	176	Sibiu	253
Giurgiu	77	Timisoara	329
Hirsova	151	Urziceni	80
Iasi	226	Vaslui	199
Lugoj	244	Zerind	374




(a) The initial state
366=0+366
Arad
(b) After expanding Arad
Arad
Sibiu
393=140+253
Timisoara
447=118+329
Zerind
449=75+374
(c) After expanding Sibiu
Arad
Sibiu
Timisoara
447=118+329
Zerind
449=75+374
Arad
646=280+366
Fagaras
415=239+176
Oradea
671=291+380
Rimnicu Vilcea
413=220+193
(d) After expanding Rimnicu Vilcea
Arad
Sibiu
Timisoara
447=118+329
Zerind
449=75+374
Arad
646=280+366
Fagaras
415=239+176
Oradea
671=291+380
Rimnicu Vilcea
Craiova
526=366+160
Pitesti
417=317+100
Sibiu
553=300+253
(e) After expanding Fagaras
Arad
Sibiu
Timisoara
447=118+329
Zerind
449=75+374
Arad
646=280+366
Fagaras
Oradea
671=291+380
Rimnicu Vilcea
Sibiu
591=338+253
Bucharest
450=450+0
Craiova
526=366+160
Pitesti
417=317+100
Sibiu
553=300+253
(f) After expanding Pitesti
Arad
Sibiu
Timisoara
447=118+329
Zerind
449=75+374
Arad
646=280+366
Fagaras
Oradea
671=291+380
Rimnicu Vilcea
Sibiu
591=338+253
Bucharest
450=450+0
Craiova
526=366+160
Pitesti
Sibiu
553=300+253
Bucharest
418=418+0
Craiova
615=455+160
Rimnicu Vilcea
607=414+193

A* search properties:

- The algorithm A* is admissible. This means that provided a solution exists, the first solution found by A* is an optimal solution. A* is admissible under the following conditions:
- Heuristic function: for every node n , $h(n) \leq h^*(n)$.
- A* is also complete.
- A* is optimally efficient for a given heuristic.
- A* is much more efficient that uninformed search.

Iterative Deeping A* Algorithm:

Algorithm:

Let L be the list of visited but not expanded node, and

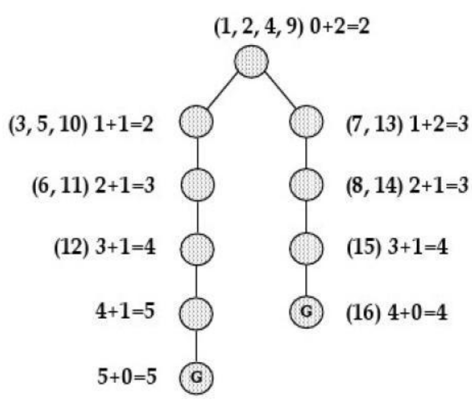
C the maximum depth

1) Let C=0
2) Initialize Lto the initial state (only)
3) If List empty increase C and goto 2),

   else

   extract a node n from the front of L
4) If n is a goal node,

   SUCCEED and return the path from the initial state to n
5) Remove n from L. If the level is smaller than C, insert at the front of L all the children n' of n with f(n') ≤ C
6) Goto 3)



- IDA* is complete & optimal Space usage is linear in the depth of solution. Each iteration is depth first search, and thus it does not require a priority queue.
- Iterative deepening A* (IDA*) eliminates the memory constraints of A* search algorithm without sacrificing solution optimality.
- Each iteration of the algorithm is a depth-first search that keeps track of the cost, f(n) = g(n) + h(n), of each node generated.
- As soon as a node is generated whose cost exceeds a threshold for that iteration, its path is cut off, and the search backtracks before continuing.
- The cost threshold is initialized to the heuristic estimate of the initial state, and in each successive iteration is increased to the total cost of the lowest-cost node that was pruned during the previous iteration.
- The algorithm terminates when a goal state is reached whose total cost dees not exceed the current threshold.

UNIT II

Problem Solving by Search-II and Propositional Logic .Adversarial Search: Games, Optimal Decisions in Games, Alpha–Beta Pruning, Imperfect Real-Time Decisions.
Constraint Satisfaction Problems: Defining Constraint Satisfaction Problems, Constraint Propagation, Backtracking Search for CSPs, Local Search for CSPs, The Structure of Problems.

Constraint Satisfaction Problems

Sometimes a problem is not embedded in a long set of action sequences but requires picking the best option from available choices. A good general-purpose problem solving technique is to list the constraints of a situation (either negative constraints, like limitations, or positive elements that you want in the final solution). Then pick the choice that satisfies most of the constraints.

Formally speaking, a **constraint satisfaction problem (or CSP**) is defined by a set of variables, X1;X2; : : : ;Xn, and a set of constraints, C1;C2; : : : ;Cm. Each variable Xi has anonempty domain Di of possible values. Each constraint Ci involves some subset of tvariables and specifies the allowable combinations of values for that subset. A state of theproblem is defined by an assignment of values to some or all of the variables, {Xi = vi;Xj =vj ; : : :} An assignment that does not violate any constraints is called a consistent or legalassignment. A complete assignment is one in which every variable is mentioned, and a solution to a CSP is a complete assignment that satisfies all the constraints. Some CSPs also require a solution that maximizes an objectivefunction.

CSP can be given an **incremental formulation** as a standard search problem as follows:

1. **Initial state**: the empty assignment fg, in which all variables are unassigned.
2. **Successor function**: a value can be assigned to any unassigned variable, provided that it does not conflict with previously assigned variables.
3. **Goal test**: the current assignment is complete.
4. **Path cost**: a constant cost for every step

Examples:

1. The best-known category of continuous-domain CSPs is that of **linear programming** problems, where constraints must be linear inequalities forming a *convex* region.
2. **Crypt arithmetic** puzzles.

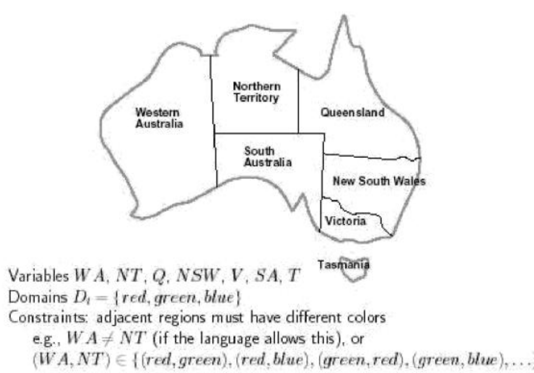
$$
\begin{array}{r}
T\ W\ O \\
+\ T\ W\ O \\
\hline
F\ O\ U\ R
\end{array}
$$

Example: The map coloring problem.

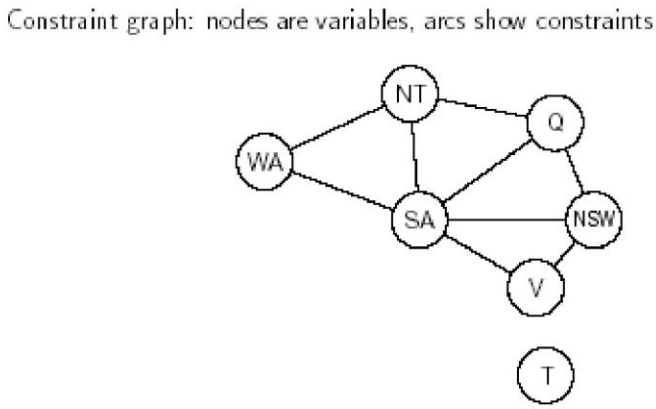
The task of coloring each region red, green or blue in such a way that no neighboring regions have the same color.

We are given the task of coloring each region red, green, or blue in such a way that the neighboring regions must not have the same color.

To formulate this as CSP, we define the variable to be the regions: WA, NT, Q, NSW, V, SA, and T. The domain of each variable is the set {red, green, blue}. The constraints require neighboring regions to have distinct colors: for example, the allowable combinations for WA and NT are the pairs {(red,green),(red,blue),(green,red),(green,blue),(blue,red),(blue,green)}. (The constraint can also be represented as the inequality WA ≠ NT). There are many possible solutions, such as {WA = red, NT = green, Q = red, NSW = green, V = red, SA = blue, T = red}.Map of Australia showing each of its states and territories



Constraint Graph: A CSP is usually represented as an undirected graph, called constraint graph where the nodes are the variables and the edges are the binaryconstraints.



The map-coloring problem represented as a constraint graph.

CSP can be viewed as a standard search problem as follows:

> **Initial state** : the empty assignment {},in which all variables are unassigned.
> **Successor function:** a value can be assigned to any unassigned variable, provided that it does not conflict with previously assigned variables.
> **Goal test:** the current assignment is complete.
> **Path cost:** a constant cost(E.g.,1) for every step.

Game Playing

Adversarial search, or game-tree search, is a technique for analyzing an adversarial game in order to try to determine who can win the game and what moves the players should make in order to win. Adversarial search is one of the oldest topics in Artificial Intelligence. The original ideas for adversarial search were developed by Shannon in 1950 and independently by Turing in 1951, in the context of the game of chess—and their ideas still form the basis for the techniques used today.

2-Person Games:

- Players: We call them Max and Min.
- Initial State: Includes board position and whose turn it is.
- Operators: These correspond to legal moves.
- Terminal Test: A test applied to a board position which determines whether the game is over. In chess, for example, this would be a checkmate or stalemate situation.
- Utility Function: A function which assigns a numeric value to a terminalstate. For example, in chess the outcome is win (+1), lose (-1) or draw (0). Note that by

convention, we always measure utility relative to Max.

MiniMax Algorithm:

1. Generate the whole game tree.
2. Apply the utility function to leaf nodes to get their values.
3. Use the utility of nodes at level n to derive the utility of nodes at level n-1.
4. Continue backing up values towards the root (one layer at a time).
5. Eventually the backed up values reach the top of the tree, at which point Max chooses the move that yields the highest value. This is called the minimax decision because it maximises the utility for Max on the assumption that Min will play perfectly to minimise it.

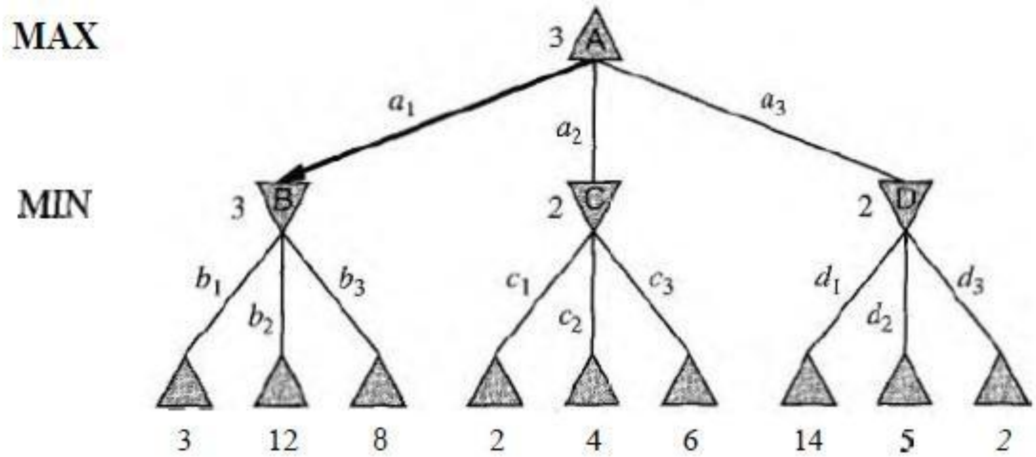
Algorithm: MINIMAX (Depth-First Version)

To determine the minimax value $V(J)$, do the following:

1. If J is terminal, return $V(J) = e(J)$; otherwise
2. Generate J's successors $J_1, J_2, \ldots, J_b$.
3. Evaluate $V(J_1), V(J_2), \ldots, V(J_b)$ from left to right.
4. If J is a MAX node, return $V(J) = \max[V(J_1), \ldots, V(J_b)]$.
5. If J is a MIN node, return $V(J) = \min[V(J_1), \ldots, V(J_b)]$.

```
function MINIMAX-DECISION(state) returns an action
    v ← MAX-VALUE(state)
    return the action in SUCCESSORS(state) with value v

function MAX-VALUE(state) returns a utility value
    if TERMINAL-TEST(state) then return UTILITY(state)
    v ← −∞
    for a, s in SUCCESSORS(state) do
        v ← MAX(v, MIN-VALUE(s))
    return v

function MIN-VALUE(state) returns a utility value
    if TERMINAL-TEST(state) then return UTILITY(state)
    v ← ∞
    for a, s in SUCCESSORS(state) do
        v ← MIN(v, MAX-VALUE(s))
    return v
```

Example:



Properties of minimax:

- Complete : Yes (if tree is finite)
- Optimal : Yes (against an optimal opponent)
- Time complexity : $O(b^m)$
- Space complexity : O(bm) (depth-first exploration)
- For chess, b ≈ 35, m ≈100 for "reasonable" games

  → exact solution completely infeasible.

Limitations

- Not always feasible to traverse entire tree
- Time limitations

Alpha-beta pruning algorithm:

- **Pruning:** eliminating a branch of the search tree from consideration without exhaustive examination of each node
- α-β **Pruning:** the basic idea is to prune portions of the search tree that cannot improve the utility value of the max or min node, by just considering the values of nodes seen so far.
- *Alpha-beta pruning* is used on top of minimax search to detect paths that do not need to be explored. The intuition is:
- The MAX player is always trying to maximize the score. Call this α.
- The MIN player is always trying to minimize the score. Call this β .
- **Alpha cutoff**: Given a Max node n, cutoff the search below n (i.e., don't generate or examine any more of n's children) if alpha(n) >= beta(n)

(alpha increases and passes beta from below)

- **Beta cutoff.:** Given a Min node n, cutoff the search below n (i.e., don't generate or examine any more of n's children) if beta(n) <= alpha(n)

  (beta decreases and passes alpha from above)

- Carry alpha and beta values down during search Pruning occurs whenever alpha >= beta

Algorithm:

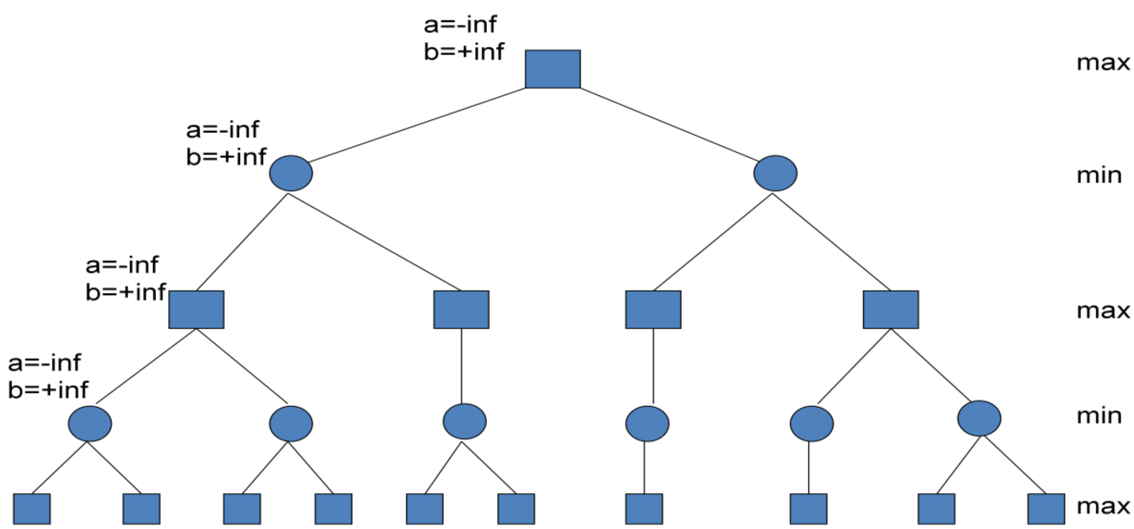
```
function ALPHA-BETA-SEARCH(state) returns an action
   inputs: state, current state in game

   v ← MAX-VALUE(state, −∞, +∞)
   return the action in SUCCESSORS(state) with value v
```

```
function MAX-VALUE(state, α, β) returns a utility value
   inputs: state, current state in game
             α, the value of the best alternative for MAX along the path to state
             β, the value of the best alternative for MIN along the path to state

   if TERMINAL-TEST(state) then return UTILITY(state)
   v ← −∞
   for a, s in SUCCESSORS(state) do
      v ← MAX(v, MIN-VALUE(s, α, β))
      if v ≥ β then return v
      α ← MAX(α, v)
   return v
```

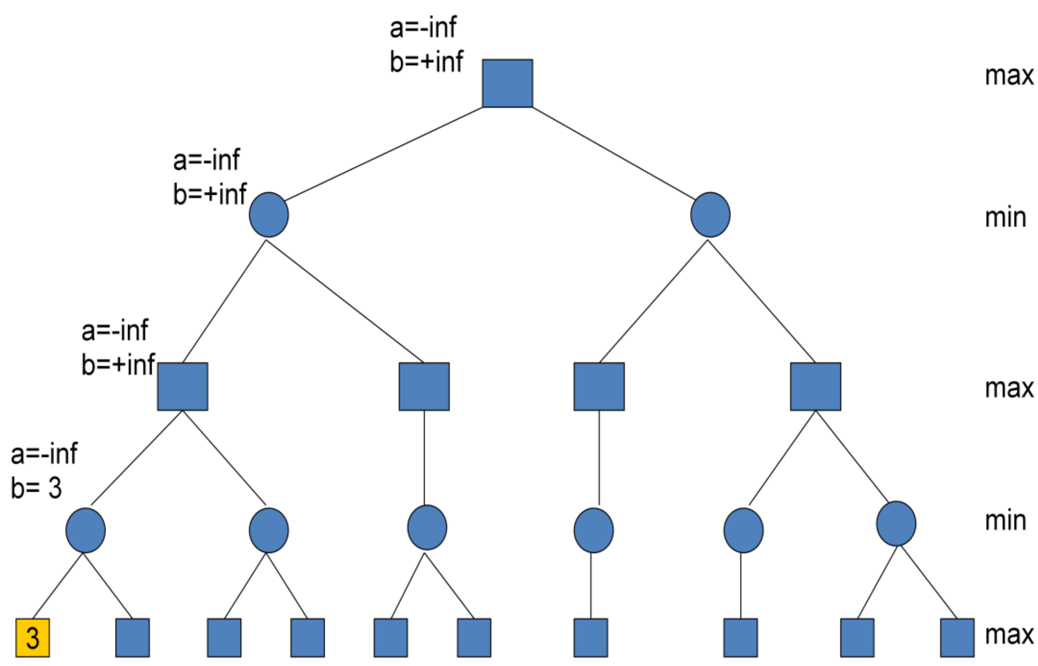
```
function MIN-VALUE(state, α, β) returns a utility value
   inputs: state, current state in game
             α, the value of the best alternative for MAX along the path to state
             β, the value of the best alternative for MIN along the path to state

   if TERMINAL-TEST(state) then return UTILITY(state)
   v ← +∞
   for a, s in SUCCESSORS(state) do
      v ← MIN(v, MAX-VALUE(%α, β))
      if v ≤ α then return v
      β ← MIN(β, v)
   return v
```

Example:

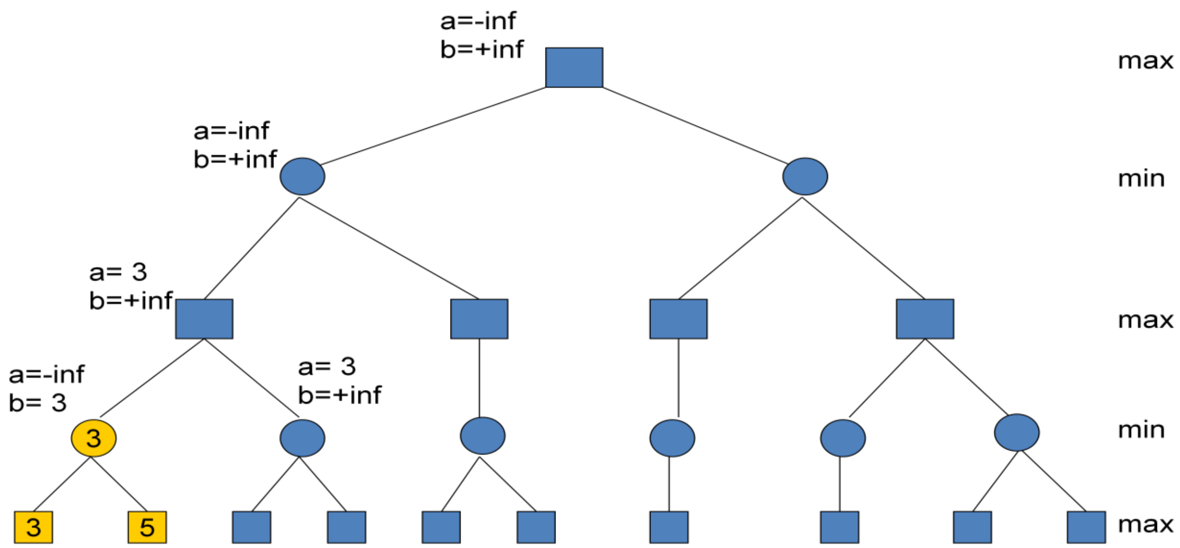
1) Setup phase: Assign to each left-most (or right-most) internal node of the tree, variables: alpha = -infinity, beta = +infinity



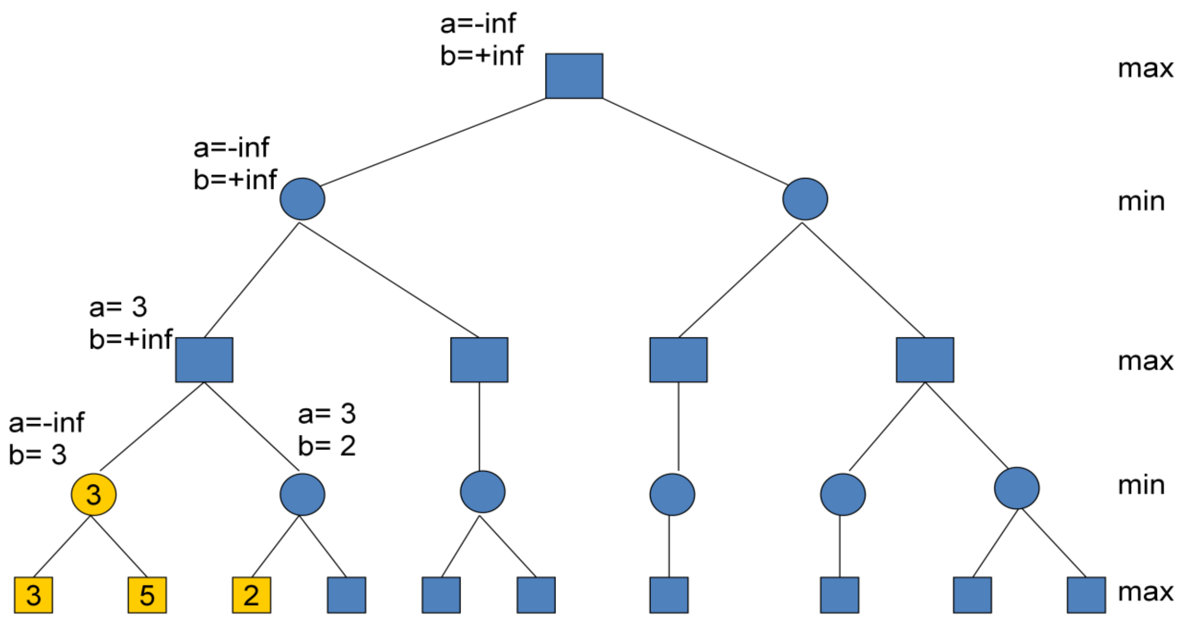
2) Look at first computed final configuration value. It's a 3. Parent is a min node, so set the beta (min) value to 3.



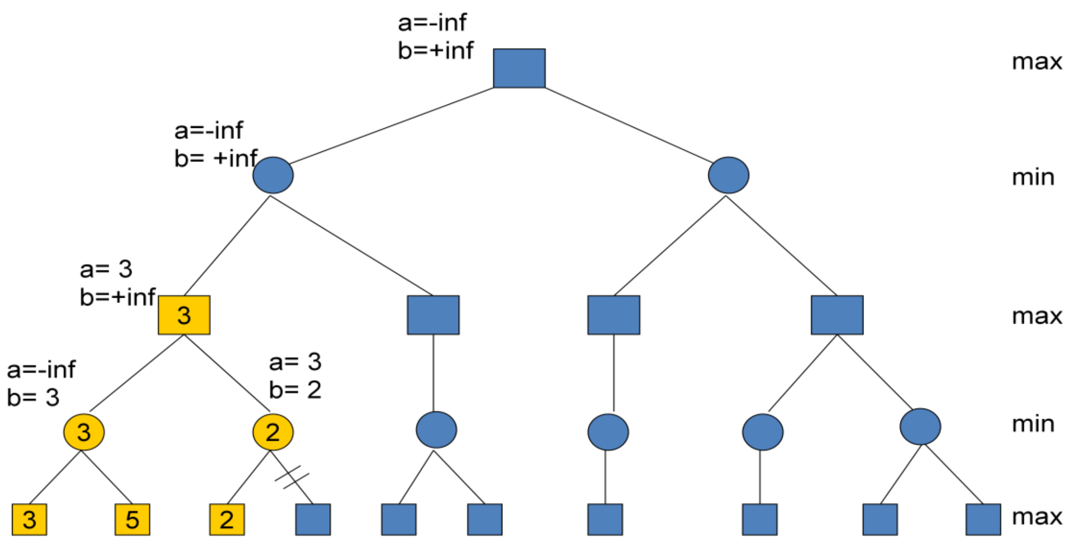
3) Look at next value, 5. Since parent is a min node, we want the minimum of 3 and 5 which is 3. Parent min node is done – fill alpha (max) value of its parent max node. Always set alpha for max nodes and beta for min nodes. Copy the state of the max parent node into the second unevaluated min child.



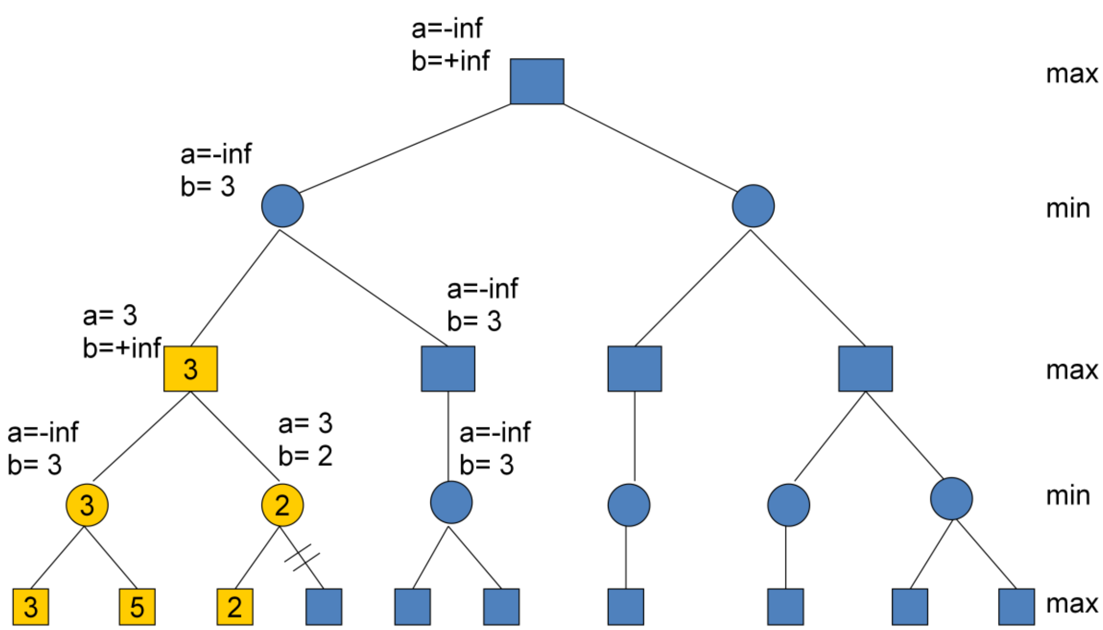
4) Look at next value, 2. Since parent node is min with b=+inf, 2 is smaller, change b.



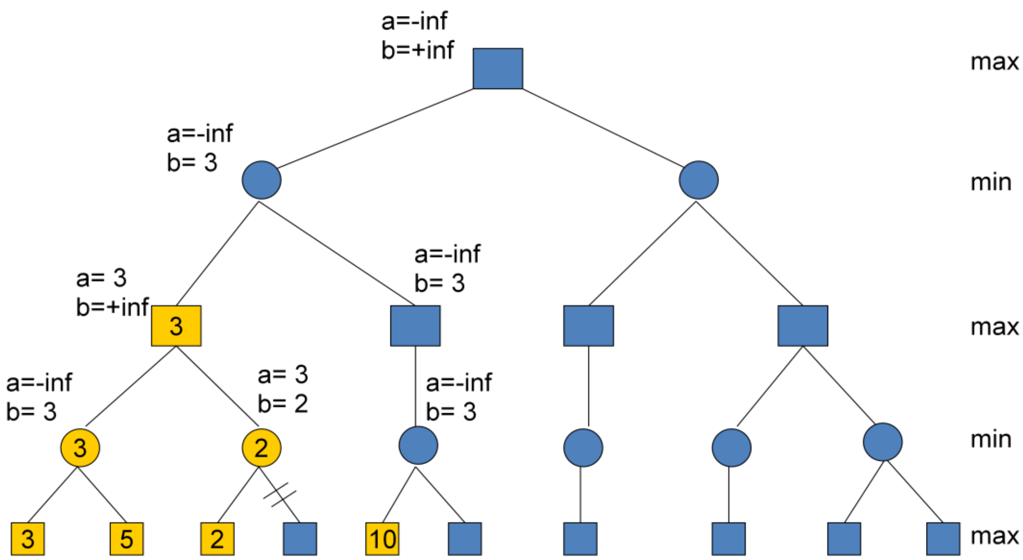
5) Now, the min parent node has a max value of 3 and min value of 2. The value of the 2nd child does not matter. If it is >2, 2 will be selected for min node. If it is <2, it will be selected for min node, but since it is <3 it will not get selected for the parent max node. Thus, we prune the right subtree of the min node. Propagate max value up the tree.



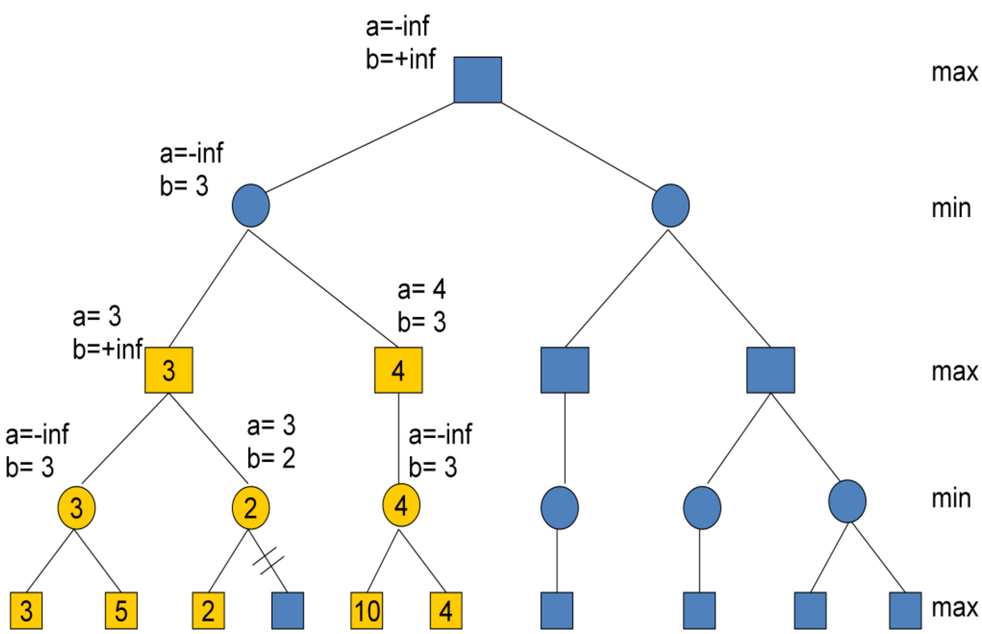
6) Max node is now done and we can set the beta value of its parent and propagate node state to sibling subtree's left-most path.



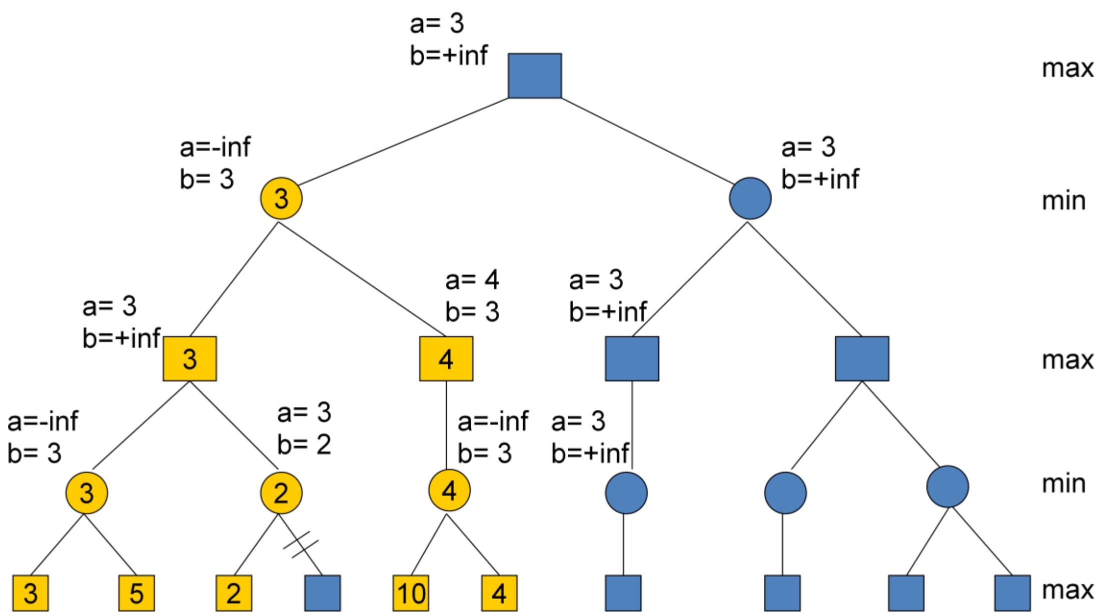
7) **The next node is 10. 10 is not smaller than 3, so state of parent does not change. We still have to look at the 2nd child since alpha is still –inf.**



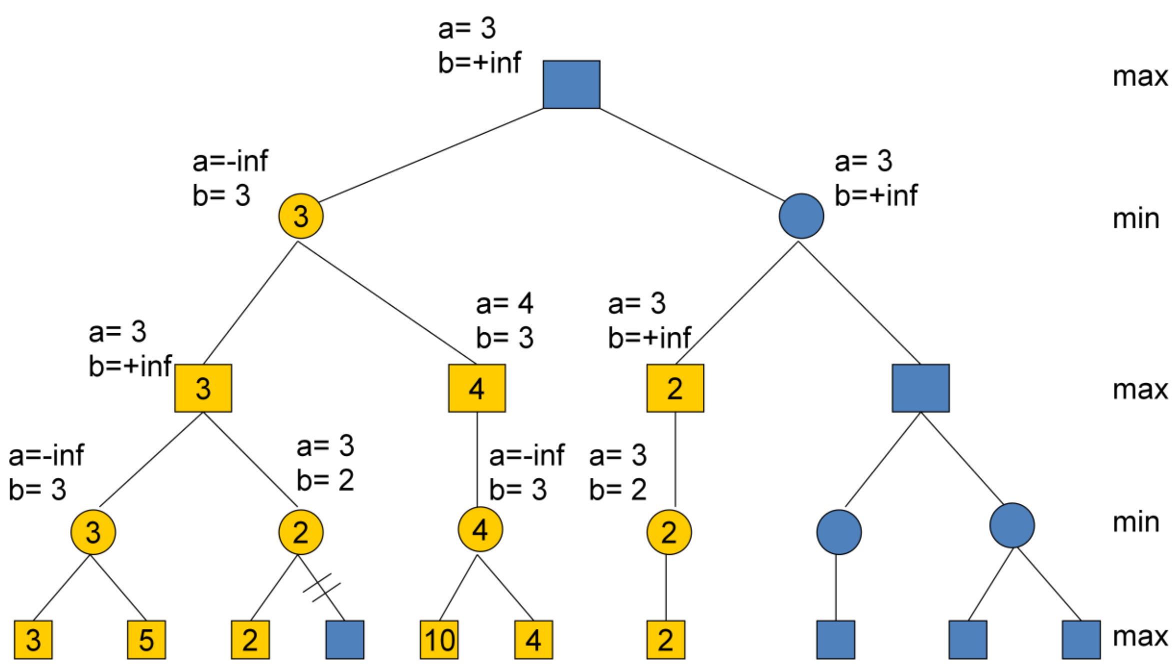
8) **The next node is 4. Smallest value goes to the parent min node. Min subtree is done, so the parent max node gets the alpha (max) value from the child. Note that if the max node had a 2nd subtree, we can prune it since a>b.**



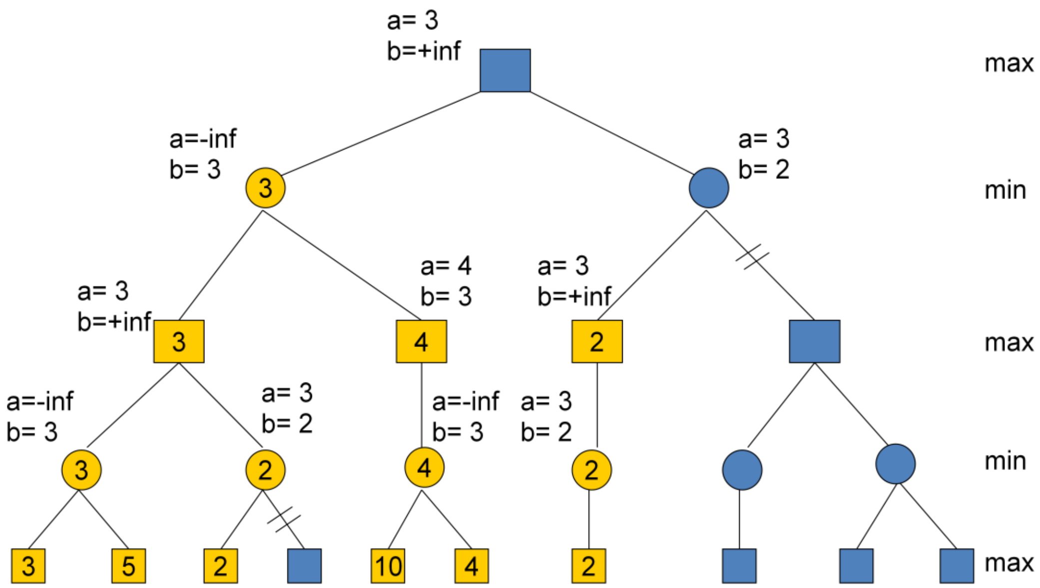
9) Continue propagating value up the tree, modifying the corresponding alpha/beta values. Also propagate the state of root node down the left-most path of the right subtree.



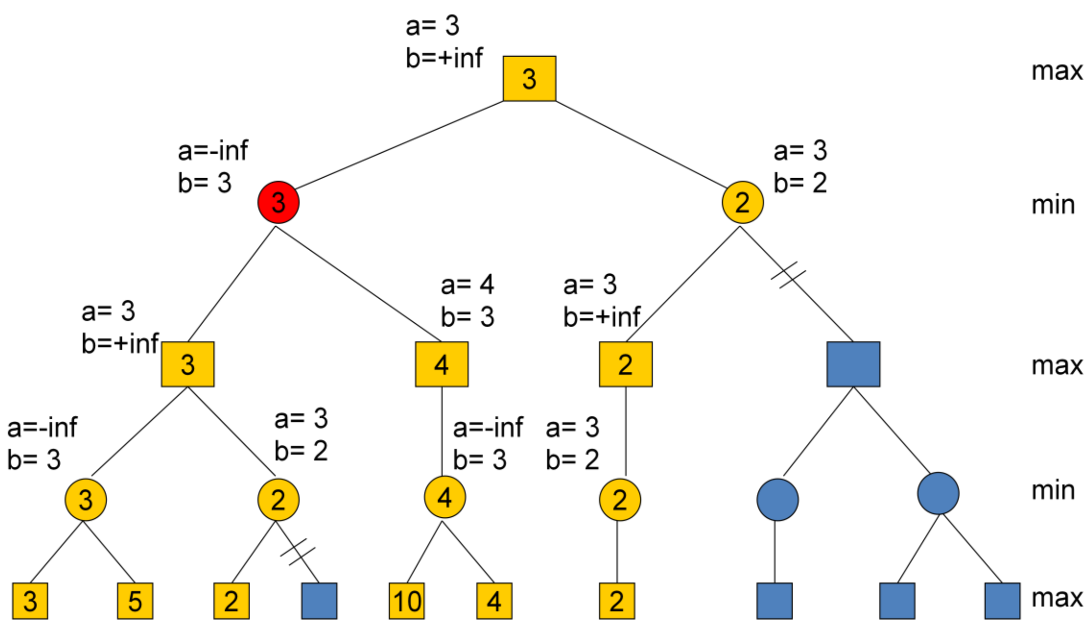
10) Next value is a 2. We set the beta (min) value of the min parent to 2. Since no other children exist, we propagate the value up the tree.



11) We have a value for the 3rd level max node, now we can modify the beta (min) value of the min parent to 2. Now, we have a situation that a>b and thus the value of the rightmost subtree of the min node does not matter, so we prune the whole subtree.



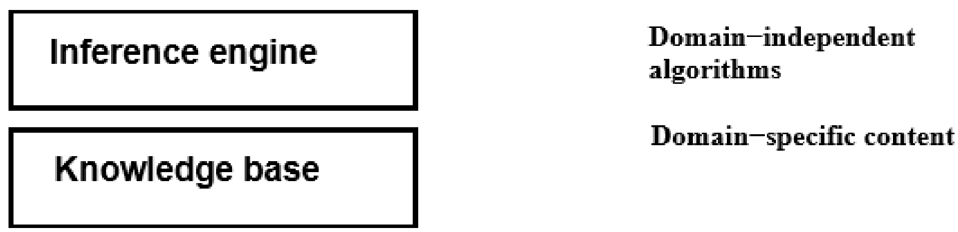
12) Finally, no more nodes remain, we propagate values up the tree. The root has a value of 3 that comes from the left-most child. Thus, the player should choose the left-most child's move in order to maximize his/her winnings. As you can see, the result is the same as with the mini-max example, but we did not visit all nodes of the tree.



UNIT III

Knowledge Based Agents A knowledge-based agent needs a KB and an inference mechanism. It operates by storing sentences in its knowledge base, inferring new sentences with the inference mechanism, and using them to deduce which actions to take The interpretation of a sentence is the fact to which it refers.

Knowledge Bases:



Knowledge base = set of sentences in a formal language Declarative approach to building an agent (or other system): Tell it what it needs toknow - Thenitcan Askitselfwhattodo—answersshouldfollowfromtheKB Agents can be viewed at the knowledge leveli.e., what they know, regardless of howimplemented or at the implementation leveli.e.,data structuresinKBand algorithmsthatmanipulatethem. The Wumpus World:

A variety of "worlds" are being used as examples for Knowledge Representation, Reasoning, and Planning. Among them the Vacuum World, the Block World, and the Wumpus World. The Wumpus World was introduced by Genesereth, and is discussed in Russell-Norvig. The Wumpus World is a simple world (as is the Block World) for which to represent knowledge and to reason. It is a cave with a number of rooms, represented as a 4x4 square

4	stench		breeze	pit
3	wumpus	stench breeze gold	pit	breeze
2	stench		breeze	
1	start ==>	breeze	pit	breeze
	1	2	3	4

Rules of the Wumpus World The neighborhood of a node consists of the four squares north, south, east, and west of the given square. In a square the agent gets a vector of percepts, with components Stench, Breeze, Glitter, Bump, Scream For example [Stench, None, Glitter, None, None] Stench is perceived at a square iff the wumpus is at this square or in its neighborhood. Breeze is perceived at a square iff a pit is in the neighborhood of this square. Glitter is perceived at a square iff gold is in this square Bump is perceived at a square iff the agent goes Forward into a wall Scream is perceived at a square iff the wumpus is killed anywhere in the cave An agent can do the following actions (one at a time): Turn (Right), Turn (Left), Forward, Shoot, Grab, Release, Climb The agent can go forward in the direction it is currently facing, or Turn Right, or Turn Left. Going forward into a wall will generate a Bump percept. The agent has a single arrow that it can shoot. It will go straight in the direction faced by the agent until it hits (and kills) the wumpus, or hits (and is absorbed by) a wall. The agent can grab a portable object at the current square or it can Release an object that it is holding. The agent can climb out of the cave if at the Start square.The Start square is (1,1) and initially the agent is facing east. The agent dies if it is in the same square asthe wumpus. The objective of the game is to kill the wumpus, to pick up the gold, and to climb out with it. Representing our Knowledge about the Wumpus World Percept(x, y) Where x must be a percept vector and y must be a situation. It means that at situation y theagentperceives x.For convenience we introduce the following definitions:

Percept([Stench,y,z,w,v],t) = > Stench(t) Percept([x,Breeze,z,w,v],t) = > Breeze(t) Percept([x,y,Glitter,w,v],t) = > AtGold(t) Holding(x, y)

Where x is an object and y is a situation. It means that the agent is holding the object x in situation y. Action(x, y) Where x must be an action (i.e. Turn (Right), Turn (Left), Forward,) and y must be a situation. It means that at situation y the agent takes action x. At(x,y,z) Where x is an object, y is a Location, i.e. a pair [u,v] with u and v in {1, 2, 3, 4}, and z is a situation. It means that the agent x in situation z is at location y. Present(x,s) Means that object x is in the current room in the situation s. Result(x, y) It means that the result of applying action x to the situation y is the situation Result(x,y).Notethat Result(x,y) is a term, not a statement. For example we can say Result(Forward, S0) = S1 Result(Turn(Right),S1) = S2 These definitions could be made more general. Since in the Wumpus World there is a single agent, there is no reason for us to make predicates and functions relative to a specific agent. In other"worlds" we should change things appropriately.

Validity And Satisfiability

A sentence is valid

if it is true in all models, e.g.,True,A∨¬A, A⇒A,(A∧(A⇒B)) ⇒B Validity is connected to inference via the Deduction Theorem: KB |= αif and onlyif(KB⇒α) isvalid Asentenceissatisfiableifitistrue insome model e.g., A∨B, C Asentence isunsatisfiableifitistrueinnomodels e.g., A A¬A Satisfiability is connected to inference via the following: KB|=α iff(KB∧¬α)isunsatisfiable i.e., prove α by reductionandabsurdum

Proof Methods

Proof methods divide into (roughly)two kinds:

Application of inference rules – Legitimate(sound)generationofnewsentencesfromold – Proof=asequenceofinferenceruleapplicationscanuseinferencerulesasoperatorsinastand ardsearch algorithm – Typicallyrequiretranslationofsentencesintoanormalform Model checking – Truthtableenumeration(alwaysexponentialinn) –

Improvedbacktracking,e.g.,Davis–Putnam–Loge Mann–Loveland – Heuristic searchinmodelspace(soundbutincomplete) e.g.,min-conflicts-likehillclimbingalgorithms

Forward and Backward Chaining

Horn Form (restricted) KB = conjunction of Horn clauses Horn clause = – proposition symbol;or – (conjunctionofsymbols) ⇒ symbol Example KB: CA(B ⇒ A) A (CAD ⇒ B) Modus Ponens (for Horn Form): complete for Horn KBs

α1,...,αn,α1A···Aα⇒ β β

Canbeusedwithforwardchaining orbackwardchaining. These algorithms areverynaturalandruninlineartime.,

ForwardChaining

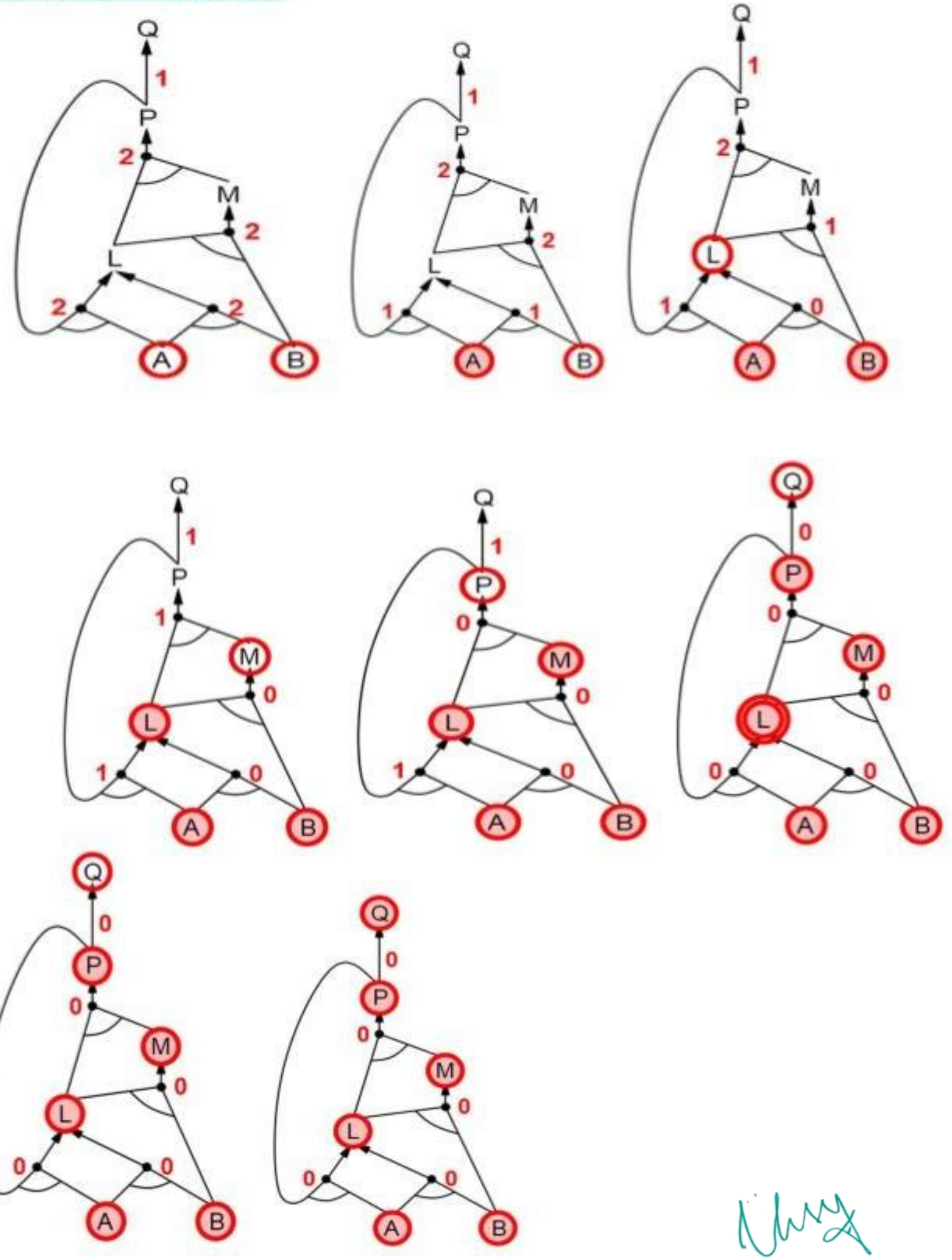
Idea: If anyrulewhosepremisesaresatisfiedintheKB, additsconclusiontotheKB,untilqueryisfound

ForwardChaining Algorithm

ForwardChaining Algorithm

```
function PL-FC-Entails?(KB,q) returns true or false
   inputs: KB, the knowledge base, a set of propositional Horn clauses
           q, the query, a proposition symbol
   local variables: count, a table, indexed by clause, initially the number of premises
                    inferred, a table, indexed by symbol, each entry initially false
                    agenda, a list of symbols, initially the symbols known in KB
   while agenda is not empty
      do p ← Pop(agenda)
      unless inferred[p] do
         inferred[p] ← true
         for each Horn clause c in whose premise p appears do
            decrement count[c]
```

ForwardChaining Example



Proof of Completeness

FC derives every atomic sentence that is entailed by KB

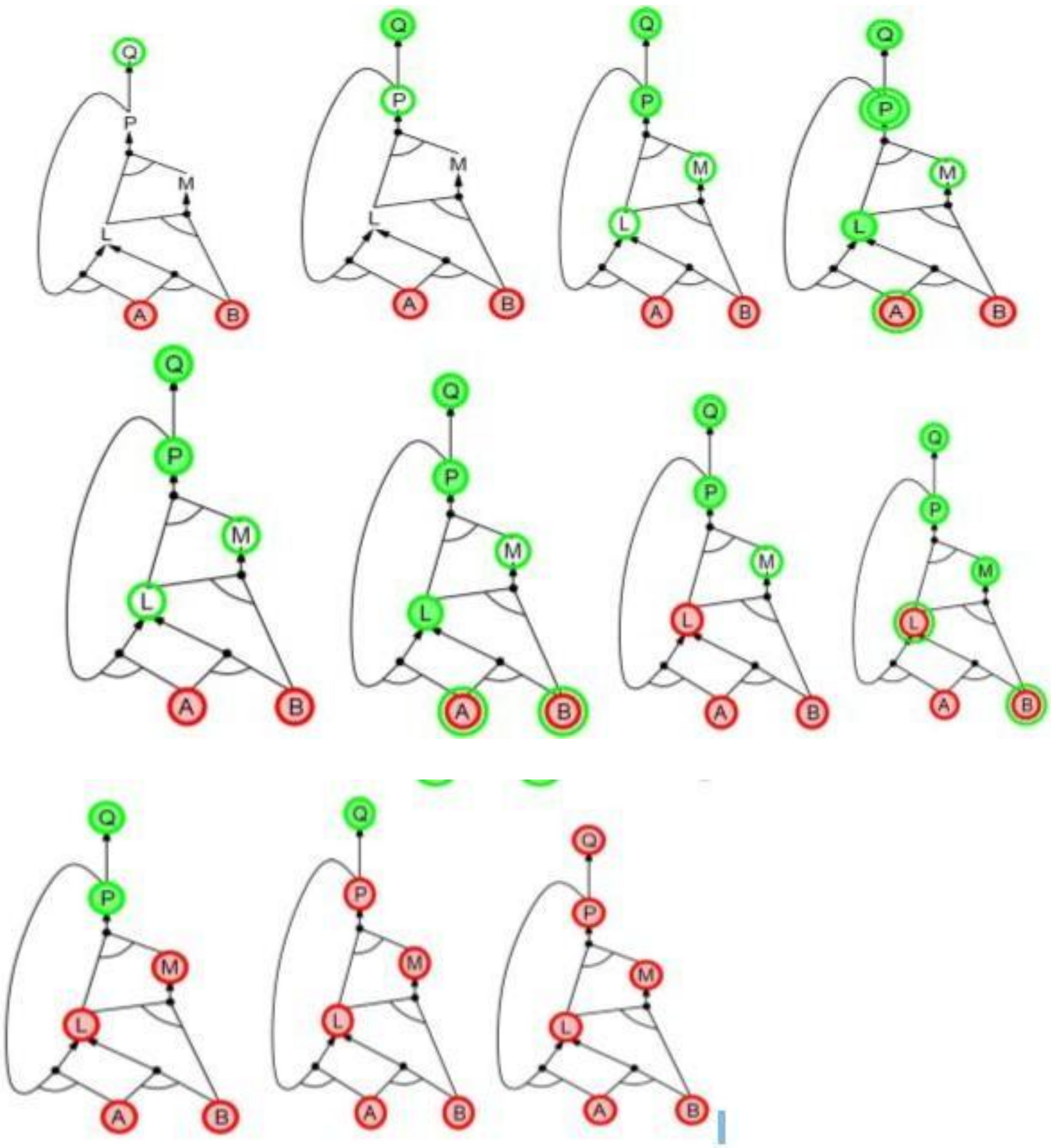
1. FCreachesafixedpointwherenonewatomicsentencesarederived

2. Considerthefinalstateasamodelm,assigningtrue/falsetosymbols

3. Every clause in the original KB is true inm i. Proof:Supposeaclausea1A...Aak⇒bisfalsei nm Then a1A. . . Aakis true in m and b is false in m Therefore thealgorithmhasnotreachedafixedpoint ! 4. Hence m is a model ofKB 5. IfKB|=q,thenqistrueineverymodelofKB,includingm a. Generalidea: constructanymodelofKBby soundinference,checkα

Backward Chaining

Idea:workbackwardsfromthequeryq: to prove q byBC, check if q is known already, or prove by BC all premises of some rule concluding q Avoidloops: checkifnewsubgoalisalreadyonthegoalstack Avoid repeated work: check if new subgoal 1. has already been proved true, or 2. has alreadyfailed



Forward vs Backward Chaining

FC is data-driven, cf. automatic, unconscious processing, e.g.,objectrecognition,routinedecisions Maydolotsofworkthatisirrelevanttothegoal BC is goal-driven, appropriate forproblem-solving, e.g., Where are my keys? How do I get into a PhD program? Complexity of BC can be much less than linear in size of KB

FIRST ORDER LOGIC:

PROCEDURAL LANGUAGES AND PROPOSITIONAL LOGIC:

Drawbacks of Procedural Languages

 Programming languages (such as C++ or Java or Lisp) are by far the largest class of formal languages in common use. Programs themselves represent only computational processes. Data structures within programs can represent facts.

For example, a program could use a 4 × 4 array to represent the contents of the wumpus world. Thus, the programming language statement World*2,2+← Pit is a fairly natural way to assert that there is a pit in square [2,2].

What programming languages lack is any general mechanism for deriving facts from other facts; each update to a data structure is done by a domain-specific procedure whose details are derived by the programmer from his or her own knowledge of the domain.

 A second drawback of is the lack the expressiveness required to handle partial information . For example data structures in programs lack the easy way to say, “There is a pit in *2,2+ or *3,1+” or “If the wumpus is in *1,1+ then he is not in *2,2+.”

Advantages of Propositional Logic

 The declarative nature of propositional logic, specify that knowledge and inference are separate, and inference is entirely domain-independent. Propositional logic is a declarative language because its semantics is based on a truth relation between sentences and possible worlds. It also has sufficient expressive power to deal with partial information, using disjunction and negation.

 Propositional logic has a third COMPOSITIONALITY property that is desirable in representation languages, namely, compositionality. In a compositional language, the meaning of a sentence is a function of the meaning of its parts. For example, the meaning of “S1,4A S1,2” is related to the meanings of “S1,4” and “S1,2.

Drawbacks of Propositional Logic Propositional logic lacks the expressive power to concisely describe an environment with many objects.

For example, we were forced to write a separate rule about breezes and pits for each square, such as B1,1⇔ (P1,2 ∨ P2,1) .

 In English, it seems easy enough to say, “Squares adjacent to pits are breezy.” The syntax and semantics of English somehow make it possible to describe the environment concisely

SYNTAX AND SEMANTICS OF FIRST-ORDER LOGIC

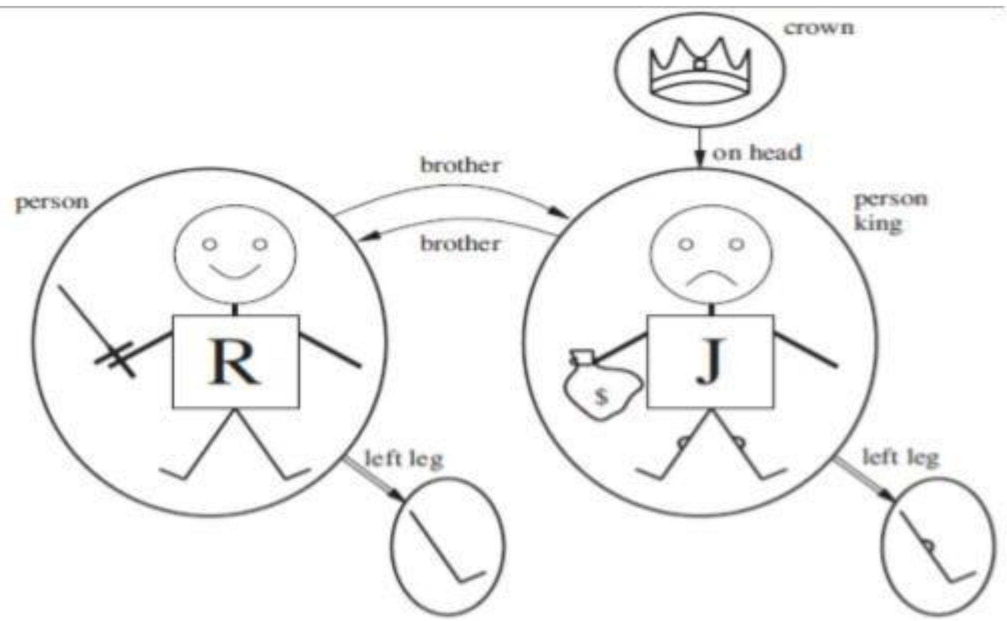
Models for first-order logic :

The models of a logical language are the formal structures that constitute the possible worlds under consideration. Each model links the vocabulary of the logical sentences to elements of the possible world, so that the truth of any sentence can be determined. Thus, models for propositional logic link proposition symbols to predefined truth values. Models for first-order logic have objects. The domain of a model is the set of objects or domain elements it contains. The domain is required to be nonempty—every possible world must contain at least one object.

A relation is just the set of tuples of objects that are related. Unary Relation: Relations relatesto single Object Binary Relation: Relation Relates to multiple objects Certain kinds of relationshipsare best considered as functions, in that a given object must be related to exactly one object.

For Example:

Richard the Lionheart, King of England from 1189 to 1199; His younger brother, the evil King John, who ruled from 1199 to 1215; the left legs of Richard and John; crown



Unary Relation : John is a king Binary Relation :crown is on head of john , Richard is brother ofjohn The unary "left leg" function includes the following mappings: (Richard the Lionheart) ->Richard's left leg (King John) ->Johns left Leg

Symbols and interpretations

Symbols are the basic syntactic elements of first-order logic. Symbols stand for objects, relations, and functions.

The symbols are of three kinds: Constant symbols which stand for objects; Example: John, Richard Predicate symbols, which stand for relations; Example: OnHead, Person, King, and Crown Function symbols, which stand for functions. Example: left leg

Symbols will begin with uppercase letters.

Interpretation The semantics must relate sentences to models in order to determine truth. For this to happen, we need an interpretation that specifies exactly which objects, relations and functions are referred to by the constant, predicate, and function symbols.

For Example:

 Richard refers to Richard the Lionheart and John refers to the evil king John. Brother refers to the brotherhood relation OnHead refers to the "on head relation that holds betweenthe crown and King John; Person, King, and Crown refer to the sets of objects that are persons, kings, and crowns. LeftLeg refers to the "left leg" function,

The truth of any sentence is determined by a model and an interpretation for the sentence's symbols. Therefore, entailment, validity, and so on are defined in terms of all possiblemodels and all possible interpretations. The number of domain elements in each model may be unbounded-for example, the domain elements may be integers or real numbers. Hence, the number of possible models is anbounded, as is the number of interpretations.

Term

A term is a logical expression that refers to an object. Constant symbols are therefore terms. Complex Terms A complex term is just a complicated kind of name. A complex term is formed by a function symbol followed by a parenthesized list of terms as arguments to the function symbol For example: "King John's left leg" Instead of using a constant symbol, we use LeftLeg(John). The formal semantics of terms :

Consider a term f (tl,. . . , t,). The function symbol frefers to some function in the model (F); the argument terms refer to objects in the domain (call them d1….dn); and the term as a whole refers to the object that is the value of the function Fapplied to dl, . . . , d,. For example,: the LeftLeg function symbol refers to the function " (King John) -+ John's left leg" and John refers to King John, then LeftLeg(John) refers to King John's left leg. In this way, the interpretation fixes the referent of every term.

Atomic sentences

An atomic sentence is formed from a predicate symbol followed by a parenthesized list of terms: For Example: Brother(Richard, John).

Atomic sentences can have complex terms as arguments. For Example: Married (Father(Richard), Mother(John)).

An atomic sentence is true in a given model, under a given interpretation, if the relation referred to by the predicate symbol holds among the objects referred to by the arguments

Complex sentences Complex sentences can be constructed using logical Connectives, just as in propositional calculus. For Example:

- ✓ ¬Brother (LeftLeg(Richard), John)
- ✓ Brother (Richard , John) ∧ Brother (John, Richard)
- ✓ King(Richard) ∨ King(John)
- ✓ ¬King(Richard) ⇒ King(John)

Quantifiers

Quantifiers express properties of entire collections of objects, instead of enumerating the objects by name.
First-order logic contains two standard quantifiers:

1. Universal Quantifier
2. Existential Quantifier

Universal Quantifier
Universal quantifier is defined as follows:
"Given a sentence ∀x P, where P is any logical expression, says that P is true for every object x."
More precisely, ∀x P is true in a given model if P is true in all possible **extended interpretations** constructed from the interpretation given in the model, where each extended interpretation specifies a domain element to which x refers.

For Example: "All kings are persons," is written in first-order logic as
∀xKing(x) ⇒Person(x) .
∀ is usually pronounced "For all"

Thus, the sentence says, ―For all x, if x is a king, then x is a person.‖ The symbol x is called a variable. Variables are lowercase letters. A variable is a term all by itself, and can also serve as the argument of a function A term with no variables is called a ground term.

Assume we can extend the interpretation in different ways: x→ Richard the Lionheart, x→ King John, x→ Richard's left leg, x→ John's left leg, x→ the crown

The universally quantified sentence ∀x King(x) ⇒Person(x) is true in the original model if the sentence King(x) ⇒Person(x) is true under each of the five extended interpretations. That is, the universally quantified sentence is equivalent to asserting the following five sentences:

Richard the Lionheart is a king ⇒Richard the Lionheart is a person. King John is a king ⇒King John is a person. Richard's left leg is a king ⇒Richard's left leg is a person. John's left leg is a king ⇒John's left leg is a person. The crown is a king ⇒the crown is a person.

Existential quantification (∃)

Universal quantification makes statements about every object. Similarly, we can make a statement about some object in the universe without naming it, by using an existential quantifier.

"The sentence ∃x P says that P is true for at least one object x. More precisely, ∃x P is true in a given model if P is true in at least one extended interpretationthat assigns x to a domain element." ∃x is pronounced "There exists an x such that . . ." or "For some x . . .".

For example, that King John has a crown on his head, we write ∃xCrown(x) ΛOnHead(x, John)

Given assertions:

Richard the Lionheart is a crown ΛRichard the Lionheart is on John's head; King John is a crown ΛKing John is on John's head; Richard's left leg is a crown ΛRichard's left leg is on John's head; John's left leg is a crown ΛJohn's left leg is on John's head; The crown is a crown Λthe crown is on John's head. The fifth assertion is true in the model, so the original existentially quantified sentence is true in the model. Just as ⇒appears to be the natural connective to use with ∀, Λis the natural connective to use with ∃.

Nested quantifiers

One can express more complex sentences using multiple quantifiers.

For example, "Brothers are siblings" can be written as ∀x∀y Brother (x, y) ⇒Sibling(x, y). Consecutive quantifiers of the same type can be written as one quantifier with several variables.

For example, to say that siblinghood is a symmetric relationship,

we can write∀x, y Sibling(x, y) ⇔Sibling(y, x).

In other cases we will have mixtures.

For example: 1. "Everybody loves somebody" means that for every person, there is someone that person loves: ∀x∃y Loves(x, y) . 2. On the other hand, to say "There is someone who is loved by everyone," we write ∃y∀x Loves(x, y) .

Connections between ∀and ∃

Universal and Existential quantifiers are actually intimately connected with each other, through negation.

Example assertions: 1. “ Everyone dislikes medicine” is the same as asserting “ there does not exist someone who likes medicine” , and vice versa: “∀x ¬Likes(x, medicine)” is equivalent to “¬∃x Likes(x, medicine)”. 2. “Everyone likes ice cream” means that “ there is no one who does not like ice cream” : ∀xLikes(x, IceCream) is equivalent to ¬∃x ¬Likes(x, IceCream) .

Because ∀is really a conjunction over the universe of objects and ∃is a disjunction that they obey De Morgan’s rules. The De Morgan rules for quantified and unquantified sentences are as follows:

Because ∀is really a conjunction over the universe of objects and ∃is a disjunction that they obey De Morgan’s rules. The De Morgan rules for quantified and unquantified sentences are as follows:

$$\begin{array}{llll} \forall x\ \neg P \equiv \neg \exists x\ P & \qquad \neg(P \vee Q) \equiv \neg P \wedge \neg Q \\ \neg \forall x\ P \equiv \exists x\ \neg P & \qquad \neg(P \wedge Q) \equiv \neg P \vee \neg Q \\ \forall x\ P \equiv \neg \exists x\ \neg P & \qquad P \wedge Q \equiv \neg(\neg P \vee \neg Q) \\ \exists x\ P \equiv \neg \forall x\ \neg P & \qquad P \vee Q \equiv \neg(\neg P \wedge \neg Q) .. \end{array}$$

Thus, Quantifiers are important in terms of readability.

Equality

First-order logic includes one more way to make atomic sentences, other than using a predicateand terms .We can use the equality symbol to signify that two terms refer to the same object.

For example,

“Father(John) =Henry” says that the object referred to by Father (John) and the object referred to by Henry are the same.

Because an interpretation fixes the referent of any term, determining the truth of an equality sentence is simply a matter of seeing that the referents of the two terms are the same object.The equality symbol can be used to state facts about a given function.It can also be used with negation to insist that two terms are not the same object.

For example,

“Richard has at least two brothers” can be written as, ∃x, y Brother (x,Richard) ABrother (y,Richard) A¬(x=y) .

The sentence

∃x, y Brother (x,Richard) ABrother (y,Richard) does not have the intended meaning. In particular, it is true only in the model where Richard has only one brother considering the extended interpretation in which both x and y are assigned to King John. The addition of ¬(x=y) rules out such models.

```
Sentence          →  AtomicSentence | ComplexSentence
AtomicSentence    →  Predicate | Predicate(Term, ...) | Term = Term
ComplexSentence   →  ( Sentence ) | [ Sentence ]
                  |  ¬ Sentence
                  |  Sentence ∧ Sentence
                  |  Sentence ∨ Sentence
                  |  Sentence ⇒ Sentence
                  |  Sentence ⇔ Sentence
                  |  Quantifier Variable, ... Sentence

Term              →  Function(Term, ...)
                  |  Constant
                  |  Variable

Quantifier        →  ∀ | ∃
Constant          →  A | X1 | John | ···
Variable          →  a | x | s | ···
Predicate         →  True | False | After | Loves | Raining | ···
Function          →  Mother | LeftLeg | ···
OPERATOR PRECEDENCE  :  ¬, =, ∧, ∨, ⇒, ⇔
```

Backus Naur Form for First Order Logic

USING FIRST ORDER LOGIC Assertions and queries in first-order logic

Assertions:

Sentences are added to a knowledge base using TELL, exactly as in propositional logic. Such sentences are called assertions.

For example,

John is a king, TELL (KB, King (John)). Richard is a person. TELL (KB, Person (Richard)). All kings are persons: TELL (KB, ∀x King(x) ⇒Person(x)).

Asking Queries:

We can ask questions of the knowledge base using ASK. Questions asked with ASK are called queries or goals.

For example,

ASK (KB, King (John)) returns true.

Anyquery that is logically entailed by the knowledge base should be answered affirmatively.

Forexample, given the two preceding assertions, the query:

"ASK (KB, Person (John))" should also return true.

Substitution or binding list

We can ask quantified queries, such as ASK (KB, ∃x Person(x)) .

The answer is true, but this is perhaps not as helpful as we would like. It is rather like answering "Can you tell me the time?" with "Yes."

If we want to know what value of x makes the sentence true, we will need a different function, ASKVARS, which we call with ASKVARS (KB, Person(x)) and which yields a stream of answers.

In this case there will be two answers: {x/John} and {x/Richard}. Such an answer is called a substitution or binding list.

ASKVARS is usually reserved for knowledge bases consisting solely of Horn clauses, because in such knowledge bases every way of making the query true will bind the variables to specific values.

The kinship domain

The objects in Kinship domain are people.

We have two unary predicates, Male and Female.

Kinship relations—parenthood, brotherhood, marriage, and so on—are represented by binary predicates: Parent, Sibling, Brother,Sister,Child, Daughter, Son, Spouse, Wife, Husband, Grandparent,Grandchild, Cousin, Aunt, and Uncle.

We use functions for Mother and Father, because every person has exactly one of each of these.

We can represent each function and predicate, writing down what we know in termsof the other symbols.

For example:- 1. one's mother is one's female parent: ∀m, c Mother (c)=m ⇔Female(m) AParent(m, c) .

2. One's husband is one's male spouse: ∀w, h Husband(h,w) ⇔Male(h) ASpouse(h,w) .

3. Male and female are disjoint categories: ∀xMale(x) ⇔¬Female(x) .

4. Parent and child are inverse relations: ∀p, c Parent(p, c) ⇔Child (c, p) .

5. A grandparent is a parent of one's parent: ∀g, c Grandparent (g, c) ⇔∃p Parent(g, p) AParent(p, c) .

6. A sibling is another child of one's parents: ∀x, y Sibling(x, y) ⇔x _= y A∃p Parent(p, x) AParent(p, y) .

Axioms:

Each of these sentences can be viewed as an axiom of the kinship domain. Axioms are commonly associated with purely mathematical domains. They provide the basic factual information from which useful conclusions can be derived.

Kinship axioms are also definitions; they have the form ∀x, y P(x, y) ⇔. . ..

The axioms define the Mother function, Husband, Male, Parent, Grandparent, and Sibling predicates in terms of other predicates.

Our definitions "bottom out" at a basic set of predicates (Child, Spouse, and Female) in terms of which the others are ultimately defined. This is a natural way in which to build up the representation of a domain, and it is analogous to the way in which software packages are built up by successive definitions of subroutines from primitive library functions.

Theorems:

Not all logical sentences about a domain are axioms. Some are theorems—that is, they are entailed by the axioms.

For example, consider the assertion that siblinghood is symmetric: ∀x, y Sibling(x, y) ⇔Sibling(y, x) .

It is a theorem that follows logically from the axiom that defines siblinghood. If we ASK the knowledge base this sentence, it should return true. From a purely logical point of view, a knowledge base need contain only axioms and no theorems, because the theorems do not increase the set of conclusions that follow from the knowledge base. From a practical point of view, theorems are essential to reduce the computational cost of deriving new sentences. Without them, a reasoning system has to start from first principles every time.

Axioms :Axioms without Definition

Not all axioms are definitions. Some provide more general information about certain predicates without constituting a definition. Indeed, some predicates have no complete definition because we do not know enough to characterize them fully.

For example, there is no obvious definitive way to complete the sentence

$\forall x Person(x) \Leftrightarrow . . .$

Fortunately, first-order logic allows us to make use of the Person predicate without completely defining it. Instead, we can write partial specifications of properties that every person has and properties that make something a person:

$\forall x Person(x) \Rightarrow . . . \forall x . . . \Rightarrow Person(x)$.

Axioms can also be “just plain facts,” such as Male (Jim) and Spouse (Jim, Laura).Such facts form the descriptions of specific problem instances, enabling specific questions to be answered. The answers to these questions will then be theorems that follow from the axioms

Numbers, sets, and lists

Number theory

Numbers are perhaps the most vivid example of how a large theory can be built up from NATURAL NUMBERS a tiny kernel of axioms. We describe here the theory of natural numbers or non-negative integers. We need:

 predicate NatNum that will be true of natural numbers; one PEANO AXIOMS constant symbol, 0; One function symbol, S (successor). The Peano axioms define natural numbers and addition.

Natural numbers are defined recursively: NatNum(0) . ∀n NatNum(n) ⇒ NatNum(S(n)) .

That is, 0 is a natural number, and for every object n, if n is a natural number, then S(n) is a natural number.

So the natural numbers are 0, S(0), S(S(0)), and so on. We also need axioms to constrain the successor function: ∀n 0 != S(n) . ∀m, n m != n ⇒ S(m) != S(n) .

Now we can define addition in terms of the successor function: ∀m NatNum(m) ⇒ + (0, m) = m . ∀m, n NatNum(m) A NatNum(n) ⇒ + (S(m), n) = S(+(m, n))

The first of these axioms says that adding 0 to any natural number m gives m itself. Addition is represented using the binary function symbol "+" in the term + (m, 0);

To make our sentences about numbers easier to read, we allow the use of infix notation. We can also write S(n) as n + 1, so the second axiom becomes :

∀m, n NatNum (m) A NatNum(n) ⇒ (m + 1) + n = (m + n)+1 .

This axiom reduces addition to repeated application of the successor function. Once we have addition, it is straightforward to define multiplication as repeated addition, exponentiation as repeated multiplication, integer division and remainders, prime numbers, and so on. Thus, the whole of number theory (including cryptography) can be built up from one constant, one function, one predicate and four axioms.

Sets

The domain of sets is also fundamental to mathematics as well as to commonsense reasoning. Sets can be represented as individualsets, including empty sets.

Sets can be built up by: - adding an element to a set or - Taking the union or intersection of two sets.

Operations that can be performed on sets are: - To know whether an element is a member of a set - Distinguish sets from objects that are not sets.

Vocabulary of set theory:

The empty set is a constant written as { }. There is one unary predicate, Set, which is true of sets. The binary predicates are

 x∈ s (x is a member of set s) s1⊆ s2 (set s1 is a subset, not necessarily proper, of set s2).

The binary functions are

 s1 ∩ s2 (the intersection of two sets), s1∪ s2 (the union of two sets), and ,x|s- (the set resulting from adjoining element x to set s).

One possible set of axioms is as follows:

 The only sets are the empty set and those made by adjoining something to a set:∀sSet(s) ⇔(s={}) ∨(∃x, s2 Set(s2) ∧s={x|s2}) . The empty set has no elements adjoined into it. In other words, thereis no way to decompose {} into a smaller set and an element: ¬∃x, s {x|s}={} . Adjoining an element already in the set has no effect: ∀x, s x∈s ⇔s={x|s} . The only members of a set are the elements that were adjoined into it. We express this recursively, saying that x is a member of s if and only if s is equal to some set s2 adjoined with some element y, where either y is the same as x or x is a member of s2: ∀x, s x∈s ⇔∃y, s2 (s={y|s2} ∧(x=y ∨x∈s2)) A set is a subset of another set if and only if all of the first set's members are members of the second set: ∀s1, s2 s1 ⊆s2 ⇔(∀x x∈s1 ⇒x∈s2) Two sets are equal if and only if each is a subset of the other: ∀s1, s2 (s1 =s2) ⇔(s1 ⊆s2 ∧s2 ⊆s1)

 An object is in the intersection of two sets if and only if it is a member of both sets:∀x, s1, s2x∈(s1 ∩ s2) ⇔(x∈s1 ∧x∈s2) An object is in the union of two sets if and only if it is a member ofeither set: ∀x, s1, s2 x∈(s1 ∪s2) ⇔(x∈s1 ∨x∈s2)

Lists : are similar to sets. The differences are that lists are ordered and the same element canappear more than once in a list. We can use the vocabulary of Lisp for lists:

 Nil is the constant list with no element;s Cons, Append, First, and Rest are functions; Find isthe predicate that does for lists what Member does for sets. List? is a predicate that is true only of lists. The empty list is * +. The term Cons(x, y), where y is a nonempty list, is written [x|y]. The term Cons(x, Nil) (i.e., the list containing the element x) is written as [x]. A list of several elements, such as [A,B,C], corresponds to the nested term Cons(A, Cons(B, Cons(C, Nil))).

The wumpus world

Agents Percepts and Actions

The wumpus agent receives a percept vector with five elements. The corresponding first-order sentence stored in the knowledge base must include both the percept and the time at which it occurred; otherwise, the agent will get confused about when it saw what.We use integers for time steps. A typical percept sentence would be

Percept ([Stench, Breeze, Glitter,None, None], 5).

Here, Percept is a binary predicate, and Stench and so on are constants placed in a list. The actions in the wumpus world can be represented by logical terms:

Turn (Right), Turn (Left), Forward,Shoot,Grab, Climb.

To determine which is best, the agent program executes the query:

ASKVARS (∃a BestAction (a, 5)), which returns a binding list such as {a/Grab}.

The agent program can then return Grab as the action to take.

The raw percept data implies certain facts about the current state.

For example: ∀t, s, g, m, c Percept ([s, Breeze, g,m, c], t) ⇒Breeze(t) , ∀t, s, b, m, c Percept ([s, b, Glitter,m, c], t) ⇒Glitter (t) ,

UNIT III – Knowledge and Reasoning

These rules exhibit a trivial form of the reasoning process called perception.

Simple ―reflex‖ behavior can also be implemented by quantified implication sentences.

For example, we have ∀tGlitter (t) ⇒BestAction(Grab, t) .

Given the percept and rules from the preceding paragraphs, this would yield the desired conclusion Best Action (Grab, 5)—that is, Grab is the right thing to do.

Environment Representation

Objects are squares, pits, and the wumpus. Each square could be named—Square1,2and so on—but then the fact that Square1,2and Square1,3 are adjacent would have to be an ―extra‖ fact, and this needs one suchfact for each pair of squares. It is better to use a complex term in which the row and columnappear as integers;

For example, we can simply use the list term [1, 2].

Adjacency of any two squares can be defined as:

∀x, y, a, b Adjacent ([x, y], [a, b]) ⇔ (x = a Λ(y = b − 1 ∨y = b + 1)) ∨(y = b Λ(x = a − 1 ∨x = a + 1)).

Each pit need not be distinguished with each other. The unary predicate Pit is true of squares containing pits.

Since there is exactly one wumpus, a constant Wumpus is just as good as a unary predicate. The agent's location changes over time, so we write At (Agent, s, t) to mean that theagent is at square s at time t.

To specify the Wumpus location (for example) at [2, 2] we can write ∀t At (Wumpus, [2, 2], t).

Objects can only be at one location at a time: ∀x, s1, s2, t At(x, s1, t) ∧At(x, s2, t) ⇒s1 = s2 .

Given its current location, the agent can infer properties of the square from properties of its current percept.

For example, if the agent is at a square and perceives a breeze, then that square is breezy:

∀s, t At(Agent, s, t) ∧Breeze(t) ⇒Breezy(s) .

It is useful to know that a square is breezy because we know that the pits cannot move about.

Breezy has no time argument.

Having discovered which places are breezy (or smelly) and, very importantly, not breezy (or not smelly), the agent can deduce where the pits =e (and where the wumpus is).

There are two kinds of synchronic rules that could allow such deductions:

Diagnostic rules:

Diagnostic rules lead from observed effects to hidden causes. For finding pits, the obvious diagnostic rules say that if a square is breezy, some adjacent square must contain a pit, or

∀s Breezy(s) ⇒∃r Adjacent (r, s)∧Pit(r) ,

and that if a square is not breezy, no adjacent square contains a pit: ∀s¬Breezy (s) ⇒¬∃r Adjacent (r, s) ∧ Pit (,r) .Combining these two, we obtain the biconditional sentence ∀s Breezy (s)⇔∃r Adjacent(r, s) ∧ Pit (r) .

Causal rules:

Causal rules reflect the assumed direction of causality in the world: some hidden property of the world causes certain percepts to be generated. For example, a pit causes all adjacent squares to be breezy:

and if all squares adjacent to a given square are pitless, the square will not be breezy: ∀s[∀r Adjacent (r, s) ⇒¬Pit (r)] ⇒¬Breezy (s) .

It is possible to show that these two sentences together are logically equivalent to the biconditional sentence ― ∀s Breezy (s)⇔∃r Adjacent(r, s) A Pit (r)‖ .

The biconditional itself can also be thought of as causal, because it states how the truth value of Breezy is generated from the world state.

Systems that reason with causal rules are called model-based reasoning systems, because the causal rules form a model of how the environment operates.

Whichever kind of representation the agent uses, ifthe axioms correctly and completely describe the way the world works and the way that percepts are produced, then any complete logical inference procedure will infer the strongest possible description of the world state, given the available percepts. Thus, the agent designer can concentrate on getting the knowledgeright, without worrying too much about the processes of deduction.

Inference in First-Order Logic

Propositional Vs First Order Inference

Earlier inference in first order logic is performed with *Propositionalization* which is a process of converting the Knowledgebase present in First Order logic into Propositional logic and on that using any inference mechanisms of propositional logic are used to check inference.

Inference rules for quantifiers:

There are some Inference rules that can be applied to sentences with quantifiers to obtain sentences without quantifiers**.** These rules will lead us to make the conversion.

Universal Instantiation (UI):

The rule says that we can infer any sentence obtained by substituting a **ground term** (a term without variables) for the variable. Let SUBST (θ*)* denote the result of applying the substitution θto the sentence *a.* Then the rule is written

$$\frac{\forall v \;\; a}{\text{SUBST}(\{v/g\}, \alpha)}$$

For any variable v and ground term *g.*

For example, there is a sentence in knowledge base stating that all greedy kings are Evils

$$\forall x \;\; King(x) \land Greedy(x) \Rightarrow Evil(x) .$$

For the variable x, with the substitutions like {x/John},{x/Richard}the following sentences can be inferred.

$$King(John) \land Greedy(John) \Rightarrow Evil(John).$$
$$King(Richard) \land Greedy(Richard) \Rightarrow Evil(Richard) .$$

Thus a universally quantified sentence can be replaced by the set of *all* possible instantiations.

***Existential Instantiation (EI)**:*

The existential sentence says there is some object satisfying a condition, and the instantiation process is just giving a name to that object, that name must not already belong to another object. This new name is called a **Skolem constant.** Existential Instantiation is a special case of a more general process called *"skolemization".*

For any sentence *a*, variable v, and constant symbol *k* that does not appear elsewhere in the knowledge base,

$$\frac{\exists v \;\; \alpha}{\text{SUBST}(\{v/k\}, \alpha)}$$

For example, from the sentence

$$\exists x \;\; Crown(x) \land OnHead(x, John)$$

So, we can infer the sentence

$$Crown(C_1) \land OnHead(C_1, John)$$

As long as C_1 does not appear elsewhere in the knowledge base. Thus an existentially quantified sentence can be replaced by one instantiation

Elimination of Universal and Existential quantifiers should give new knowledge base which can be shown to be *inferentially equivalent*to oldin the sense that it is satisfiable exactly when the original knowledge base is satisfiable.

Reduction to propositional inference:

Once we have rules for inferring non quantified sentences from quantified sentences, it becomes possible to reduce first-order inference to propositional inference. For example, suppose our knowledge base contains just the sentences

$$\forall x \;\; King(x) \land Greedy(x) \Rightarrow Evil(x)$$
$$King(John)$$
$$Greedy(John)$$
$$Brother(Richard, John) .$$

Then we apply UI to the first sentence using all possible ground term substitutions from the vocabulary of the knowledge base-in this case, *{xl John)* and *{x/Richard)*. We obtain

$$King(John) \wedge Greedy(John) \Rightarrow Evil(John),$$
$$King(Richard) \wedge Greedy(Richard) \Rightarrow Evil(Richard)$$

We discard the universally quantified sentence. Now, the knowledge base is essentially propositional if we view the ground atomic sentences-King *(John), Greedy (John),* and Brother (Richard, *John*) as proposition symbols. Therefore, we can apply any of the complete propositional algorithms to obtain conclusions such as *Evil (John).*

Disadvantage:

If the knowledge base includes a function symbol, the set of possible ground term substitutions is infinite. Propositional algorithms will have difficulty with an infinitely large set of sentences.

NOTE:

Entailment for first-order logic is *semi decidable* which means algorithms exist that say yes to every entailed sentence, but no algorithm exists that also says no to every non entailed sentence

2. Unification and Lifting

Consider the above discussed example, if we add Siblings (Peter, Sharon) to the knowledge base then it will be

$$\forall x\ King(x) \wedge Greedy(x) \Rightarrow Evil(x)$$
$$King(John)$$
$$Greedy(John)$$
$$Brother(Richard, John)$$
$$\mathbf{Siblings(Peter, Sharon)}$$

Removing Universal Quantifier will add new sentences to the knowledge base which are not necessary for the query *Evil (John)?*

$$King(John) \wedge Greedy(John) \Rightarrow Evil(John)$$
$$King(Richard) \wedge Greedy(Richard) \Rightarrow Evil(Richard)$$
$$King(Peter) \wedge Greedy(Peter) \Rightarrow Evil(Peter)$$
$$King(Sharon) \wedge Greedy(Sharon) \Rightarrow Evil(Sharon)$$

Hence we need to teach the computer to make better inferences. For this purpose Inference rules were used.

First Order Inference Rule:

The key advantage of lifted inference rules over *propositionalization* is that they make only those substitutions which are required to allow particular inferences to proceed.

Generalized Modus Ponens:

If there is some substitution **θ** that makes the premise of the implication identical to sentences already in the knowledge base, then we can assert the conclusion of the implication, after applying **θ**. This inference process can be captured as a single inference rule called Generalized Modus Ponens which is a ***lifted***version of Modus Ponens-it raises Modus Ponens from propositional to first-order logic

For atomic sentences pi, pi ', and q, where there is a substitution θ such that SUBST(θ , pi) = SUBST(θ , pi '), for all i,

$$\frac{\mathbf{p1', p2', \ldots, pn', (p1 \wedge p2 \wedge \ldots \wedge pn \Rightarrow q)}}{\mathbf{SUBST(\theta, q)}}$$

There are N + 1 premises to this rule, N atomic sentences + one implication.

Applying SUBST (θ, q) yields the conclusion we seek. It is a sound inference rule.

Suppose that instead of knowing Greedy (John) in our example we know that everyone is greedy:

∀y Greedy(y)

We would conclude that Evil(John).

Applying the substitution {x/John, y / John) to the implication premises King (x) and Greedy (x) and the knowledge base sentences King(John) and Greedy(y)will make them identical. Thus, we can infer the conclusion of the implication.

For our example,

p_1' is $King(John)$ p_1 is $King(x)$
p_2' is $Greedy(y)$ p_2 is $Greedy(x)$
θ is $\{x/John, y/John\}$ q is $Evil(x)$
$\text{SUBST}(\theta, q)$ is $Evil(John)$.

Unification:

It is the process used to find substitutions that make different logical expressions look identical. **Unification** is a key component of all first-order Inference algorithms.

UNIFY (p, q) = θ where SUBST (θ, p) = SUBST (θ, q) θ is our unifier value (if one exists).

Ex: —Who does John know?‖

UNIFY (Knows (John, x), Knows (John, Jane)) = {x/ Jane}.

UNIFY (Knows (John, x), Knows (y, Bill)) = {x/Bill, y/ John}.

UNIFY (Knows (John, x), Knows (y, Mother(y))) = {x/Bill, y/ John}

UNIFY (Knows (John, x), Knows (x, Elizabeth)) = FAIL

- The last unification fails because both use the same variable, X. X can't equal both John and Elizabeth. To avoid this change the variable X to Y (or any other value) in Knows(X, Elizabeth)

Knows(X, Elizabeth) → Knows(Y, Elizabeth)

Still means the same. This is called **standardizing apart.**

- sometimes it is possible for more than one unifier returned:

UNIFY (Knows (John, x), Knows(y, z)) =???

This can return two possible unifications: {y/ John, x/ z} which means Knows (John, z) OR {y/ John, x/ John, z/ John}. For each unifiable pair of expressions there is a single **most general unifier (MGU)**, In this case it is *{y/ John, x/z).*

An algorithm for computing most general unifiers is shown below.

```
function UNIFY(x, y, θ) returns a substitution to make x and y identical
   inputs: x, a variable, constant, list, or compound
           y, a variable, constant, list, or compound
           θ, the substitution built up so far (optional, defaults to empty)

   if 0 = failure then return failure
   else if x = y then return θ
   else if VARIABLE?(x) then return UNIFY-VAR(x, y, 0)
   else if VARIABLE?(y) then return UNIFY-VAR(y, x, 0)
   else if COMPOUND?(x) and COMPOUND?(y) then
       return UNIFY(ARGS[x], ARGS[y], UNIFY(OP[x], OP[y], θ))
   else if LIST?(x) and LIST?(y) then
       return UNIFY(REST[x], REST[y], UNIFY(FIRST[x], FIRST[y], θ))
   else return failure
```

```
function UNIFY-VAR(var, x, 0) returns a substitution
   inputs: var, a variable
           x, any expression
           0, the substitution built up so far

   if {var/val} ∈ 6 then return UNIFY(val, x, θ)
   else if {x/val} ∈ θ then return UNIFY(var, val, θ)
   else if OCCUR-CHECK?(var, x) then return failure
   else return add {varlx) to 6
```

Figure 2.1 *The unification algorithm. The algorithm works by comparing the structures of the inputs, element by element. The substitution 0 that is the argument to UNIFY is built up along the way and is used to make sure that later comparisons are consistent with bindings that were established earlier. In a compound expression, such as F (A, B), the function OP picks out the function symbol F and the function ARCS picks out the argument list (A, B).*

The process is very simple: recursively explore the two expressions simultaneously "side by side," building up a unifier along the way, but failing if two corresponding points in the structures do not match. **Occur check** step makes sure same variable isn't used twice.

Storage and retrieval

- STORE(s) stores a sentence *s* into the knowledge base

➢ FETCH(s) returns all unifiers such that the query q unifies with some sentence in the knowledge base.

Easy way to implement these functions is Store all sentences in a long list, browse list one sentence at a time with UNIFY on an ASK query. But this is inefficient.

To make FETCH more efficient by ensuring that unifications are attempted only with sentences that have *some* chance of unifying. (i.e. Knows(John, x) vs. Brother(Richard, John) are not compatible for unification)

➢ To avoid this, a simple scheme called ***predicate indexing***puts all the *Knows* facts in one bucket and all the *Brother* facts in another.

➢ The buckets can be stored in a hash table for efficient access. Predicate indexing is useful when there are many predicate symbols but only a few clauses for each symbol.

But if we have many clauses for a given predicate symbol, facts can be stored under multiple index keys.

For the fact *Employs (AIMA.org, Richard),* the queries are
Employs (A IMA. org, Richard) Does AIMA.org employ Richard?
Employs (x, Richard) who employs Richard?
Employs (AIMA.org, y) whom does AIMA.org employ?
Employs Y(x), who employs whom?

We can arrange this into a **subsumption lattice,** as shown below**.**

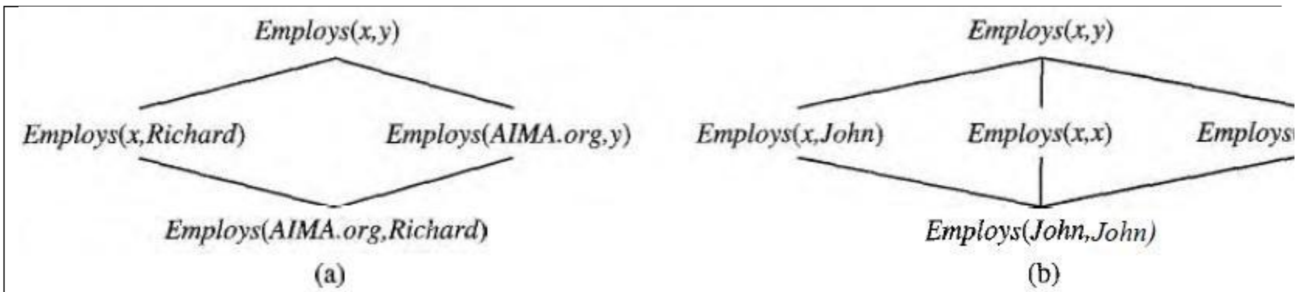


Figure 2.2 *(a) The subsumption lattice whose lowest node is the sentence Employs (AIMA.org, Richard). (b) The subsumption lattice for the sentence Employs (John, John).*

A subsumption lattice has the following properties:

✓ child of any node obtained from its parents by one substitution

✓ the ―highest‖ common descendant of any two nodes is the result of applying their most general unifier

- ✓ predicate with n arguments contains O(2n) nodes (in our example, we have two arguments, so our lattice has four nodes)
- ✓ Repeated constants = slightly different lattice.

<u>3.</u> <u>*Forward Chaining*</u>

First-Order Definite Clauses:

A definite clause either is atomic or is an implication whose antecedent is a conjunction of positive literals and whose consequent is a single positive literal. The following are first-order definite clauses:

$$King(x) \; A \; Greedy(x) \Rightarrow Evil(x) .$$
$$King(John) .$$
$$Greedy(y) .$$

Unlike propositional literals, first-order literals can include variables, in which case those variables are assumed to be universally quantified.

Consider the following problem;

"The law says that it is a crime for an American to sell weapons to hostile nations. The country Nono, an enemy of America, has some missiles, and all of its missiles were sold to it by Colonel West, who is American."

We will represent the facts as first-order definite clauses

". . . It is a crime for an American to sell weapons to hostile nations":

$American(x) \wedge Weapon(y) \wedge Sells(x, y, z) \wedge Hostile(z) \Rightarrow Criminal(x)$ **---------** (1)

"Nono . . . has some missiles." The sentence 3 x *Owns (Nono,* .rc) *A Missile* (x) is transformed into two definite clauses by Existential Elimination, introducing a new constant *M1:*

Owns (Nono, M1) ------------------(2)

Missile (Ml)-------------------------- (3*)*

"All of its missiles were sold to it by Colonel West":

***Missile (x) A Owns (Nono, x) =>Sells (West, z, Nono)* ----------------- (4)**

We will also need to know that missiles are weapons:

Missile (x) =>Weapon (x)* -----------*(5)

We must know that an enemy of America counts as "hostile":

***Enemy (x, America) =>Hostile(x)* ----------- (6)**

"West, who is American":

***American (West)* ----------------(7)**

"The country Nono, an enemy of America ":

Enemy (Nono, America) ------------ (8)

A simple forward-chaining algorithm:

- Starting from the known facts, it triggers all the rules whose premises are satisfied, adding their conclusions lo the known facts
- The process repeats until the query is answered or no new facts are added. Notice that a fact is not "new" if it is just *renaming*of a known fact.

We will use our crime problem to illustrate how FOL-FC-ASK works. The implication sentences are (1), (4), (5), and (6). Two iterations are required:

- ✓ On the first iteration, rule (1) has unsatisfied premises.

Rule (4) is satisfied with *{x/Ml),* and *Sells (West,* M1, *Nono)* is added.

Rule (5) is satisfied with *{x/M1) and Weapon (M1)* is added.

Rule (6) is satisfied with *{x/Nono},* and *Hostile (Nono)* is added.

- ✓ On the second iteration, rule (1) is satisfied with *{x/West, Y/MI, z /Nono),* and *Criminal* (*West)* is added.

It is ***sound,*** because every inference is just an application of Generalized Modus Ponens, it is ***complete***for definite clause knowledge bases; that is, it answers every query whose answers are entailed by any knowledge base of definite clauses

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```
function FOL-FC-ASK(KB, a) returns a substitution or false
   inputs: KB, the knowledge base, a set of first-order definite clauses
           a, the query, an atomic sentence
   local variables: new, the new sentences inferred on each iteration

   repeat until new is empty
      new ← { }
      for each sentence r in KB do
         (p1 ∧ . . . ∧ pn ⇒ q) ← STANDARDIZE-APART(r)
         for each θ such that SUBST(θ, p1 ∧ . . . ∧ pn) = SUBST(θ, p'1 ∧ . . . ∧ p'n)
                     for some p'1, . . . , p'n in KB
            q' ← SUBST(θ, q)
            if q' is not a renaming of some sentence already in KB or new then do
               add q' to new
               φ ← UNIFY(q', a)
               if φ is not fail then return φ
      add new to KB
   return false
```

***Figure 3.1 A** conceptually straightforward, but very inefficient, forward-chaining algorithm. On each iteration, it adds to KB all the atomic sentences that can be inferred in one step from the implication sentences and the atomic sentences already in KB.*

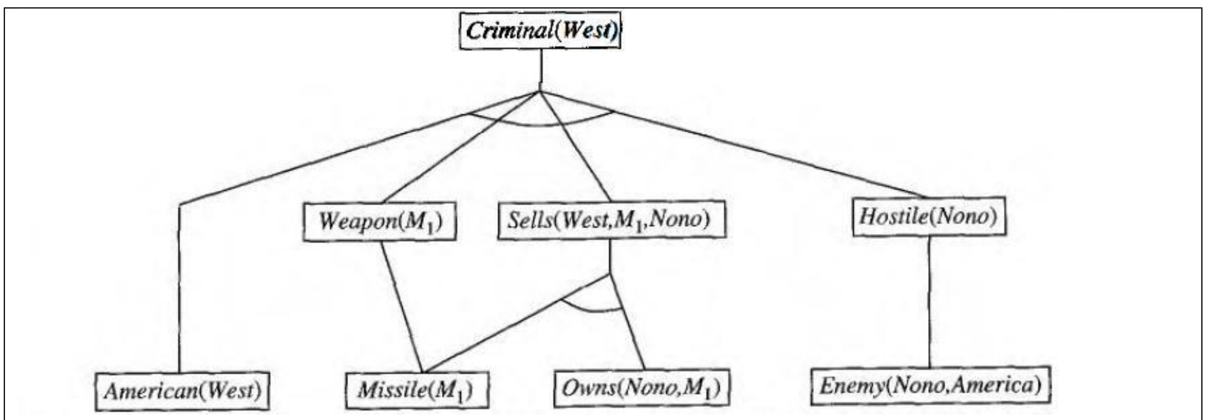


***Figure 3.2** The proof tree generated by forward chaining on the crime example. The initial facts appear at the bottom level, facts inferred on the first iteration in the middle level, and facts inferred on the second iteration at the top level.*

Efficient forward chaining:

The above given forward chaining algorithm was lack with efficiency due to the the three sources of complexities:

- ✓ Pattern Matching

- ✓ Rechecking of every rule on every iteration even a few additions are made to rules
- ✓ Irrelevant facts

1. ***Matching rules against known facts:***

For example, consider this rule,

Missile(x) A Owns (Nono, x) =>Sells (West, x, Nono).

The algorithm will check all the objects owned by Nono in and then for each object, it could check whether it is a missile. This is the ***conjunct ordering problem:***

–Find an ordering to solve the conjuncts of the rule premise so that the total cost is minimized‖.

The **most constrained variable** heuristic used for CSPs would suggest ordering the conjuncts to look for missiles first if there are fewer missiles than objects that are owned by Nono.

The connection between pattern matching and constraint satisfaction is actually very close. We can view each conjunct as a constraint on the variables that it contains-for example, Missile(x) is a unary constraint on x. Extending this idea, we can express everyfinite-domain CSP as a single definite clause together with some associated ground facts. Matching a definite clause against a set of facts is NP-hard

2. Incremental forward chaining:

On the second iteration, the rule ***Missile (x) =>Weapon (x)***

Matches against Missile (M1) (again), and of course the conclusion Weapon(x/M1) is already known so nothing happens. Such redundant rule matching can be avoided if we make the following observation:

–Every new fact inferred on iteration t must be derived from at leastone new fact inferred on iteration t – 1‖.

This observation leads naturally to an incremental forward chaining algorithm where, at iteration t, we check a rule only if its premise includes a conjunct p, that unifies with a fact p: newly inferred at iteration t - 1. The rule matching step then fixes p, to match with p', but allows the other conjuncts of the rule to match with facts from any previous iteration.

3. Irrelevant facts:

- One way to avoid drawing irrelevant conclusions is to use backward chaining.
- Another solution is to restrict forward chaining to a selected subset of rules
- A third approach, is to rewrite the rule set, using information from the goal.so that only relevant variable bindings-those belonging to a so-called **magic** set-are considered during forward inference.

For example, if the goal is Criminal (West), the rule that concludes Criminal (x) will be rewritten to include an extra conjunct that constrains the value of x:

Magic(x) A American(z) A Weapon(y)A Sells(x, y, z) A Hostile(z) =>Criminal(x)

The fact *Magic (West)* is also added to the KB. In this way, even if the knowledge base contains facts about millions of Americans, only Colonel West will be considered during the forward inference process.

4. Backward Chaining

This algorithm work backward from the goal, chaining through rules to find known facts that support the proof. It is called with a list of goals containing the original query, and returns the set of all substitutions satisfying the query. The algorithm takes the first goal in the list and finds every clause in the knowledge base whose **head,** unifies with the goal. Each such clause creates a new recursive call in which **body,** of the clause is added to the goal stack .Remember that facts are clauses with a head but no body, so when a goal unifies with a known fact, no new sub goals are added to the stack and the goal is solved. The algorithm for backward chaining and proof tree for finding criminal (West) using backward chaining are given below.

```
function FOL-BC-ASK(KB, goals, θ) returns a set of substitutions
   inputs: KB, a knowledge base
           goals, a list of conjuncts forming a query (θ already applied)
           θ, the current substitution, initially the empty substitution { }
   local variables: answers, a set of substitutions, initially empty

   if goals is empty then return {θ}
   q′ ← SUBST(θ, FIRST(goals))
   for each sentence r in KB where STANDARDIZE- APART(^)     = (p1 A ... A pn ⇒
          and θ′ ← UNIFY(q, q′) succeeds
      new-goals ← [p1, ..., pn|REST(goals)]
      answers ← FOL-BC-ASK(KB, new-goals, COMPOSE(θ′, 0))∪ answers
   return answers
```

Figure 4.1_A simple backward-chaining algorithm._

.

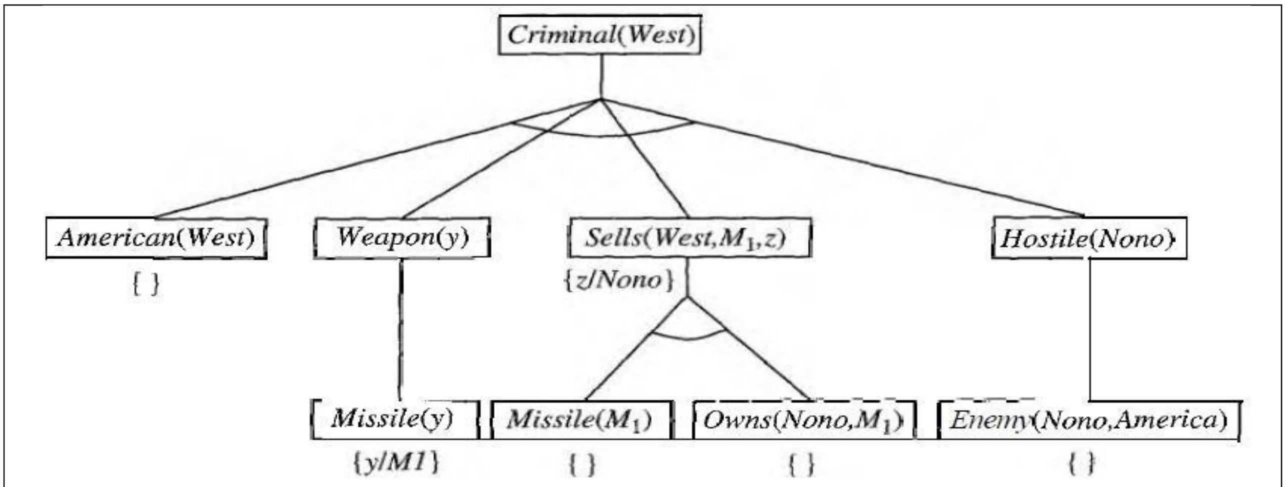


Figure 4.2 _Proof tree constructed by backward chaining to prove that West is a criminal. The tree should be read depth first, left to right. To prove Criminal (West), we have to prove the four conjuncts below it. Some of these are in the knowledge base, and others require further backward chaining. Bindings for each successful unification are shown next to the corresponding sub goal. Note that once one sub goal in a conjunction succeeds, its substitution is applied to subsequent sub goals._

Logic programming:

- **Prolog** is by far the most widely used logic programming language.
- Prolog programs are sets of definite clauses written in a notation different from standard first-order logic.

- Prolog uses uppercase letters for variables and lowercase for constants.
- Clauses are written with the head preceding the body; " : -" is used for left implication, commas separate literals in the body, and a period marks the end of a sentence

```
criminal(X) :- american(X), weapon(Y), sells(X,Y,Z), hostile(Z)
```

Prolog includes "syntactic sugar" for list notation and arithmetic. Prolog program for append (X, Y, Z), which succeeds if list Z is the result of appending lists x and Y

```
append([],Y,Y).
append([A|X],Y,[A|Z]) :- append(X,Y,Z)
```

For example, we can ask the query append (A, B, [1, 2]): what two lists can be appended to give [1, 2]? We get back the solutions

```
A=[]     B=[1,2]
A=[1]    B=[2]
A=[1,2]  B=[]
```

- The execution of Prolog programs is done via depth-first backward chaining
- Prolog allows a form of negation called **negation as failure.** A negated goal not P is considered proved if the system fails to prove p. Thus, the sentence

Alive (X) : - not dead(X) can be read as "Everyone is alive if not provably dead."

- Prolog has an equality operator, =, but it lacks the full power of logical equality. An equality goal succeeds if the two terms are *unifiable* and fails otherwise. So X+Y=2+3 succeeds with x bound to *2* and Y bound to 3, but Morningstar=evening star fails.
- The occur check is omitted from Prolog's unification algorithm.

Efficient implementation of logic programs:

The execution of a Prolog program can happen in two modes: interpreted and compiled.

- Interpretation essentially amounts to running the FOL-BC-ASK algorithm, with the program as the knowledge base. These are designed to maximize speed.

First, instead of constructing the list of all possible answers for each sub goal before continuing to the next, Prolog interpreters generate one answer and a "promise" to generate the rest when the current answer has been fully explored. This promise is called a **choice point.**FOL-BC-ASK spends a good deal of time in generating and composing substitutions when a path in search fails. Prolog will backup to previous choice point and unbind some variables. This is called ―TRAIL‖. So, new variable is bound by UNIFY-VAR and it is pushed on to trail.

- Prolog Compilers compile into an intermediate language i.e., Warren Abstract Machine or WAM named after David. H. D. Warren who is one of the implementers of first prolog compiler. So, WAM is an abstract instruction set that is suitable for prolog and can be either translated or interpreted into machine language.

Continuations are used to implement choice point'scontinuation as packaging up a procedure and a list of arguments that together define what should be done next whenever the current goal succeeds.

- Parallelization can also provide substantial speedup. There are two principal sources of parallelism

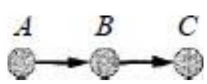
1. The first, called **OR-parallelism,** comes from the possibility of a goal unifying with many different clauses in the knowledge base. Each gives rise to an independent branch in the search space that can lead to a potential solution, and all such branches can be solved in parallel.
2. The second, called **AND-parallelism,** comes from the possibility of solving each conjunct in the body of an implication in parallel. AND-parallelism is more difficult to achieve, because solutions for the whole conjunction require consistent bindings for all the variables.

Redundant inference and infinite loops:

Consider the following logic program that decides if a path exists between two points on a directed graph.

```
path(X,Z) :- link(X,Z).
path(X,Z) :- path(X,Y), link(Y,Z)
```

A simple three-node graph, described by the facts link (a, b) and link (b, c)



It generates the query path (a, c)

Hence each node is connected to two random successors in the next layer.

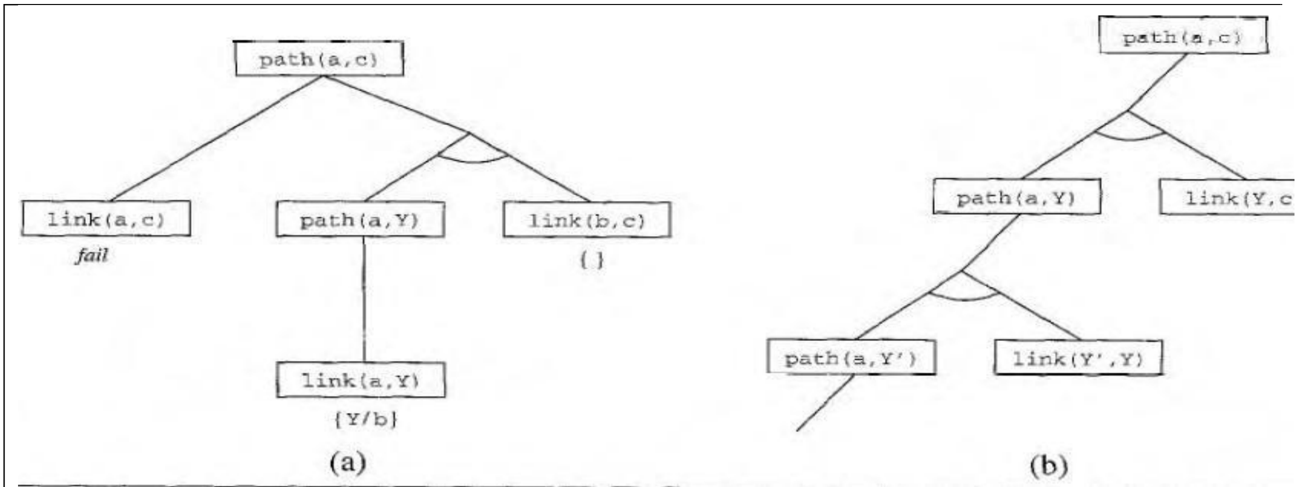


Figure 4.3 (a) Proof that a path exists from A to C. (b) Infinite proof tree generated when the clauses are in the "wrong" order.

Constraint logic programming:

The Constraint Satisfaction problem can be solved in prolog as same like backtracking algorithm.

Because it works only for finite domain CSP's in prolog terms there must be finite number of solutions for any goal with unbound variables.

```
triangle(X,Y,Z) :-
    X>=0, Y>=0, Z>=0, X+Y>=Z, Y+Z>=X, X+Z>=Y.
```

- If we have a query, triangle (3, 4, and 5) works fine but the query like, triangle (3, 4, Z) no solution.
- The difficulty is variable in prolog can be in one of two states i.e., Unbound or bound.
- Binding a variable to a particular term can be viewed as an extreme form of constraint namely ―equality‖.CLP allows variables to be constrained rather than bound.

The solution to triangle (3, 4, Z) is Constraint 7>=Z>=1.

5. Resolution

As in the propositional case, first-order resolution requires that sentences be in **conjunctive normal form** (CNF) that is, a conjunction of clauses, where each clause is a disjunction ofliterals.

Literals can contain variables, which are assumed to be universally quantified. Every sentence of first-order logic can be converted into an inferentially equivalent CNF sentence. We will illustrate the procedure by translating the sentence

"Everyone who loves all animals is loved by someone," or

$$\forall x\ [\forall y\ Animal(y) \Rightarrow Loves(x,y)] \Rightarrow [\exists y\ Loves(y,x)]$$

The steps are as follows:

- Eliminate implications:

$$ti\ x\ [\neg\forall y\ \neg Animal(y) \vee Loves(x,y)]\ v\ [\exists y\ Loves(y,x)]$$

- Move Negation inwards: In addition to the usual rules for negated connectives, we need rules for negated quantifiers. Thus, we have

$$\neg\forall x\ p \quad \text{becomes} \quad 3\ x\ \neg p$$
$$\neg\exists x\ p \quad \text{becomes} \quad \forall x\ \neg p$$

Our sentence goes through the following transformations:

$$\forall x\ [\exists y\ \neg(\neg Animal(y) \vee Loves(x,y))] \vee [\exists y\ Loves(y,x)]\,.$$
$$\forall x\ [\exists y\ \neg\neg Animal(y) \wedge \neg Loves(x,y)] \vee [\exists y\ Loves(y,x)].$$
$$\forall x\ [\exists y\ Animal(y) \wedge \neg Loves(x,y)]\ v\ [\exists y\ Loves(y,x)]\,.$$

- Standardize variables: For sentences like $(\forall x\ \ P(x))\ V\ (3x\ \ Q(x))$ which use the same variable name twice, change the name of one of the variables. This avoids confusion later when we drop the quantifiers. Thus, we have

$$\forall x\ [\exists y\ Animal(y) \wedge \neg Loves(x,y)] \vee [\exists z\ Loves(z,x)]$$

- Skolemize: Skolemization is the process of removing existential quantifiers by elimination. Translate *3 x P(x)* into *P(A),* where *A* is a new constant. If we apply this rule to our sample sentence, however, we obtain

$$\forall x \;\; [Animal(A) \land \neg Loves(x, A)] \lor Loves(B, x)$$

Which has the wrong meaning entirely: it says that everyone either fails to love a particular animal *A* or is loved by some particular entity *B.* In fact, our original sentence allows each person to fail to love a different animal or to be loved by a different person.

Thus, we want the Skolem entities to depend on *x:*

$$\forall x \;\; [Animal(F(x)) \land \neg Loves(x, F(x))] \lor Loves(G(x), x)$$

Here *F* and *G* are Skolem functions. The general rule is that the arguments of the Skolem function are all the universally quantified variables in whose scope the existential quantifier appears.

- Drop universal quantifiers: At this point, all remaining variables must be universally quantified. Moreover, the sentence is equivalent to one in which all the universal quantifiers have been moved to the left. We can therefore drop the universal quantifiers

$$[Animal(F(x)) \land \neg Loves(x, F(x))] \lor Loves(G(x), x)$$

- Distribute V over A

$$[Animal(F(x)) \lor Loves(G(x), x)] \land [\neg Loves(x, F(x)) \lor Loves(G(x), x)].$$

This is the CNF form of given sentence.

The resolution inference rule:

The resolution rule for first-order clauses is simply a lifted version of the propositional resolution rule. Propositional literals are complementary if one is the negation of the other; first-order literals are complementary if one ***unifies with*** the negation of the other. Thus we have

$$\frac{\ell_1 \lor \cdots \lor \ell_k, \qquad m_1 \lor \cdots \lor m_n}{\textsc{Subst}(\theta, \ell_1 \lor \cdots \lor \ell_{i-1} \lor \ell_{i+1} \lor \cdots \lor \ell_k \lor m_1 \lor \cdots \lor m_{j-1} \lor m_{j+1} \lor \cdots \lor m_n)}$$

Where UNIFY (l_i, m_j) == θ.

For example, we can resolve the two clauses

$$[Animal(F(x)) \lor Loves(G(x), x)] \quad \text{and} \quad [\neg Loves(u, v) \lor \neg Kills(u, v)]$$

By eliminating the complementary literals *Loves (G(x), x)* and ¬*Loves (u, v)*, with unifier θ = *{u/G(x), v/x)*, to produce the resolvent clause

$$[Animal(F(x)) \vee \neg Kills(G(x), x)] .$$

Example proofs:

Resolution proves that KB /= *a* by proving *KB* A *la* unsatisfiable, i.e., by deriving the empty clause. The sentences in CNF are

$$\neg American(x) \vee \neg Weapon(y) \vee \neg Sells(x, y, z) \vee \neg Hostile(z) \vee Criminal(x)$$
$$\neg Missile(x) \vee \neg Owns(Nono, x) \vee Sells(West, x, Nono) .$$
$$\neg Enemy(x, America) \vee Hostile(x) .$$
$$\neg Missile(x) \vee Weapon(x) .$$
$$Owns(Nono, M_1) . \qquad Missile(M_1) .$$
$$American(West) . \qquad Enemy(Nono, America) .$$

The resolution proof is shown in below figure;

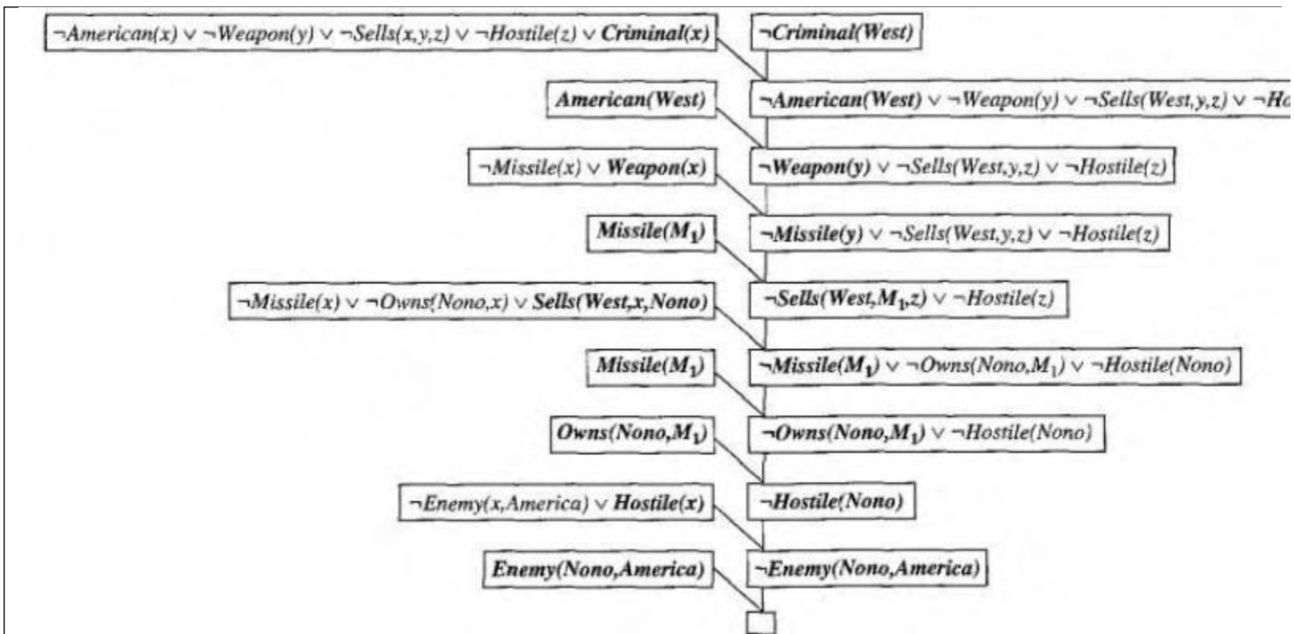


Figure 5.1 A resolution proof that West is a criminal.

Notice the structure: single "spine" beginning with the goal clause, resolving against clauses from the knowledge base until the empty clause is generated. Backward chaining is really just a special case of resolution with a particular control strategy to decide which resolution to perform next.

UNIT-IV

Planning
Classical Planning: Definition of Classical Planning, Algorithms for Planning with StateSpace Search, Planning Graphs, other Classical Planning Approaches, Analysis of Planning approaches.
Planning and Acting in the Real World: Time, Schedules, and Resources, Hierarchical Planning, Planning and Acting in Nondeterministic Domains, Multi agent Planning

Planning Classical Planning: AI as the study of rational action, which means that planning—devising a plan of action to achieve one's goals—is a critical part of AI. We have seen two examples of planning agents so far the search-based problem-solving agent.

DEFINITION OF CLASSICAL PLANNING: The problem-solving agent can find sequences of actions that result in a goal state. But it deals with atomic representations of states and thus needs good domain-specific heuristics to perform well. The hybrid propositional logical agent can find plans without domain-specific heuristics because it uses domain-independent heuristics based on the logical structure of the problem but it relies on ground (variable-free) propositional inference,whichmeansthatitmaybeswampedwhentherearemanyactionsandstates.For example,intheworld,thesimpleactionofmovingastepforwardhadtoberepeated for all four agent orientations, *T* time steps, and n^2 currentlocations.

In response to this, planning researchers have settled on a **factored representation**— one in which a state of the world is represented by a collection of variables. We use a language called **PDDL**, the Planning Domain Definition Language that allows us to express all $4Tn^2$ actions with one action schema. There have been several versions of PDDL.we select a simple version and alter its syntax to be consistent with the rest of the book. We now show how PDDL describes the four things we need to define a search problem: the initial state, the actions that are available in a state, the result of applying an action, and the goal test.

Each state is represented as a conjunction of flaunts that are ground, functionless atoms. For example, Poor A Unknown might represent the state of a hapless agent, and a state in a package delivery problem might be At(Truck 1, Melbourne) A At(Truck 2, Sydney). Database semantics is used: the

closed-world assumption means that any flaunts that are not mentioned are false, and the unique names assumption means that Truck 1 and Truck 2 are distinct.

A set of ground (variable-free) actions can be represented by a single action schema. The schema is a lifted representation—it lifts the level of reasoning from propositional logic to a restricted subset of first-order logic. For example, here is an action schema for flying a plane from one location to another:

Action(Fly (p, from, to),

PRECOND:At(p, from) A Plane(p) A Airport (from) A Airport (to)

EFFECT:¬At(p, from) A At(p, to))

The schema consists of the action name, a list of all the variables used in the schema, a precondition and an effect.

A set of action schemas serves as a definition of a planning domain. A specific problem within the domain is defined with the addition of an initial state and a goal.

state is a conjunction of ground atoms. (As with all states, the closed-world assumption is used, which means that any atoms that are not mentioned are false.) The goal is just like a precondition: a conjunction of literals (positive or negative) that may contain variables, such as At(p, SFO) A Plane(p). Any variables are treated as existentially quantified, so this goal is to have any plane at SFO. The problem is solved when we can find a sequence of actions that end in a states that entails the goal.

Example: Air cargo transport

An air cargo transport problem involving loading and unloading cargo and flying it from place to place. The problem can be defined with three actions: Load , Unload , and Fly . The actions affect two predicates: In(c, p) means that cargo c is inside plane p, and At(x, a) means that object x (either plane or cargo) is at airport a. Note that some care must be taken to make sure the At predicates are maintained properly. When a plane flies from one airport to another, all the cargo inside the plane goes with it. In first-order logic it would be easy to quantify over all objects that are inside the plane. But basic PDDL does not have a universal quantifier, so we need a different solution. The approach we use is to say that a piece of cargo ceases to be At anywhere when it is In a plane; the cargo only becomes At the new airport when it is unloaded. So At really means “available for use at a given location.”

The complexity of classical planning :

We consider the theoretical complexity of planning and distinguish two decision problems. PlanSAT is the question of whether there exists any plan that solves a planning problem. Bounded PlanSAT asks whether there is a solution of length k or less; this can be used to find an optimal plan.

The first result is that both decision problems are decidable for classical planning. The proof follows from the fact that the number of states is finite. But if we add function symbols to the language, then the number of states becomes infinite, and PlanSAT becomes only semi decidable: an algorithm exists that will terminate with the correct answer for any solvable problem, but may not terminate on unsolvable problems. The Bounded PlanSAT problem remains decidable even in the presence of function symbols.

Both PlanSAT and Bounded PlanSAT are in the complexity class PSPACE, a class that is larger (and hence more difficult) than NP and refers to problems that can be solved by a deterministic Turing machine with a polynomial amount of space. Even if we make some rather severe restrictions, the problems remain quite difficult.

Algorithms for Planning with State Space Search

Forward (progression) state-space search:

Now that we have shown how a planning problem maps into a search problem, we can solve planning problems with any of the heuristic search algorithms from Chapter 3 or a local search algorithm from Chapter 4 (provided we keep track of the actions used to reach the goal). From the earliest days of planning research (around 1961) until around 1998 it was assumed that forward state-space search was too inefficient to be practical. It is not hard to come up with reasons why .

First, forward search is prone to exploring irrelevant actions. Consider the noble task of buying a copy of AI: A Modern Approach from an online bookseller. Suppose there is an action schema Buy(isbn) with effect Own(isbn). ISBNs are 10 digits, so this action schema represents 10 billion ground actions. An uninformed forward-search algorithm would have to start enumerating these 10 billion actions to find one that leads to the goal.

Second, planning problems often have large state spaces. Consider an air cargo problem with 10 airports, where each airport has 5 planes and 20 pieces of cargo. The goal is to move all the cargo at airport A to airport B. There is a simple solution to the problem: load the 20 pieces of cargo into one of the planes at A, fly the plane to B, and unload the cargo. Finding the solution can be difficult because the average branching factor is huge: each of the 50 planes can fly to 9 other airports, and each of the 200 packages can be either unloaded (if it is loaded) or loaded into any plane at its airport (if it is unloaded). So in any state there is a minimum of 450 actions (when all the packages are at airports with no planes) and a maximum of 10,450 (when all packages and planes are at the same airport). On average, let's say there are about 2000 possible actions per state, so the search graph up to the depth of the obvious solution has about 2000 nodes.

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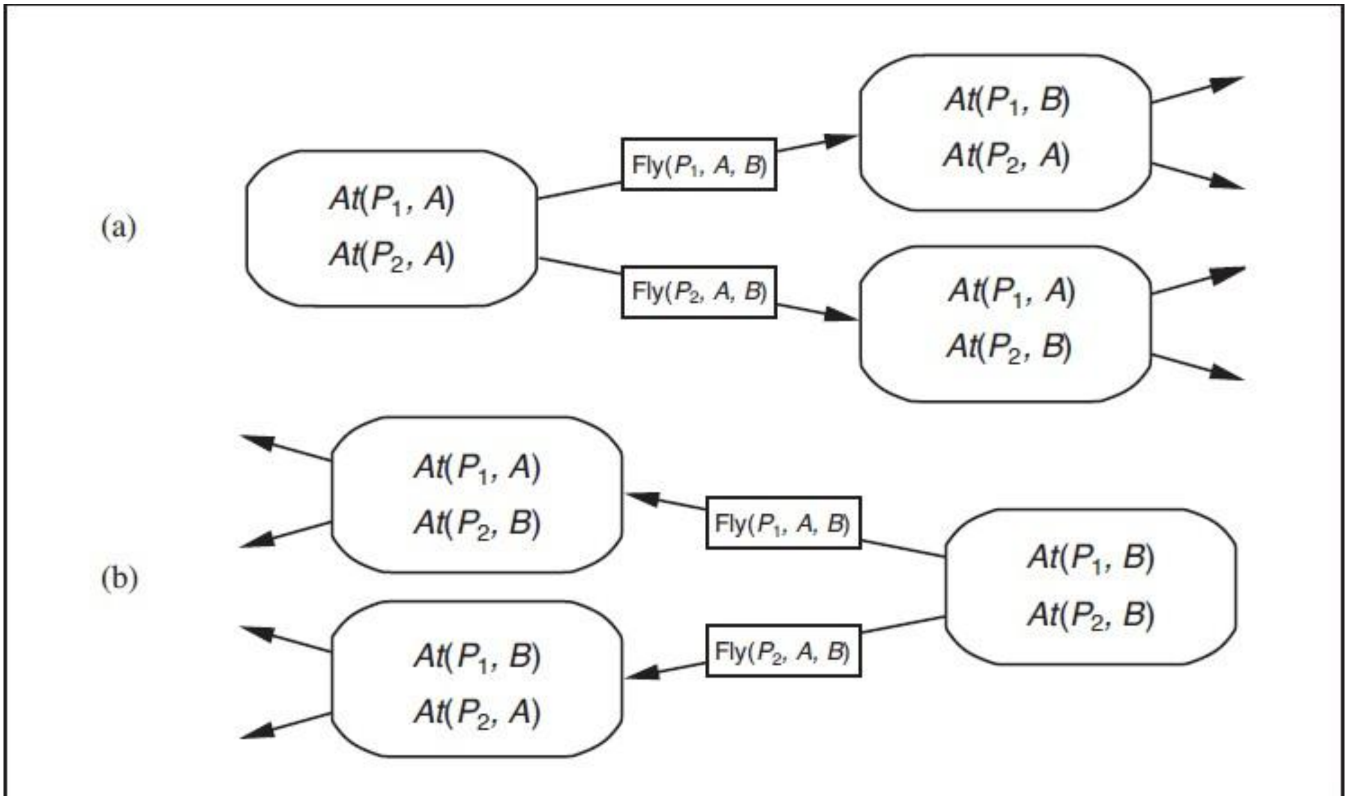

Figure 10.5 Two approaches to searching for a plan. (a) Forward (progression) search through the space of states, starting in the initial state and using the problem's actions to search forward for a member of the set of goal states. (b) Backward (regression) search through sets of relevant states, starting at the set of states representing the goal and using the inverse of the actions to search backward for the initial state.

Backward (regression) relevant-states search:

In regression search we start at the goal and apply the actions backward until we find a sequence of steps that reaches the initial state. It is called relevant-states search because we only consider actions that are relevant to the goal (or current state). As in belief-state search (Section 4.4), there is a set of relevant states to consider at each step, not just a single state.

We start with the goal, which is a conjunction of literals forming a description of a set of states—for example, the goal ¬Poor A Famous describes those states in which Poor is false, Famous is true, and any other fluent can have any value. If there are n ground flaunts in a domain, then there are 2n ground states (each fluent can be true or false), but 3n descriptions of sets of goal states (each fluent can be positive, negative, or not mentioned).

In general, backward search works only when we know how to regress from a state description to the predecessor state description. For example, it is hard to search backwards for a solution to the n-queens problem because there is no easy way to describe the states that are one move away from the goal. Happily, the PDDL representation was designed to make it easy to regress actions—if a domain can be expressed in PDDL, then we can do regression search on it.

The final issue is deciding which actions are candidates to regress over. In the forward direction we chose actions that were applicable—those actions that could be the next step in the plan. In backward search we want actions that are relevant—those actions that could be the last step in a plan leading up to the current goal state.

Heuristics for planning:

Neither forward nor backward search is efficient without a good heuristic function. Recall from Chapter 3 that a heuristic function h(s) estimates the distance from a state s to the goal and that if we can derive an admissible heuristic for this distance—one that does not overestimate—then we can use A∗ search to find optimal solutions. An admissible heuristic can be derived by defining a relaxed problem that is easier to solve. The exact cost of a solution to this easier problem then becomes the heuristic for the original problem.

By definition, there is no way to analyze an atomic state, and thus it it requires some ingenuity by a human analyst to define good domain-specific heuristics for search problems with atomic states. Planning uses a factored representation for states and action schemas. That makes it possible to define good domain-independent heuristics and for programs to automatically apply a good domain-independent heuristic for a given problem.

<u>Planning Graphs</u>:

All of the heuristics we have suggested can suffer from inaccuracies. This section shows how a special data structure called a planning graph can be used to give better heuristic estimates. These heuristics can be applied to any of the search techniques we have seen so far. Alternatively, we can search for a solution over the space formed by the planning graph, using an algorithm called GRAPHPLAN.

A planning problem asks if we can reach a goal state from the initial state. Suppose we are given a tree of all possible actions from the initial state to successor states, and their successors, and so on. If we indexed this tree appropriately, we could answer the planning question “can we reach state G from state S0” immediately, just by looking it up. Of course, the tree is of exponential size, so this approach is impractical. A planning graph is polynomial- size approximation to this tree that can be constructed quickly. The planning graph can’t answer definitively whether G is reachable from S0, but it can estimate how many steps it takes to reach G. The estimate is always correct when it reports the goal is not reachable, and it never overestimates the number of steps, so it is an admissible heuristic.

A planning graph is a directed graph organized into levels: first a level S0 for the initial state, consisting of nodes representing each fluent that holds in S0; then a level A0 consisting of nodes for each ground action that might be applicable in S0; then alternating levels Si followed by Ai; until we reach a termination condition (to be discussed later).

Roughly speaking, Si contains all the literals that could hold at time i, depending on the actions executed at preceding time steps. If it is possible that either P or ¬P could hold, then both will be represented in Si. Also roughly speaking, Ai contains all the actions that could have their preconditions satisfied at time i. We say "roughly speaking" because the planning graph records only a restricted subset of the possible negative interactions among actions; therefore, a literal might show up at level Sj when actually it could not be true until a later level, if at all. (A literal will never show up too late.) Despite the possible error, the level j at which a literal first appears is a good estimate of how difficult it is to achieve the literal from the initial state.

We now define mutex links for both actions and literals. A mutex relation holds between two actions at a given level if any of the following three conditions holds:

- Inconsistent effects: one action negates an effect of the other. For example, Eat(Cake) and the persistence of Have(Cake) have inconsistent effects because they disagree on the effect Have(Cake).
- Interference: one of the effects of one action is the negation of a precondition of the other. For example Eat(Cake) interferes with the persistence of Have(Cake) by its precondition.
- Competing needs: one of the preconditions of one action is mutually exclusive with a precondition of the other. For example, Bake(Cake) and Eat(Cake) are mutex because they compete on the value of the Have(Cake) precondition.

A mutex relation holds between two literals at the same level if one is the negation of the other or if each possible pair of actions that could achieve the two literals is mutually exclusive. This condition is called inconsistent support. For example, Have(Cake) and Eaten(Cake) are mutex in S1 because the only way of achieving Have(Cake), the persistence action, is mutex with the only way of achieving Eaten(Cake), namely Eat(Cake). In S2 the two literals are not mutex, because there are new ways of achieving them, such as Bake(Cake) and the persistence of Eaten(Cake), that are not mutex.

other Classical Planning Approaches:

Currently the most popular and effective approaches to fully automated planning are:

- Translating to a Boolean satisfiability (SAT) problem
- Forward state-space search with carefully crafted heuristics
- Search using a planning graph (Section 10.3)

These three approaches are not the only ones tried in the 40-year history of automated planning. Figure 10.11 shows some of the top systems in the International Planning Competitions, which have been held every even year since 1998. In this section we first describe the translation to a satisfiability problem and then describe three other influential approaches: planning as first-order logical deduction; as constraint satisfaction; and as plan refinement.

Classical planning as Boolean satisfiability :

we saw how SATPLAN solves planning problems that are expressed in propositional logic. Here we show how to translate a PDDL description into a form that can be processed by SATPLAN. The translation is a series of straightforward steps:

• Proposition Alize the actions: replace each action schema with a set of ground actions formed by substituting constants for each of the variables. These ground actions are not part of the translation, but will be used in subsequent steps.

• Define the initial state: assert F 0 for every fluent F in the problem's initial state, and ¬F for every fluent not mentioned in the initial state.

• Proposition Alize the goal: for every variable in the goal, replace the literals that contain the variable with a disjunction over constants. For example, the goal of having block A on another block, On(A, x) A Block (x) in a world with objects A, B and C, would be replaced by the goal

(On(A, A) A Block (A)) ∨ (On(A, B) A Block (B)) ∨ (On(A, C) A Block (C)) .

• Add successor-state axioms: For each fluent F , add an axiom of the form

F t+1 ⇔ ActionCausesF t ∨ (F t A ¬ActionCausesNotF t) ,

where Action CausesF is a disjunction of all the ground actions that have F in their add list, and Action CausesNotF is a disjunction of all the ground actions that have F in their delete list.

Analysis of Planning approaches:

Planning combines the two major areas of AI we have covered so far: search and logic. A planner can be seen either as a program that searches for a solution or as one that (constructively) proves the existence of a solution. The cross-fertilization of ideas from the two areas has led both to improvements in performance amounting to several orders of magnitude in the last decade and to an increased use of planners in industrial applications. Unfortunately, we do not yet have a clear understanding of which techniques work best on which kinds of problems. Quite possibly, new techniques will emerge that dominate existing methods.

Planning is foremost an exercise in controlling combinatorial explosion. If there are n propositions in a domain, then there are 2n states. As we have seen, planning is PSPACE- hard. Against such pessimism, the identification of independent sub problems can be a powerful weapon. In the best case—full decomposability of the problem—we get an exponential speedup.

Decomposability is destroyed, however, by negative interactions between actions. GRAPHPLAN records mutexes to point out where the difficult interactions are. SATPLAN rep- resents a similar range of mutex relations, but does so by using the general CNF form rather than a specific data structure. Forward search addresses the problem heuristically by trying to find patterns (subsets of propositions) that cover the independent sub problems. Since this approach is heuristic, it can work even when the sub problems are not completely independent.

Sometimes it is possible to solve a problem efficiently by recognizing that negative interactions can be ruled out. We say that a problem has serializable sub goals if there exists an order of sub goals such that the planner can achieve them in that order without having to undo any of the previously achieved sub goals. For example, in the blocks world, if the goal is to build a tower (e.g., A on B, which in turn is on C, which in turn is on the Table, as in Figure 10.4 on page 371), then the sub goals are serializable bottom to top: if we first achieve C on Table, we will never have to undo it while we are achieving the other sub goals. Planners such as GRAPHPLAN, SATPLAN, and FF have moved the field of planning forward, by raising the level of performance of planning systems.

Planning and Acting in the Real World:

This allows human experts to communicate to the planner what they know about how to solve the problem. Hierarchy also lends itself to efficient plan construction because the planner can solve a problem at an abstract level before delving into details. Presents agent architectures that can handle uncertain environments and interleave deliberation with execution, and gives some examples of real-world systems.

Time, Schedules, and Resources:

The classical planning representation talks about what to do, and in what order, but the representation cannot talk about time: how long an action takes and when it occurs. For example, the planners of Chapter 10 could produce a schedule for an airline that says which planes are assigned to which flights, but we really need to know departure and arrival times as well. This is the subject matter of scheduling. The real world also imposes many resource constraints; for example, an airline has a limited number of staff—and staff who are on one flight cannot be on another at the same time. This section covers methods for representing and solving planning problems that include temporal and resource constraints.

The approach we take in this section is "plan first, schedule later": that is, we divide the overall problem into a planning phase in which actions are selected, with some ordering constraints, to meet the goals of the problem, and a later scheduling phase, in which temporal information is added to the plan to ensure that it meets resource and deadline constraints.

$Jobs(\{AddEngine1 \prec AddWheels1 \prec Inspect1\},$
$\quad \{AddEngine2 \prec AddWheels2 \prec Inspect2\})$

$Resources(EngineHoists(1), WheelStations(1), Inspectors(2), LugNuts(500))$

$Action(AddEngine1, \text{DURATION}:30,$
$\quad \text{USE}: EngineHoists(1))$
$Action(AddEngine2, \text{DURATION}:60,$
$\quad \text{USE}: EngineHoists(1))$
$Action(AddWheels1, \text{DURATION}:30,$
$\quad \text{CONSUME}: LugNuts(20), \text{USE}: WheelStations(1))$
$Action(AddWheels2, \text{DURATION}:15,$
$\quad \text{CONSUME}: LugNuts(20), \text{USE}: WheelStations(1))$
$Action(Inspect_i, \text{DURATION}:10,$
$\quad \text{USE}: Inspectors(1))$

Figure 11.1 A job-shop scheduling problem for assembling two cars, with resource constraints. The notation $A \prec B$ means that action A must precede action B.

This approach is common in real-world manufacturing and logistical settings, where the planning phase is often performed by human experts. The automated methods of Chapter 10 can also be used for the planning phase, provided that they produce plans with just the minimal ordering constraints required for correctness. G RAPHPLAN (Section 10.3), SATPLAN (Section 10.4.1), and partial-order planners (Section 10.4.4) can do this; search-based methods (Section 10.2) produce totally ordered plans, but these can easily be converted to plans with minimal ordering constraints.

Hierarchical Planning :

The problem-solving and planning methods of the preceding chapters all operate with a fixed set of atomic actions. Actions can be strung together into sequences or branching networks; state-of-the-art algorithms can generate solutions containing thousands of actions.

For plans executed by the human brain, atomic actions are muscle activations. In very round numbers, we have about 103 muscles to activate (639, by some counts, but many of them have multiple subunits); we can modulate their activation perhaps 10 times per second; and we are alive and awake for about 109 seconds in all. Thus, a human life contains about 1013 actions, give or take one or two orders of magnitude. Even if we restrict ourselves to planning over much shorter time horizons—for example, a two-week vacation in Hawaii—a detailed motor plan would contain around 1010 actions. This is a lot more than 1000.

To bridge this gap, AI systems will probably have to do what humans appear to do: plan at higher levels of abstraction. A reasonable plan for the Hawaii vacation might be "Go to San Francisco airport; take Hawaiian Airlines flight 11 to Honolulu; do vacation stuff for two weeks; take Hawaiian Airlines flight 12 back to San Francisco; go home." Given such a plan, the action "Go to San Francisco airport" can be viewed as a planning task in itself, with a solution such as "Drive to the long-term parking lot; park; take the shuttle to the terminal." Each of these actions, in turn, can be decomposed further, until we reach the level of actions that can be executed without deliberation to generate the required motor control sequence.

Planning and Acting in Nondeterministic Domains: While the basic concepts are the same as in Chapter 4, there are also significant differences. These arise because planners deal with factored representations rather than atomic representations. This affects the way we represent the agent's capability for action and observation and the way we represent belief states—the sets of possible physical states the agent might be in—for unobservable and partially observable environments. We can also take ad- vantage of many of the domain-independent methods given in Chapter 10 for calculating search heuristics.

Consider this problem: given a chair and a table, the goal is to have them match—have the same color. In the initial state we have two cans of paint, but the colors of the paint and the furniture are unknown. Only the table is initially in the agent's field of view:

Init(Object(Table) A Object(Chair) A Can(C1) A Can(C2) A InView (Table)) Goal (Color (Chair , c) A Color (Table, c))

There are two actions: removing the lid from a paint can and painting an object using the paint from an open can. The action schemas are straightforward, with one exception: we now allow preconditions and effects to contain variables that are not part of the action's variable list. That is, Paint(x, can) does not mention the variable c, representing the color of the paint in the can. In the fully observable case, this is not allowed—we would have to name the action Paint(x, can, c). But in the partially observable case, we might or might not know what color is in the can. (The variable c is universally quantified, just like all the other variables in an action schema.)

Action(RemoveLid (can),

PRECOND:Can(can)

EFFECT:Open(can))

Action(Paint(x , can),

PRECOND:Object(x) A Can(can) A Color (can, c) A Open(can)

EFFECT:Color (x, c))

To solve a partially observable problem, the agent will have to reason about the percepts it will obtain when it is executing the plan. The percept will be supplied by the agent's sensors when it is actually acting, but when it is planning it will need a model of its sensors. In Chapter 4, this model was given by a function, PERCEPT(s). For planning, we augment PDDL with a new type of schema, the percept schema:

Multi agent Planning:

we have assumed that only one agent is doing the sensing, planning, and acting. When there are multiple agents in the environment, each agent faces a multi agent planning problem in which it tries to achieve its own goals with the help or hindrance of others.

Between the purely single-agent and truly multi agent cases is a wide spectrum of problems that exhibit various degrees of decomposition of the monolithic agent. An agent with multiple effectors that can operate concurrently—for example, a human who can type and speak at the same time—needs to do multi effector planning to manage each effector while handling positive and negative interactions among the effectors. When the effectors are physically decoupled into detached units—as in a fleet of delivery robots in a factory— multi effector planning becomes multibody planning. A multibody problem is still a "standard" single-agent problem as long as the relevant sensor information collected by each body can be pooled—either centrally or within each body—to form a common estimate of the world state that then informs the execution of the overall plan; in this case, the multiple bodies act as a single body.

When a single entity is doing the planning, there is really only one goal, which all the bodies necessarily share. When the bodies are distinct agents that do their own planning, they may still share identical goals; for example, two human tennis players who form a doubles team share the goal of winning the match. Even with shared goals, however, the multibody and multi agent cases are quite different. In a multibody robotic doubles team, a single plan dictates which body will go where on the court and which body will hit the ball. In a multi- agent doubles team, on the other hand, each agent decides what to do; without some method for coordination, both agents may decide to cover the same part of the court and each may leave the ball for the other to hit.

Planning with multiple simultaneous actions

For the time being, we will treat the multi effector, multibody, and multi agent settings in the same way, labeling them generically as **multi actor** settings, using the generic term **actor** to cove cover effectors, bodies, and agents. The goal of this section is to work out how to define transition models, correct plans, and efficient planning algorithms for the multi actor setting.

A correct plan is one that, if executed by the actors, achieves the goal. (In the true multi agent setting, of course, the agents may not agree to execute any particular plan, but at least they will know what plans would work if they did agree to execute them.) For simplicity, we assume perfect synchronization: each action takes the same amount of time and actions at each point in the joint plan are simultaneous.

$Actors(A, B)$
$Init(At(A, LeftBaseline) \wedge At(B, RightNet) \wedge$
$\quad Approaching(Ball, RightBaseline)) \wedge Partner(A, B) \wedge Partner(B, A)$
$Goal(Returned(Ball) \wedge (At(a, RightNet) \vee At(a, LeftNet))$
$Action(Hit(actor, Ball),$
$\quad$ PRECOND: $Approaching(Ball, loc) \wedge At(actor, loc)$
$\quad$ EFFECT: $Returned(Ball))$
$Action(Go(actor, to),$
$\quad$ PRECOND: $At(actor, loc) \wedge to \neq loc,$
$\quad$ EFFECT: $At(actor, to) \wedge \neg At(actor, loc))$

Figure 11.10 The doubles tennis problem. Two actors A and B are playing together and can be in one of four locations: *LeftBaseline*, *RightBaseline*, *LeftNet*, and *RightNet*. The ball can be returned only if a player is in the right place. Note that each action must include the actor as an argument.

Having put the actors together into a multi actor system with a huge branching factor, the principal focus of research on multi actor planning has been to decouple the actors to the extent possible, so that the complexity of the problem grows linearly with n rather than exponentially. If the actors have no interaction with one another—for example, n actors each playing a game of solitaire—then we can simply solve n separate problems. If the actors are loosely coupled, can we attain something close to this exponential improvement? This is, of course, a central question in many areas of AI.

The standard approach to loosely coupled problems is to pretend the problems are completely decoupled and then fix up the interactions. For the transition model, this means writing action schemas as if the actors acted independently. Let's see how this works for the doubles tennis problem. Let's suppose that at one point in the game, the team has the goal of returning the ball that has been hit to them and ensuring that at least one of them is covering the net.

Planning with multiple agents Cooperation andcoordination:

Now let us consider the true multi agent setting in which each agent makes its own plan. To start with, let us assume that the goals and knowledge base are shared. One might think that this reduces to the multibody case—each agent simply computes the joint solution and executes its own part of that solution. Alas, the “the” in “the joint solution” is misleading. For our doubles team, more than one joint solution exists:

If both agents can agree on either plan 1 or plan 2, the goal will be achieved. But if A chooses plan 2 and B chooses plan 1, then nobody will return the ball. Conversely, if A chooses 1 and B chooses 2, then they will both try to hit the ball.

One option is to adopt a convention before engaging in joint activity. A convention is any constraint on the selection of joint plans. For example, the convention “stick to your side of the court” would rule out plan 1, causing the doubles partners to select plan 2. Drivers on a road face the problem of not colliding with each other; this is (partially) solved by adopting the convention “stay on the right side of the road” in most countries; the alternative, “stay on the left side,” works equally well as long as all agents in an environment agree. Similar considerations apply to the development of human language, where the important thing is not which language each individual should speak, but the fact that a community all speaks the same language. When conventions are widespread, they are called social laws.

Conventions can also arise through evolutionary processes. For example, seed-eating harvester ants are social creatures that evolved from the less social wasps. Colonies of ants execute very elaborate joint plans without any centralized control—the queen’s job is to re- produce, not to do centralized planning—and with very limited computation,

Communication, and memory capabilities in each ant (Gordon, 2000, 2007). The colony has many roles, including interior workers, patrollers, and foragers. Each ant chooses to perform a role ac- cording to the local conditions it observes. One final example of cooperative multi agent behavior appears in the flocking behavior of birds.

We can obtain a reasonable simulation of a flock if each bird agent (sometimes called a boid) observes the positions of its nearest neighbors and then chooses the heading and acceleration that maximizes the weighted sum of these three components.

(a) (b) (c)

Figure 11.11 (a) A simulated flock of birds, using Reynold's boids model. Image courtesy Giuseppe Randazzo, novastructura.net. (b) An actual flock of starlings. Image by Eduardo (pastaboy sleeps on flickr). (c) Two competitive teams of agents attempting to capture the towers in the NERO game. Image courtesy Risto Miikkulainen.

1. Cohesion: a positive score for getting closer to the average position of the neighbors
2. Separation: a negative score for getting too close to any one neighbor
3. Alignment: a positive score for getting closer to the average heading of the neighbors

If all the boids execute this policy, the flock exhibits the emergent behavior of flying as a pseudo rigid body with roughly constant density that does not disperse over time, and that occasionally makes sudden swooping motions. You can see a still images in Figure 11.11(a) and compare it to an actual flock in (b). As with ants, there is no need for each agent to possess a joint plan that models the actions of other agents. The most difficult multi agent problems involve both cooperation with members of one's own team and competition against members of opposing teams, all without centralized control.

UNIT-V

Learning: Forms of Learning, Supervised Learning, Learning Decision Trees.
Knowledge in Learning: Logical Formulation of Learning, Knowledge in Learning, Explanation-Based Learning, Learning Using Relevance Information, Inductive Logic Programming

Learning

An agent is **learning** if it improves its performance on future tasks after making observations about the world.

Forms Of Learning

Any component of an agent can be improved by learning from data.It depends upon 4 factors:

- Which *component* is to be improved
  - direct mapping from conditions on the current state to actions
  - infer relevant properties of the world
  - results of possible actions
  - Action-value information
  - Goals that describe classes of states
- What *prior knowledge* the agent already has.
- What *representation* is used for the data and the component.
  - representations: propositional and first-order logical sentences
  - Bayesian networks for the inferential components
  - **factored representation**—a vector of attribute values—and outputs that can be either a continuous numerical value or a discrete value
- What *feedback* is available to learn from : *types of feedback* that determine the three main types of learning
  - In **unsupervised learning** the agent learns patterns in the input even though no explicit feedback is supplied
  - **reinforcement learning** the agent learns from a series of reinforcements—rewards or punishments.
  - **supervised learning** the agent observes some example input–output pairs and learns a function that maps from input to output
  - **semi-supervised learning** we are given a few labeled examples and must make what we can of a large collection of unlabelled examples

SUPERVISED LEARNING

Given a **training set** of N example input–output pairs (x1, y1), (x2, y2), . . . (xN, yN) , where each yj was generated by an unknown function y = f(x), discover a function h that approximates the true function f. The function h is a hypothesis. To measure the accuracy of a hypothesis we give it a test set of examples that are distinct from the training set.

Conditional Probability Distribution : the function f is stochastic—it is not strictly a function of x, and what we have to learn is a , **P**(Y | x)

Classification :When the output y is one of a finite set of values the learning problem is called **classification**

Regression : When y is a number (such as tomorrow's temperature), the learning problem is called **regression**

Hypothesis space, H, can be a set of polynomials. A polynomial is fitting a function of a single variable to some data points.

Ockham's razor *:how do we choose a function or a polynomial from among multiple consistent hypotheses?* One answer is to prefer the *simplest* hypothesis consistent with the data. This principle is called **Ockham's razor**

Realizable : a learning problem is **realizable** if the hypothesis space contains the true function. Unfortunately, we cannot always tell whether a given learning problem is realizable, because the true function is not known.

Supervised learning can be done by choosing the hypothesis " h"that is most probable one for the given data:

$$h^* = \underset{h \in \mathcal{H}}{\operatorname{argmax}}\, P(h|data)\ .$$

By Bayes' rule this is equivalent to

$$h^* = \underset{h \in \mathcal{H}}{\operatorname{argmax}}\, P(data|h)\, P(h)\ .$$

There is a tradeoff between the expressiveness of a hypothesis space and the complexity of finding a good hypothesis within that space.

LEARNING DECISION TREES

Decision tree induction is one of the simplest and yet most successful forms of machine learning.

The decision tree representation : The aim here is to learn a definition for the **goal predicate.**

A decision tree represents a function that takes as input a vector of attribute values and returns a "decision"—a single output value. The input and output values can be discrete or continuous

- A decision tree reaches its decision by performing a sequence of tests.
- Each internal node in the tree corresponds to a test of the value of one of the input attributes, Ai,
- the branches from the node are labeled with the possible values of the attribute, Ai =vik.
- Each leaf node in the tree specifies a value to be returned by the function.

Decision Tree Algorithm:

The DECISION-TREE-LEARNING algorithm adopts a greedy divide-and-conquer strategy. This test divides the problem up into smaller sub problems that can then be solved recursively.

function DECISION-TREE-LEARNING(examples, attributes, parent examples) **returns** a tree
if examples is empty **then return** PLURALITY-VALUE(parent examples)
else if all examples have the same classification **then return** the classification
else if attributes is empty **then return** PLURALITY-VALUE(examples)
else
A←argmaxa ∈ attributes IMPORTANCE(a, examples)
tree←a new decision tree with root test A
for each value vk of A **do**
exs ←,e : e ∈examples **and** e.A = vk}
subtree←DECISION-TREE-LEARNING(exs, attributes −A, examples)
add a branch to tree with label (A = vk) and subtree subtree
return tree

Expressiveness of decision trees

A Boolean decision tree is logically equivalent to the assertion that the goal attribute is true if and only if the input attributes satisfy one of the paths leading to a leaf with value true.
Goal ⇔(Path1 ∨Path2 ∨ · · ·) , where each Path is a conjunction of attribute-value tests required to follow that path. A tree consists of just tests on attributes in the interior nodes, values of attributes on the branches, and output values on the leaf nodes. For a wide variety of problems, the decision tree format yields a nice, concise result. But some functions cannot be represented concisely. We can evaluate the accuracy of a learning algorithm with a **learning curve.**

Choosing attribute tests

The greedy search used in decision tree learning is designed to approximately minimize the depth of the final tree. The idea is to pick the attribute that goes as far as possible toward providing an exact classification of the examples. A perfect attribute divides the examples into sets, each of which are all positive or all negative and thus will be leaves of the tree.

Entropy is a measure of the uncertainty of a random variable; acquisition of information corresponds to a reduction in entropy.

$$\text{Entropy:} \quad H(V) = \sum_k P(v_k) \log_2 \frac{1}{P(v_k)} = -\sum_k P(v_k) \log_2 P(v_k) \; .$$

We can check that the entropy of a fair coin flip is indeed 1 bit:
H(Fair) = −(0.5 log2 0.5 + 0.5 log2 0.5) = 1 .

The information gain from the attribute INFORMATION GAIN test on A is the expected reduction in entropy:

$$Gain(A) = B(\frac{p}{p+n}) - Remainder(A) .$$

$$Remainder(A) = \sum_{k=1}^{d} \frac{p_k+n_k}{p+n} B(\frac{p_k}{p_k+n_k}) .$$

Pruning

In decision trees, a technique called **decision tree pruning** combats overfitting. Pruning works by eliminating nodes that are not clearly relevant.

Issues in decision trees:

- Missing data
- Multivalued attributes
- Continuous and integer-valued input attributes
- Continuous-valued output attributes

LEARNING

A LOGICAL FORMULATION OF LEARNING

Current-best-hypothesis search

The idea behind current-best-hypothesis search is to maintain a single hypothesis, and to adjust it as new examples arrive in order to maintain consistency.

The extension of the hypothesis must be increased to include new examples. This is called generalization.

function CURRENT-BEST-LEARNING(examples, h) returns a hypothesis or fail
if examples is empty then
return h
e←FIRST(examples)
if e is consistent with h then
return CURRENT-BEST-LEARNING(REST(examples), h)
else if e is a false positive for h then
for each hin specializations of h consistent with examples seen so far do
h←CURRENT-BEST-LEARNING(REST(examples), h)
if h = fail then return h
else if e is a false negative for h then
for each hin generalizations of h consistent with examples seen so far do
h←CURRENT-BEST-LEARNING(REST(examples), h)
if h = fail then return h
return fail

The extension of the hypothesis must be decreased to exclude the example. This is called s**pecialization.**

Least-commitment search

Backtracking arises because the current-best-hypothesis approach has to *choose* a particular hypothesis as its best guess even though it does not have enough data yet to be sure of the choice. What we can do instead is to keep around all and only those hypotheses that are consistent with all the data so far. Each new example will either have no effect or will get rid of some of the hypotheses.

One important property of this approach is that it is incremental: one never has to go back and reexamine the old examples.

Boundary Set :

We also have an ordering on the hypothesis space, namely, generalization/specialization. This is a partial ordering, which means that each boundary will not be a point but rather a set of hypotheses called a boundary set.

The great thing is that we can represent the entire G-SET version space using just two boundary sets: a most general boundary (the G-set) and a most S-SET specific boundary (the S-set). Everything in between is guaranteed to be consistent with the examples.

The members Si and Gi of the S- and G-sets.

For each one, the new example may be a false positive or a false negative.

1. False positive for Si: This means Si is too general, but there are no consistent specializations of Si (by definition), so we throw it out of the S-set.
2. False negative for Si: This means Si is too specific, so we replace it by all its immediate generalizations, provided they are more specific than some member of G.
3. False positive for Gi: This means Gi is too general, so we replace it by all its immediate specializations, provided they are more general than some member of S.
4. False negative for Gi: This means Gi is too specific, but there are no consistent generalizations of Gi (by definition) so we throw it out of the G-set

EXPLANATION-BASED LEARNING

Explanation-based learning is a method for extracting general rules from individual observations.

Memoization

The technique of memoization has long been used in computer science to speed up programs by saving the results of computation. The basic idea of memo functions is to accumulate a database of input–output pairs; when the function is called, it first checks the database to see whether it can avoid solving the problem from scratch.

Explanation-based learning takes this a good deal further, by creating general rules that cover an entire class of cases.

Basic EBL process works as follows:

1. Given an example, construct a proof that the goal predicate applies to the example using the available background knowledge
2. In parallel, construct a generalized proof tree for the variabilized goal using the same inference steps as in the original proof.

3. Construct a new rule whose left-hand side consists of the leaves of the proof tree and whose right-hand side is the variabilized goal (after applying the necessary bindings from the generalized proof).
4. Drop any conditions from the left-hand side that are true regardless of the values of the variables in the goal.

Three factors involved in the analysis of efficiency gains from EBL:
1. Adding large numbers of rules can slow down the reasoning process, because the inference mechanism must still check those rules even in cases where they do not yield a solution. In other words, it increases the branching factor in the search space.
2. To compensate for the slowdown in reasoning, the derived rules must offer significant increases in speed for the cases that they do cover. These increases come about mainly because the derived rules avoid dead ends that would otherwise be taken, but also because they shorten the proof itself.
3. Derived rules should be as general as possible, so that they apply to the largest possible set of cases.

LEARNING USING RELEVANCE INFORMATION

The learning algorithm is based on a straightforward attempt to find the simplest determination consistent with the observations.
A determination P ' Q says that if any examples match on P, then they must also match on Q. A determination is therefore consistent with a set of examples if every pair that matches on the predicates on the left-hand side also matches on the goal predicate.

An algorithm for finding a minimal consistent determination

function MINIMAL-CONSISTENT-DET(E,A) **returns** a set of attributes
inputs: E, a set of examples
A, a set of attributes, of size n
for i = 0 **to** n **do**
for each subset A_i of A of size i **do**
if CONSISTENT-DET?(A_i,E) **then return** A_i
function CONSISTENT-DET?(A,E) **returns** a truth value
inputs: A, a set of attributes
E, a set of examples
local variables: H, a hash table
for each example e **in** E **do**
if some example in H has the same values as e for the attributes A
but a different classification **then return** false
store the class of e in H, indexed by the values for attributes A of the example e
return true

Given an algorithm for learning determinations, a learning agent has a way to construct a minimal hypothesis within which to learn the target predicate. For example, we can combine MINIMAL-CONSISTENT-DET with the DECISION-TREE-LEARNING algorithm.
This yields a relevance-based decision-tree learning algorithm RBDTL that first identifies a minimal set of relevant attributes and then passes this set to the decision tree algorithm for learning.

INDUCTIVE LOGIC PROGRAMMING

Inductive logic programming (ILP) combines inductive methods with the power of first-order representations, concentrating in particular on the representation of hypotheses as logic programs.
It has gained popularity for three reasons.

1. ILP offers a rigorous approach to the general knowledge-based inductive learning problem.
2. It offers complete algorithms for inducing general, first-order theories from examples, which can therefore learn successfully in domains where attribute-based algorithms are hard to apply.
3. Inductive logic programming produces hypotheses that are (relatively) easy for humans to read

The object of an inductive learning program is to come up with a set of sentences for the Hypothesis such that the entailment constraint is satisfied. Suppose, for the moment, that the agent has no background knowledge: Background is empty. Then one possible solution we would need to make pairs of people into objects.

Top-down inductive learning methods

The first approach to ILP works by starting with a very general rule and gradually specializing it so that it fits the data.
This is essentially what happens in decision-tree learning, where a decision tree is gradually grown until it is consistent with the observations.
To do ILP we use first-order literals instead of attributes, and the hypothesis is a set of clauses instead of a decision tree.
Three kinds of literals

1. *Literals using predicates*
2. *Equality and inequality literals*
3. *Arithmetic comparisons*

Inductive learning with inverse deduction

The second major approach to ILP involves inverting the normal deductive proof process.
Inverse resolution is based INVERSE on the observation.
Recall that an ordinary resolution step takes two clauses C1 and C2 and resolves them to produce the resolvent C.
An inverse resolution step takes a resolvent C and produces two clauses C1 and C2, such that C is the result of resolving C1 and C2.
Alternatively, it may take a resolvent C and clause C1 and produce a clause C2 such that C is the result of resolving C1 and C2.

A number of approaches to taming the search implemented in ILP systems

1. *Redundant choices can be eliminated*
2. *The proof strategy can be restricted*
3. *The representation language can be restricted*
4. *Inference can be done with model checking rather than theorem proving*
5. *Inference can be done with ground propositional clauses rather than in first-order logic.*

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COURSE FILE

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YEAR / SEMESTER	:	III / I
DEPARTMENT	:	CIVIL ENGINEERING
ACADEMIC YEAR	:	2020-2021

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1. Vision, Mission, PEO's, PO's & PSOs

a).Vision of Civil Engineering Department

- To give the world new age civil engineers who can transform the society with their creative vibe for the sustainable development by instilling scientific temper with ethical human outlook.

b). Mission of Civil Engineering Department

- To make the department a Centre of excellence in the field of civil engineering and allied research
- To promote innovative and original thinking in the minds of budding engineers to face the challenges of future.

c). Program Educational Objectives of Civil Engineering Department

PEO1	Graduates will utilize the foundation in Engineering and Science to improve lives and livelihoods through a successful career in Civil Engineering or other fields
PEO2	Graduates will become effective collaborators and innovators, leading or participating in efforts to address Social, Technical and Business Challenges
PEO3	Graduates will engage in Life-Long Learning and professional development through Self-Study, continuing education or graduate and professional studies in engineering & Business

d) Program Outcomes of Civil Engineering Department

PO1	**Fundamental engineering analysis skills:** An ability to apply knowledge of computing, mathematical foundations, algorithmic principles, and civil engineering theory in the modelling and design of to civil engineering problems.
PO2	**Information retrieval skills:** An ability to design and conduct experiments, as well as to analyze and interpret data.

PO3	**Creative skills:** An ability to design, implement, and evaluate a system, process, component, or program to meet desired needs, within realistic constraints such as economic, environmental, social, political, health and safety, manufacturability, and sustainability. Graduates have design the competence.
PO4	**Teamwork:** An ability to function effectively on multi-disciplinary teams.
PO5	**Engineering problem solving skills:** An ability to analyze a problem, and identify, formulate and use the appropriate computing and engineering requirements for obtaining its solution.
PO6	**Professional integrity:** An understanding of professional, ethical, legal, security and social issues and responsibilities. Graduates must understand the principles of ethical decision making and can interpret the ASCE Code of Ethics. Graduates will understand the proper use of the work of others (e.g., plagiarism, copyrights, and patents). Graduates will understand the special duty they owe to protect the public's health, safety and welfare by virtue of their professional status as engineers in society.
PO7	**Speaking / writing skills**: An ability to communicate effectively, both in writing and orally. Graduates are able to produce engineering reports using written, oral and graphic methods of communication.
PO8	**Engineering impact assessment skills:** The broad education necessary to analyze the local and global impact of computing and engineering solutions on individuals, organizations, and society.
PO9	**Social awareness:** Knowledge of contemporary issues. Students are aware of emerging technologies and current professional issues.
PO10	**Practical engineering analysis skills**: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
PO11	**Software hardware interface:** An ability to apply design and development principles in the construction of software and hardware systems of varying complexity.
PO12	**Successful career and immediate employment:** An ability to recognize the importance of professional development by pursuing postgraduate studies or face competitive examinations that offer challenging and rewarding careers in Civil Engineering

e). Program Specific Outcomes (PSO'S)

PSO	DESCRIPTION
PSO1	Educating students with fundamental mathematical, scientific, and engineering knowledge to have a significant and positive long-term impact on the field of Civil Engineering.
PSO 2	Emphasizing the importance of working in a team effectively and to communicate properly within the team to achieve the desired outcome.
PSO 3	Motivate students in learning to learn and the ability to keep learning for a life-time to increase their professionalism, update and deepen their knowledge through the development of the profession.

2. SYLLABUS UNIVERSITY COPY

CE511PE: CONCRETE TECHNOLOGY (Professional Elective – I)

B.Tech. III Year I Sem.

L	T/P/D	C
3	0/0/0	3

Pre-Requisites: Building Materials

Course Objectives: The objectives of the course are to

- **Know** different types of cement as per their properties for different field applications.
- **Understand Design** economic concrete mix proportion for different exposure conditions and intended purposes.
- **Know** field and laboratory **tests** on concrete in plastic and hardened stage.

Course Outcomes: After the completion of the course student should be able to

- **Determine** the properties of concrete ingredients i.e. cement, sand, coarse aggregate by conducting different tests. Recognize the effects of the rheology and early age properties of concrete on its long-term behavior.
- **Apply** the use of various chemical admixtures and mineral additives to design cement-based materials with tailor-made properties
- **Use** advanced laboratory techniques to characterize cement-based materials.
- **Perform** mix design and engineering properties of special concretes such as high-performance concrete, self-compacting concrete, and fibre reinforced concrete.

UNIT I

Cement: Portland cement – chemical composition – Hydration, Setting of cement – Structure of hydrated cement – Tests on physical properties – Different grades of cement. Admixtures: Types of admixtures – mineral and chemical admixtures.

UNIT - II

Aggregates: Classification of aggregate – Particle shape & texture – Bond, strength & other mechanical properties of aggregate – Specific gravity, Bulk density, porosity, adsorption & moisture content of aggregate – Bulking of sand – Deleterious substance in aggregate – Soundness of aggregate – Alkali aggregate reaction – Thermal properties – Sieve analysis – Fineness modulus – Grading curves – Grading of fine, Manufactured sand and coarse Aggregates – Gap graded aggregate – Maximum aggregate size- Properties Recycled aggregate.

UNIT – III

Fresh Concrete: Workability – Factors affecting workability – Measurement of workability by different tests – Setting times of concrete – Effect of time and temperature on workability – Segregation & bleeding – Mixing, vibration and revibration of concrete – Steps in manufacture of concrete – Quality of mixing water.

UNIT - IV

Hardened Concrete: Water / Cement ratio – Abram's Law – Gel/space ratio – Gain of strength of concrete – Maturity concept – Strength in tension and compression – Factors affecting strength – Relation between compression and tensile strength - Curing.

Testing of Hardened Concrete: Compression tests – Tension tests – Factors affecting strength – Flexure tests – Splitting tests – Pull-out test, Non-destructive testing methods – codal provisions for NDT.

ELASTICITY, CREEP & SHRINKAGE – Modulus of elasticity – Dynamic modulus of elasticity – Posisson's ratio – Creep of concrete – Factors influencing creep – Relation between creep & time – Nature of creep – Effects of creep – Shrinkage – types of shrinkage.

UNIT – V

Mix Design: Factors in the choice of mix proportions – Durability of concrete – Quality Control of concrete – Statistical methods – Acceptance criteria – Proportioning of concrete mixes by various methods – BIS method of mix design.

Special Concretes: Introduction to Light weight concrete – Cellular concrete – No-fines concrete – High density concrete – Fibre reinforced concrete – Polymer concrete – High performance concrete – Self compacting concrete.

TEXT BOOKS:

1. Concrete Technology by M.S. Shetty, – S. Chand & Co.; 2004
2. Concrete Technology by A.R. Santhakumar, 2nd Edition, Oxford university Press, New Delhi
3. Concrete Technology by M. L. Gambhir, – Tata Mc. Grew Hill Publishers, New Delhi

REFERENCE BOOKS:

1. Properties of Concrete by A. M. Neville – Low priced Edition – 4th edition
2. Concrete: Micro structure, Properties and Materials – P.K. Mehta and J.M. Monteiro, Mc-Graw Hill Publishers

IS Codes:

IS 383
IS 516
IS 10262 - 2009

3. COURSE OBJECTIVES, COURSE OUTCOMES AND TOPIC OUTCOMES

a). COURSE OBJECTIVES

(i) Student should be able to differentiate the materials that can be effectively used for preparing concrete.

(ii) Student should be able to design, prepare and work with the concrete

(iii) The mechanism of hydration and potential hydration with the concrete heat of hydration kinetic. Shrinkage and its potential to generate cracks in concrete, including chemical, autogen, drying, and carbonation shrinkage.

(iv) The basic principles of mix designing various types of concrete as well as curing technology required for each of the following types.

(v) High performance concrete, ultra high strength concrete, self-compacting concrete, under water.

b). COURSE OUTCOMES

CO1: Identify Quality Control tests on concrete making materials

CO2: Understand the durability requirements of fresh concrete

CO3: Identify Quality Control tests hardened concrete

CO4: Design concrete mixes as per IS and ACI codes

CO5: Understand the need for special concretes

c). TOPIC OUTCOMES

S. No.	Topic to be covered	Topic Outcome (At the end of this topic student will be able to)
L1	**UNIT-I: Cement** Introduction on concrete technology course.	Define cement, aggregates and water.
L2	History of port land cement and Manufacturing process of Portland cement	Various methods and stages of cement manufacturing.
L3	Chemical composition & Bogies compounds of Portland cement	Various chemical composition and compounds.
L4	Hydration of cement, Structure of hydrate cement and setting time of cement	Illustrate cement hydration and consistency of cement
L5	Test on physical properties of cement.	Explain physical properties test of

S. No.	Topic to be covered	Topic Outcome (At the end of this topic student will be able to)
		cement
L6	Different grades of cement.	Describe the cement grades.
L7	Admixtures and types of admixtures, mineral and chemical admixtures	Define admixture, Classify the admixture types – List out the different types of mineral and chemical admixtures
L8	**UNIT-II: Aggregates** Introduction on Aggregates and Classification of aggregate, Particle shape and texture, Bond strength	Define aggregates- Classify aggregates based on their particle shape and texture, bond strength
L9	Mechanical properties of aggregate: Specific gravity, Bulk density, porosity, absorption and moisture content of aggregate.	Define specific gravity, bulk density and porosity. Conclude its importance in mix design. aggregate mechanical properties
L10	Bulking of aggregate and Soundness of aggregate	Demonstrate bulking of sand. Explain soundness of aggregate
L11	Alkali aggregate reaction, Thermal properties	Discuss deleterious substances in aggregates and its effect on properties of concrete. Define and alkali aggregate reaction and its effect on concrete properties. Explain thermal properties of aggregates
L12	Sieve analysis, Fineness modulus, Grading curves,	Demonstrate sieve analysis of aggregates and discuss importance of maximum size of aggregates. Determine fineness modulus, Prepare grading curves to make aggregates correction in design mix.
L13	Grading of fine and coarse Aggregates, Gap graded aggregate, Maximum aggregate size	Examine grading of fine and coarse aggregates; discuss gap graded and maximum aggregate sizes.
L14	**UNIT-III: Fresh Concrete** Introduction of workability and factors affecting workability	Explain properties of concrete define workability and list out factors effecting of workability.
L15	Measurement of workability by different tests, Setting time of concrete	Demonstrate workability test to measure it.
L16	Effect of time and temperature on workability	Define concrete setting, discuss about time and temperature effect on workability.

S. No.	Topic to be covered	Topic Outcome (At the end of this topic student will be able to)
L17	Segregation and bleeding of concrete	Define segregation & bleeding. Demonstrate concrete mixing and vibration.
L18	Steps in manufacture of concrete, Mixing and vibration of concrete	List out concrete manufacturing steps; describe the water quality and its importance in quality of concrete.
L19	Quality of mixing water	Quality of mixing water in concrete.
	MID EXAMINATION-II	
L20	**UNIT-IV: Hardened Concrete** Introduction on hardened concrete, water/cement ratio, Abrum's law	Define Water/Cement ratio, Abram's law.
L21	Gel space ratio, nature of strength of concrete	Calculate gel-space ratio to predict concrete strength.
L22	Maturity concept in concrete and problems	Explain concrete strength natures and discuss maturity of concrete to calculate concrete strength.
L23	Strength in tension and compression, factors affecting strength	List out factors effecting concrete strength.
L24	Relation between compression and tensile strength, curing	Distinguish between concrete compressive and tensile strength
L25	Testing of hardened concrete-compression test and tensile strength	Demonstrate compression and tension test of concrete.
L26	Flexural test and splitting test	Explain flexure, splitting tensile and pull out test of concrete.
L27	NDT methods and codal provisions	Explain Non-destructive testing, Name it with codal provisions.
L28	Modulus of elasticity, dynamic modulus of elasticity and poisons ratio	Define elasticity, creep and shrinkage of concrete. Explain experimental process to determine modulus of elasticity.
L29	Creep of concrete, factors influencing creep of concrete, relation between creep and time	Define dynamic modulus of elasticity; differentiate static and dynamic modulus of elasticity. Show the relation between creep and time, list out the effects of creep on concrete strength.
L30	Nature of creep, effects of creep	Explain concrete creep and list out factors effecting on concrete creep.
L31	Shrinkage and types of shrinkage	Define shrinkage and list out types of shrinkages.

L32	**Unit-V: Mix Design & Special Concrete** Factors in the choice of mix proportion	Define mix design and its importance in concrete strength. List out the factors to choose the mix proportions.
L33	Durability of concrete	Define concrete durability.
L34	Quality control of concrete, Statistical quality control of concrete	Explain concrete quality control; demonstrate statistical quality control and acceptance criteria.
L35	Proportioning of concrete mix by normal concretes by BIS method	Select concrete mix proportions for normal concrete.
L36	Normal Mix design problem	Design a mix design as per BIS method and conclude the concrete mix proportions.
L37	Normal Mix design problem	Design a M20 or M25 concrete mix for local available materials.
L38	Proportioning of concrete mix by pump able concretes by BIS method	Select concrete mix proportions for pump able concrete.
L39	Pumpable Mix design problem	Design a mix design as per BIS method and conclude the concrete mix proportions.
L40	Proportioning of concrete mix by pump able concretes by ACI method	Select concrete mix proportions for pump able concrete.
L41	ACI mix design problem	Select concrete mix proportions for ACI Method.
L42	Introduction to Light weight concrete	Define special concretes. Explain light weight concrete and list out the merits and demerits of it.
L43	Cellular concretes	Define cellular concrete. Explain preparation produce of cellular and its applications in construction industry.
L44	No fines concrete	Define no fine concrete. Explain preparation produce of no fines concrete and its applications in construction industry.
L45	Fiber reinforced concrete	Define fiber reinforced concrete. Explain the ingredient of its importance in FRC.
L46	Polymer concrete and types of polymer concrete	Define polymer concrete. Explain the ingredient of its importance in polymer concrete
L47	Self-compacting concrete	Demonstration of self-compacting concrete, list out the test to conclude self-compacting concrete.
L48	High density concrete	Demonstration high density concrete, list out the test to conclude high density concrete

4. COURSE PRE–REQUISITES

1. Ingredients of concrete
2. Elements of building components
3. Characteristics of cement, fine aggregate and coarse aggregates

5. COURSE INFORMATION SHEET

5 a).COURSE DESCRIPTION:

PROGRAMME: B. Tech. (Civil Engineering)	DEGREE: BTECH
COURSE: CONCRETE TECHNOLOGY	YEAR: III SEM: I CREDITS: 4
COURSE CODE: CE511PE REGULATION: R18	COURSE TYPE: CORE
COURSE AREA/DOMAIN: Theory	CONTACT HOURS: 4+0 (L+T)) hours/Week.
CORRESPONDING LAB COURSE CODE (IF ANY): YES	LAB COURSE NAME: CONCRETE TECHNOLOGY LAB

5. b). SYLLABUS:

Unit	Details	Hours
I	**Cement:**Portland cement – chemical composition – Hydration, Setting of cement – Structure of hydrate cement – Test on physical properties – Different grades of cement. Admixtures: Types of admixtures – mineral and chemicaladmixtures	7
II	**Aggregate:**Classification of aggregate – Particle shape & texture –, strength & other mechanical properties of aggregate – Specific gravity, Bulk density, porosity, adsorption & moisture content of aggregate – Bulking of sand – Deleterious substance in aggregate – Soundness of aggregate – Alkali aggregate reaction – Thermal properties – Sieve analysis – Fineness modulus – Grading curves – Grading of fine & coarse Aggregates – Gap graded aggregate – Maximum aggregate size	8
III	**Fresh Concrete:** Workability – Factors affecting workability – Measurement of workability bydifferenttests–Settingtimesofconcrete–Effectoftimeandtemperatureonworkability– Segregation & bleeding – Mixing and vibration of concrete – Steps in manufacture of concrete – Quality of mixing Water	7
IV	**Hardened Concrete :** Water / Cement ratio – Abram's Law – Gel/space ratio – Nature of strength of concrete – Maturity concept – Strength in tension & compression – Factors affecting strength – Relation between compressive & tensile strength - Curing. **Testing of Hardened Concrete:** Compression tests – Tension tests– Flexure tests – Splitting tests – Pull-out test, Non-destructive testing methods – codal provisions for NDT. Elasticity, Creep & Shrinkage – Modulus of elasticity – Dynamic modulus of elasticity – Poisson's ratio – Creep of concrete – Factors influencing creep – Relation between creep & time – Nature of creep – Effects of creep – Shrinkage –types of shrinkage	12

V	**Mix Design:** Factors in the choice of mix proportions – Durability of concrete – Quality Control of concrete – Statistical methods – Acceptance criteria – Proportioning of concrete mixes by– BIS method and ACI mix design. **Special Concretes:** Introduction to light weight concrete – Cellular concrete – No-fines concrete – High density concrete – Fibre reinforced concrete – Polymer concrete – High performance concrete – Self compacting concrete.	18
	Contact classes for syllabus coverage	52
	Total No. of classes	52

5.c). GAPS IN THE SYLLABUS - TO MEET INDUSTRY/PROFESSION REQUIREMENTS:

NIL

5.d). TOPICS BEYOND SYLLABUS/ ADVANCED TOPICS:

NIL

5. e). WEB SOURCE REFERENCES:

Sl. No	Name of book/ website
a.	nptel.ac.in/courses/112104121/1
b.	https://www.youtube.com/watch?v=cx5gPKp9CEc&list=PLbMVogVj5nJQU7M0LdA77p_XaaWBJniNc
c.	http://www.civilenggforall.com/2015/09/concrete-technology-theory-and-practice-by-ms-shetty-free-download-pdf-civilenggforall.html

5. f). DELIVERY/INSTRUCTIONAL METHODOLOGIES:

☑ CHALK & TALK	☑ STUD. ASSIGNMENT	☑ WEB RESOURCES
☑ LCD/SMART BOARDS	☑ STUD. SEMINARS	☐ ADD-ON COURSES

5.g). ASSESSMENT METHODOLOGIES-DIRECT

☑ ASSIGNMENTS	☑ STUD. SEMINARS	☑ TESTS/MODEL EXAMS	☑ UNIV. EXAMINATION
☐ STUD. LAB PRACTICES	☐ STUD. VIVA	☐ MINI/MAJOR PROJECTS	☐ CERTIFICATIONS
☐ ADD-ON COURSES	☐ OTHERS		

5.h). ASSESSMENT METHODOLOGIES - INDIRECT

☑ ASSESSMENT OF COURSE OUTCOMES (BY FEEDBACK, ONCE)	☑ STUDENT FEEDBACK ON FACULTY (TWICE)
☐ ASSESSMENT OF MINI/MAJOR PROJECTS BY EXT. EXPERTS	☐ OTHERS

5.i). TEXT / REFERENCE BOOKS:

T/R	BOOK TITLE/AUTHORS/PUBLICATION
Text Book	Properties of concrete / A.M.Neville / Pearson 5th edition
Text Book	Concrete technology / M.S.Shetty / S.Chand&co
Text Book	Concrete technology / Job Thomas / Cengage Learning
Reference Book	Concrete technology / M.L Gmbhir / Tata Mc.Grawhill
Reference Book	Concrete: Micro structure. Properties and materials/P.K.Mehta and J.M. Monteiro, McGraw Hill Publishers.

6. TEACHING SCHEDULE

Subject	CONCRETE TECHNOLOGY					
	Text Books (to be purchased by the Students)					
Book 1	Concrete Technology by M.S. Shetty					
Book 2	Properties of concrete by A.M. Neville					
	Reference Books					
Book 3	Concrete technology / Job Thomas / Cengage Learning					
Book 4	Concrete Technology by M.L Gambhir					
Unit	Topic	Chapters Nos				No of classes
		Book 1	Book 2	Book 3	Book 4	

	Introduction on concrete technology course.	1	1	4	2	
	History of port land cement and Manufacturing of process of Portland cement	1	1	4	2	
	Chemical composition & Bogies' compounds of Portland cement	1	1	4	2	
I	Hydration of cement, Structure of hydrate cement and setting time of cement	1	1	4	2	
	Test on physical properties of cement.	1	2	4	2	
	Test on physical properties of cement.	1	2	4	2	
	Different grades of cement.	1	2	4	2	
	Admixtures and types of admixtures,	5	5	5	5	
	mineral and chemical admixtures	5	5	5	5	
	Introduction on Aggregates and Classification of aggregate, Particle shape and texture, Bond strength.	3	3	4	3	
II	Mechanical properties of aggregate: Specific gravity, Bulk density, porosity, absorption and moisture content of aggregate.	3	3	4	3	
	Bulking of aggregate and Soundness of aggregate	3	3	4	3	

	Alkali aggregate reaction, Thermal properties	3	3	4	3	
	Sieve analysis, Fineness modulus, Gradingcurves,	3	3	4	3	
	Grading of fine and coarse Aggregates, Gap graded aggregate, Maximum aggregate size	3	3	4	3	
	Introduction of workability and factors affecting workability	6	4	6	6	
	Measurement of workability by different tests, Setting time of concrete	6	4	6	6	
III	Effect of time and temperature on workability	6	8	6	6	
	Segregation and bleeding of concrete	6	4	6	6	
	Steps in manufacture of concrete, Mixing and vibration of concrete	6	4	6	11	
	Quality of mixing water	5	4	-	6	
IV	Introduction on hardened concrete, water/cement ratio, Abram's law	7	6	2	8	
	Gel space ratio, nature of strength of concrete	7	6	2	8	
	Maturity concept in concrete and problems	7	6	2	8	
	Strength in tension and compression, factors affecting strength	7	6	2	8	
	Relation between compression and tensile strength, curing	7	6	2	8	
	Testing of hardened concrete-compression test and tensile strength	10	12	5	8	
	Testing of hardened concrete-Flexural test and splitting test	10	12	5	8	
	NDT methods and codal provisions	7	12	5	8	

	Modulus of elasticity, dynamic modulus of elasticity and poisons ratio	8	9	3	8	
	Creep of concrete, factors influencing creep of concrete, relation between creep and time	8	9	3	8	
	Nature of creep, effects of creep	8	9	3	8	
	Shrinkage and types of shrinkage	8	9	3	8	
	Factors in the choice of mix proportion	11	14	7	10	
	Durability of concrete	11	10	7	10	
	Quality control of concrete, Statistical quality control of concrete	-	14	7	9	
	Proportioning of concrete mix by normal concretes by BIS method	11	14	11to15	10	
	Normal Mix design problem	11	14	11to15	10	
	Normal Mix design problem	11	14	11to15	10	
	Proportioning of concrete mix by pump able concretes by BIS method	11	14	11to15	10	
V	Pumpable Mix design problem	11	14	11to15	10	
	Proportioning of concrete mix by pump able concretes by ACI method	11	14	11to15	10	
	ACI mix design problem	11	14	11to15	10	
	Introduction to Light weight concrete	12	14	11to15	14	
	Cellular concretes	12	13	11to15	14	
	No fines concrete	12	13	11to15	14	
	Fibre reinforced concrete	12	13	11to15	14	
	Polymer concrete	12	13	11to15	14	

	Self-compacting concrete	12	13	11to15	14	
	High density concrete	12	13	11to15	14	
Contact classes for syllabus coverage					60	
Total No. of classes					60	

7. UNIT WISE HAND WRITTEN NOTES

UNIT-I

CEMENTS & ADMIXTURES

HISTORY OF PORTLAND CEMENT :-

-> The history of cementing materials is as old as the history of engineering construction.

-> Some kind of cementing materials were used by egyptians, Romans and Indians in their ancient constructions.

-> Egyptians mostly used cementing materials obtained by burning gypsum

-> Analysis of mortar from great pyramid showed that it contained 81.5% calcium sulphate and only 9.5% carbonate.

-> The early Greeks and Romans used cementing materials obtained by burning limestones.

-> The Greeks and Romans later became aware of the fact that certain volcanic ash, which mixed with lime and sand yields mortar possessing superior strength and better durability in fresh (or) salt water.

-> Roman builders used volcanic ash found near to Pozzuoli village near in Italy. This volcanic ash mostly siliceous in nature thus acquired the name pozzolana. Later on the name pozzolana was applied to any other material natural (or) artificial having nearly the same composition as that of volcanic ash found at Pozzuoli.

-> In India powdered brick named surkhi has been used in ~~mortar~~ the Indian practice through many and long continued ~~[illegible]~~ of lime mortar with (or) without the addition of surkhi yielded strong and impervious mortar which confirmed the secret of superiority of Roman mortar.

→ Roman would ... to ... better workability. Hemoglobin is a powerful air entraining agent and plasticiser, which perhaps is yet another reason for the durability of Roman construction.

→ When we come to more recent times, the most important advance in the knowledge of cements, the further to the discoveries and manufacture of all modern cements is undoubtedly the investigations carried out by John Smeaton. When he was called upon to rebuild the Eddystone Light house in 1756, he made extensive enquiries into the state of an existing in those days and also conducted experiments with a view of find out the best material to withstand the severe action of crazy matter yielded better lime possessing superior hydraulic properties.

→ In spite of the success of this experiment, the use of hydraulic lime made little progress and the old practice of mixture of lime and pozzolana remained popular in long period.

→ The story of the investigation of portland cement is however attributed to Joseph Aspdin, a Leeds builder and brick layer, eventhough similar procedures had been adopted by other inventors.

→ In early period cement was used for making mortar only. Later the use of cement was extended for making concrete.

→ In India, portland cement was first manufactured in 1904 near Madras by the South India Industries Ltd. But this venture failed. Later Indian cement Co. Ltd, was established at Porbandar the company was able to deliver about 1000 tons of portland cement.

→ During the first five year plan cement production from India rise from 2.69 million to 4.6 millions tons.

MANUFACTURING OF PORTLAND CEMENT :-

→ The raw materials required for manufacture of portland cement are calcareous materials such as limestone or chalk and argillaceous materials such as shale or clay.

→ The process of manufacture of cement consists of grinding the raw materials, mixing them intimately in certain portion depending upon their purity and composition and burning them in a kiln at a temperature of about 1300 to 1500°C at which temperature the materials sinters and partially fuses to form nodular shaped clinker.

→ The clinker is cooled and ground to fine powder with addition of about 3 to 5% of gypsum. The product formed by using this procedure is portland cement.

→ There are two process known as "wet" and "dry" process depending upon whether the mixing and grinding of raw materials is done in wet or in dry conditions.

→ With a little change in the above process we have the semi-dry process also where the raw materials are ground dry and then mixed with about 10-14% of water and further burnt to clinkering temperature.

→ For many years the wet process remained popular because of the possibility of more accurate control in the mixing of raw materials.

→ The dry process requires much less fuel as the materials are already in a dry state, whereas in the wet process the slurry contains about 35-50% of water.

WET PROCESS

-> In wet process the limestone brought from the quarries is first crushed to smaller fragments.

-> Then it is taken to a ball (or) tube mill where it is mixed with clay (or) shale as the case may be ground to a fine consistency of slurry with addition of water.

-> The slurry is a liquid of creamy consistency with water content of about 35-50% where in particles crushed to the fineness of Indian standard sieve number 9 are held in suspension.

-> The slurry is pumped to slurry tanks (or) basins where it is kept in an agitated condition by means of rotating arms with chains (or) blowing compressed air from the bottom to prevent setting of lime stone and clay particles.

-> The composition of slurry is tested to give the required chemical composition and corrected periodically in the tube mill and also in the slurry tank by blending slurry from different storage tanks.

-> Finally the corrected slurry is stored in storage tanks and kept in homogeneous condition by agitation of slurry.

-> The corrected slurry is sprayed on to the upper end of rotary kiln against hot heavy hanging chains.

-> The rotary kiln is an important component of a cement factory. It is a steel cylinder of diameter anything from 3 m to 8 m lined with refractory materials, mounted on roller bearings capable of rotating about its own axis at a specified speed.

→ The length of rotary kiln may vary from 30 to 60 mm.
→ The slurry on being sprayed against a hot surface of flexible chains loses moisture and became flakes.
→ The flakes peel off and fall on the floor. The rotation of rotary kiln causes the flakes to move from the upper end towards the lower end of the kiln subjects itself to higher and higher temperature.

→ The kiln is fired from the lower end. The fuel is either powdered coal oil or natural gas. By the time the material downs to the lower end of rotary kiln, the dry materials undergoes a series of chemical reactions. until finally in the hottest part of the kiln where the temperature in the hottest part of the kiln, where the tempe- rature is in order of 1500°C about 20 to 30% of the material get fused.

→ Lime silica and alumina get recombined. The fused mass fuses into nodular form of size 3mm to 20mm known as clinker.
→ The clinker drops into a rotary cooler where it is cooled under controlled conditions.
→ The clinker is stored in silos or bins. The clinker weighs about 1100 to 1300 gms per litre. The litre weight of clinker indicates the quality of clinker.
→ The cooled clinker is then ground in a ball mill with the addition of 3 to 5% of gypsum in orders to prevent flash – setting of cement.
→ A ball mill consists of several compartments charged with progressively smaller hardened steel balls. The particles are crushed to the required fineness are separated by currents of air and taken to storage silos from where

the cement is bagged or filled into containers for supply.

WET PROCESS

Clay ← water → Limestone

Clay → Wash mill → Storage basins → wet grinding mills ← Storage basins ← Crusher ← Limestone

↓

Blending of slurry to correct composition

↓

Storage of corrected slurry

↓

Powdered coal / oil / gas → corrected slurry fed to rotary kiln

↓

Slurry is converted into clinker

↓

addition of 2-3% of gypsum → Clinker is ground in ball mill

↓

Cement silos

↓

packing plant

DRY PROCESS

→ In the dry and semi dry process the raw materials are crushed dry and fed in correct proportions into grinding mill where they are dried and reduced to a very fine powder.

→ The dry powder leaves the raw meal is then further blended and corrected for its right composition and mixed by means of compressed air. The aerated powder tends to behave almost like liquid and in about one hour of aeration a uniform mixture is obtained.

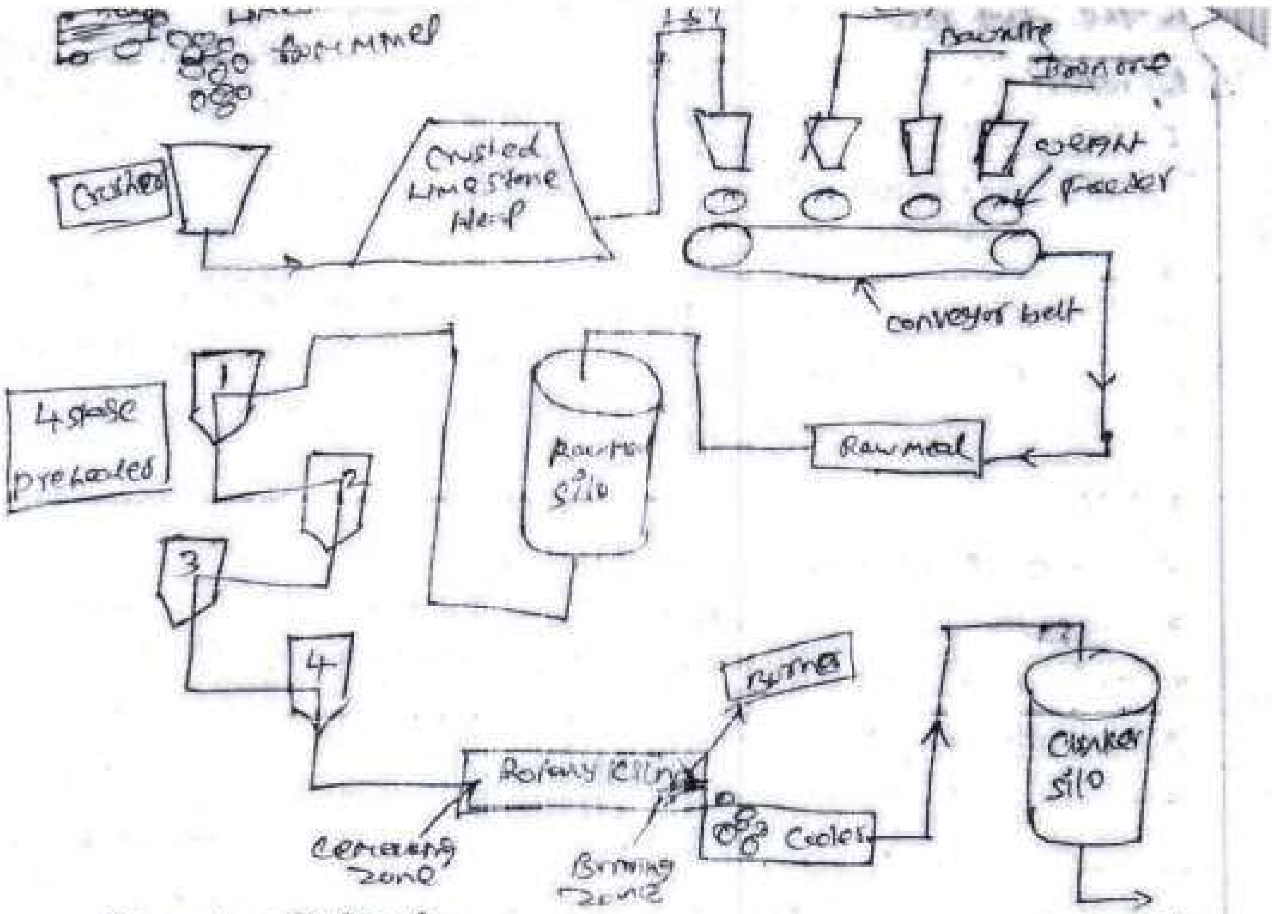
→ The blended meal is further sieved and fed into a rotating disc called granulator. A quantity of water about 12% by weight is added to make the blended meal into pellets.

→ The equipment used in the dry process kilns is comparatively smaller. The process is quite economical. The total consumption of coal in this method is only about 100kg when compared to the requirement of about 350 kg for producing a ton of cement in the wet process.

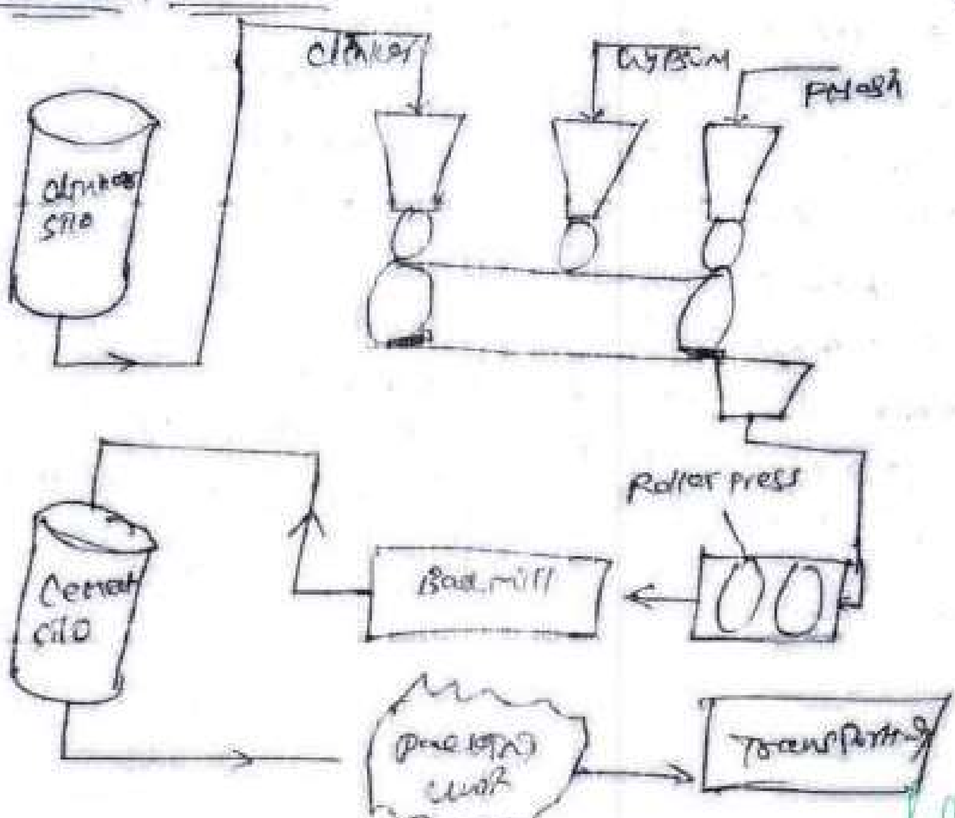
→ During march 1998 in India there were 173 large plants operating, out of which 49 plants used wet process, 115 plants used dry process and 9 plants used semi-dry process.

→ The methods are commonly employed for direct control of quality of clinker. The first method involves reflected light optical microscopy of polished and etched section of clinker, followed by point count of areas occupied by various compounds.

→ For moderate cooling it is implied that from about 1200°C the clinker is brought to about 500°C in about 15 minutes and from the 500°C the temperature is brought down to normal atmospheric temperature in about 10 minutes.



Cement mill section



Chemical composition

→ The raw materials used for the manufacture of cement consists mainly of lime, silica, alumina and iron oxide. These oxides materials with one another in the kiln at high temperature to form more complex compounds.

→ The relative composition of these oxides composition are responsible for influencing the various properties of cement.

Oxide	% Content
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.1-4
Alkalies	0.4-1.3
SO_3	1.3-3.0

Approximate oxide composition limits of ordinary portland cement.

→ As mentioned earlier the oxides present in the raw materials when subjected to high clinkering combine with each other to form complex compounds.

→ The identification of the major compound is largely based on R.H Bogue's work and hence it is called Bogue's compounds. The four compounds usually regarded as major compounds.

BOGUE'S COMPOUNDS

Name of compounds	Formula	Abbreviated Formula	%
Tricalcium silicate	3CaO SiO2	C3S	54.1
Dicalcium silicate	2CaO SiO2	C2S	16.6
Tricalcium Aluminate	3CaO Al2O3	C3A	10.8
Tetracalcium Alumino ferrite	4CaO Al2O3 Fe2O3	C4AF	9.1

→ Tricalcium silicate and dicalcium silicate are the most important compounds responsible for strength. Together constitute 70-80% of cement. The average C3S content in modern cement is about 45% and C2S is about 25%. The sum of the contents of C3A and C4AF has decreased slightly in modern cement.

→ An increase in lime content beyond a certain value makes it difficult to combine with other compounds and free lime will exist in the clinker which causes unsoundness in cement.

→ An increase in silica content at the expense of the content of alumina and ferric oxide will make the cement difficult to fuse and form clinker.

→ Cements with a high (early) total alumina and high ferric oxide content is favourable to the production of early strength in cement.

→ Bogue's compounds C3S, C2S, C3A, C4AF are sometimes called as Alite, Belite, Celite, and Felite respectively.

Hydration of Cement.

→ Anhydrous cement does not bind fine and coarse aggregate. It acquires adhesive property only when mixed with water.

→ The chemical reaction that take place between cement and water is refered as hydration of cement.

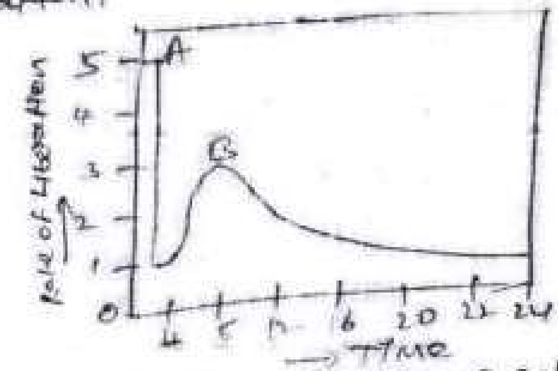
→ On account of hydration certain products are formed. These products are important because they have cementing or adhesive value.

→ The hydration of cement is visualised in two ways. The first is "through solution" mechanism. In this cement compounds dissolve to produce a supersaturated solution from which different hydrated products get precipitate.

→ The second possibility is that water attacks cement compounds in the solid state converting the compounds into hydrated products starting from the surface and proceeds to the interior of the compounds with time.

→ It is probable that both "through solution" and "solid state" type of mechanism may occur during the course of reactions between the cement and water.

→ The former mechanism is predominate in the early stages of hydration in view of large quantities of water being available and then later mechanism may operate during the later stages of hydration.



Heat liberation from a setting cement

STRUCTURE OF HYDRATED CEMENT

→ To understand the behaviour of concrete is necessary to acquaint ourselves with structure of hydrated hardened cement paste.

→ If the concrete is considered to be a two phase material, namely the paste phase and the aggregate phase, the understanding of the paste phase will become more important as it influences the behaviour of the concrete to a much greater extent.

→ The strength, permeability, durability, drying shrinkage, elastic properties, the creep and volume change properties of the concrete are much influenced by the paste structure.

→ So to understand the concrete it is important that we have a deep understanding of the structure of the hydrated hardened cement paste.

Transition zone:

→ Transition zone which represents the interfacial region between the particles of coarse aggregate and hardened cement paste.

→ Transition zone is generally a plane of weakness and therefore has far greater influence on the mechanical behaviour of concrete.

→ Although transition zone is composed of same bulk cement paste, the quality of paste in the transition zone is of poor quality. Firstly due to internal bleeding, water accumulation below elongated, flaky and large pieces of aggregates. This reduces the bond between paste and aggregate in general.

-> Due to drying shrinkage (or) temperature variation, the transition zone develops microcracks even before a structure is loaded. When structure is loaded at high stressed levels, these micro cracks propagate and bigger cracks are formed resulting in failure bond. Therefore transition zone generally the weakest part of the chain is considered strength limiting phase in concrete.

-> The techniques used to study the structure of cement paste include measurements of setting time, compressive strength, quantity of heat of hydration evolved etc.

-> Measurements of heat evolved during the exothermic reactions also give valuable insight into the nature of hydration reactions, since approximately 50% of total heat evolution occurs during 3 days of hydration, a continuous record of heat liberation during this time is extremely useful in understanding the degree of hydration and the resultant structure of hardening cement paste.

-> The mechanical properties of the hardened concrete depends more on the physical structure of the product of hydration than on the chemical composition of the cement.

-> For simplicity's sake we will consider only the structure of the paste phase. Fresh cement paste is a plastic mass consisting of water and cement. With the lapse of time, say one hour, the hardening paste consists of hydrates of various compounds, unhydrated cement particles and water. With further lapse of time the quantity of unhydrated cement left in the paste decreases and the hydrates of the various compounds increase

TEST ON PHYSICAL PROPERTIES

Testing of cement

testing of cement can be brought under two categories

1) Field testing
2) Laboratory testing

Field testing

→ It is sufficient to test the cement in field when it is used for minor works. The following are the field tests.

a) Open the bag and take a good look at a cement. There should not be any visible lumps. The colour of the cement should normally be greenish grey.

b) Thrust your hand into the cement bag it must give a cool feeling there should not be any lumps inside.

c) Take a pinch of cement and feel b/w the fingers it should give a smooth and not a gritty feeling.

d) Take a hand full of cement and throw it on a bucket full of water the particles should not float for sometimes before they sink.

Laboratory tests

The following tests are usually conducted in the lab

i) Fineness test
ii) setting time test
iii) Soundness test.
iv) Strength test.

i) Fineness test:-

→ The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat.

-> Fineness cement offers greater surface area for hydration and hence faster development of strength. The disadvantage of fine grinding is that it is susceptible to air set and early deterioration.

-> Max no of particles in a sample of cement should have a size less than 100 microns and the smallest particles may have a size about 1.5 μ

-> Fineness of cement is tested by sieving.

<u>sieve test</u>

-> weigh correctly 100 grams of cement and take it on a standard IS sieve No 9 (90 microns). Break down the air-set lumps in the sample with fingers. continuously sieve the sample giving circular and vertical motion for a period of 15 min. mechanical sieving devices may also be used. weigh the residue left on the sieve this weight should not exceed 10% of ordinary cement.

ii) <u>setting time test</u>

-> An arbitrary division has been made for the setting time of cement as initial setting time and final setting time. It is difficult to draw a rigid line b/w these two arbitrary division for convinience initial setting time is regarded as the time elapsed b/w the moment that the water is added to cement to the time that the paste starts losing its plasticity

-> The final setting time is the time elapsed b/w the moment the water is added to cement and the time when the paste has completely lost its plasticity has attained sufficient firmness to resist certain definite pressure.

-> initial setting time is normally 30 min and final setting time should not be more than 10 hrs.

-> For initial and final setting time test is tested by the vicat's apparatus.

Initial setting time

-> take about 500gms of cement sample and gauge it with 0.85 times the water required to produce cement paste of standard consistency 0.85P.

-> The paste shall be gauged and filled into the vicat mould in specific manner within 3-5 min.

-> start the stop watch the instant water is added to the cement.

-> lower the needle gently and bring it in contact with the surface of the test block and quickly release. Allow it to penetrate [illegible] into the test block.

-> In beginning the needle will completely pierce through the test block. But after sometimes when the paste starts losing its plasticity, the needle may penetrate only to a depth of 33-35mm from top.

-> The period elapsing b/w the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35 from the top is taken as initial setting time.

Final setting time

-> Replace the needle of the vicat apparatus by a circular attachment. The cement shall be considered as finally set when upon lowering the attachment gently cover the surface of the test block, the centre needle makes an impression, while the circular cutting edge of the attachment fails to do so. In other words the paste has attained such hardness that the centre needle does not pierce through the paste more than 0.5 mm.

iii) Soundness test

-> It is very important that cement after setting shall not undergoes any appreciable change of volume. certain cement have been found to undergo a large expansion after setting causing disruption of the set and hardened mass.

-> The apparatus consist of small split cylinder of spring brass (or) other suitable metal. It is 30 mm in diameter and 30 mm high on either side of split are attached two indicator arms 165 mm long with pointed ends.

-> cement is gauged with 0.78 times the water required for standard consistency 0.78P. in a standard manner and filled into the mould kept on a glass plate.

-> The mould is covered on the top with another glass plate. the whole assembly is immersed in water at a temp. of 27°C -32°C and kept there for 24 hrs.

-> measure the distance b/w the indicator points. Submerge the mould again in water. Heat the water and bring to boiling point in about 25-30 min. keep it boiling for 3 hrs.

-> Remove the mould from the water allow it to cool and measure the distance b/w the indicator points.

-> The difference b/w these two measurements represents the expansion of cement. This must not exceed 10 mm for ordinary portland cement. If in case the expansion is more than 10 mm as tested above the cement is said to be unsound.

iv) Strength test

-> The compressive strength of hardened cement is the most important of all the properties

-> strength of cement is indirectly found on cement sand mortar in specific proportions

→ Take 555 gms of standard sand, 185 gms of cement (1:3) in a non porous enamel tray and mix them with a trowel for one minute, then add water of quantity $\frac{P}{4}+3$ percent of combined weight of cement and sand and mix the three ingredients thoroughly until the mixture is of uniform colour.

→ The time of mixing should not be less than 3 minutes nor more than 4 minutes.

→ Immediately after mixing, the mortar is filled into a cube mould of size 7.06cm. The area of the face of the cube will be equal to 50 sq cm. Compact the mortar either by hand compaction in standard specified manner (or) in the vibrating equipment for 2 minutes.

→ Keep the compacted cube in the mould at a temp of 27°C ± 2°C and at least 90% relative humidity for ~~the 1 hour~~ 24 hrs.

→ After 24 hrs the cubes are removed from the mould and immersed in clean fresh water until taken out for testing.

TYPES OF CEMENT (GRADES OF CEMENT)

1) Ordinary Portland cement.
2) Rapid hardening cement
3) Extra Rapid hardening cement
4) Sulphate resisting cement
5) Portland slag cement
6) Quick setting cement

7) Super sulphated cement
8) Low heat cement
9) Portland pozzolana cement
10) Air entraining cement
11) coloured cement (white cement)
12) Hydrophobic cement
13) Masonry cement
14) expansive cement
15) oil well cement
16) Rediset cement
17) concrete deeper grade cement
18) High alumina cement
19) very high strength cement

ADMIXTURES :

→ Admixture is defined as a material, other than cement, water and aggregates that is used as ingredient of concrete and is added to the batch immediately before (or) during mixing. Additive is a material which is added at the time of grinding cement clinker at the cementory.

→ These days concrete is using for wide varities of purposes to make it suitable in different condition. In these conditions ordinary (cement) concrete may fail to exhibit the required quality performance (or) durability in such cases, admixtures is used to modify the properties of ordinary concrete so as to make it more suitable for any situation.

→ A few type of admixtures called water reducers (or) High range water reducers, generally ~~referred as~~ plasticizers (or) super plasticizers.

Types of Admixtures

(1) Chemical Admixtures

1) Plasticizers (water reducers)

2) Super plasticizers

3) Retarders and Retarding plasticizers

4) Accelerators and Accelerating plasticizers

5) Air Entraining Admixtures

(2) Mineral Admixtures

6) Pozzolanic (or) Mineral admixtures

7) Damp-proofing and water proofing admixtures

8) Gas foaming admixtures

9) Air detraining admixtures

10) Alkali aggregate expansion inhibiting admixtures.

11) Workability admixtures

12) Grouting admixtures

13) Corrosion inhibiting admixtures

14) Bonding admixtures

15) Colouring admixtures

CONSTRUCTION CHEMICALS

1) Concrete curing compounds

2) Polymer Bonding Agents

3) Mould Releasing Agents

4) Protective and Decorative Coatings

5) Installation Aids

6) Surface Retarders

7) Bond Aid for proofing

8) Guniting Aid.

AGGREGATES :- Unit - II

→ Aggregates are important constituents in concrete. they give body to the concrete, reduce shrinkage and effect economy.

→ they aggregates occupy 70-80% of volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.

Classification of aggregates

→ Aggregates are classified as

1) Normal aggregates

2) Lightweight aggregates

3) Heavy weight aggregates.

→ In this chapter properties of normal aggregates will be discuss.

→ Normal weight aggregates further classified as Natural and artificial aggregates

Natural	Artificial
Sand,	Broken brick,
Gravel,	Air cooled slag,
Crushed rock such as	sintered flyash,
Granite, Quartzite, Basalt,	Bloated clay
Sand stone.	

→ aggregates can be classified on the basis of the size of the aggregates as coarse aggregates and fine aggregates

Particle shape & texture of aggregates

SHAPE:

-> The shape of aggregate is an important characteristic since it affects the workability of concrete. It is difficult to really measure the shape of irregular body like concrete aggregates which are derived from various rocks.

-> One of the methods of expressing the angularity qualitatively is by a figure called angularity number.

-> This is based on % voids in the aggregate after compaction in a specified manner.

-> A quantity of single sized aggregates are ~~considered~~ is ~~standard~~ filled into metal cylinder of 3 lit capacity. The aggregates are compacted in a standard manner and % of voids is found out.

-> The void is found out can be knowing the sp.gravity of aggregates and bulk density (or) by pouring water to the cylinder to bring the level of water upto the brim. If the voids 33% the angularity of such aggregates is considered zero. If the void is 44% the angularity no of such aggregate is considered 11.

-> The normal aggregates which are suitable for making the concrete may have angularity number ranging from 0 to 11.

-> Angularity number zero represents the most practicable rounded aggregates and the number 11 indicates the most angular aggregates that could be tolerated for making concrete not so unduly harsh and uneconomical.

TEXTURE:

-> Surface texture is the property the measure of which depends upon the relative degree to which particle surfaces are polished (or) dull, smooth (or) rough.

-> Rough textured aggregates develops higher bond strength in tension than smooth textured aggregates

Strength of aggregate

→ When the cement paste is of good quality and its bond with ~~the aggregate will influence~~ ~~[illegible]~~ is satisfactory, then the mechanical properties of rock (or) aggregates will influence the strength of concrete.

→ The test for strength of aggregate is required to be made in the following statements (or) situations.

i) For production of high strength & extra high strength concrete.

ii) When contemplating to use aggregates manufacture from weathered rocks.

iii) Aggregates manufactured by industrial process.

Aggregate crushing value

→ Strength of rock is found out by making a test specimen of cylinder shape of size 25mm dia and 25mm height.

→ The cylinder is subjected to compressive stress different rock samples are found to give different compressive strength varying from a min of 45MPa – 545MPa.

→ As said earlier the compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete. For this reason assessment of strength of the aggregate is made by using a sample of bulk aggregate in standardised manner. The test is known as "aggregate crushing value test".

Aggregate Impact value

-> With respect to concrete aggregates, toughness is usually considered the resistance of the material to failure by impact.
-> Several attempts to develop a method of test for aggregates impact value have been made.
-> The most successful is the one in which a sample of standard aggregates kept in a mould is subjected to 15 blows of a metal hammer of weight 14kgs falling from a height of 38cms.
-> The quantity of finer materials resulting from pounding will indicate the toughness of the sample of aggregates.
-> The ratio of the fines formed to the weight of the total sample taken is expressed as a %.

Aggregate Abrasion value

-> Apart from testing aggregates with respect to crushing value, impact resistance testing the aggregate with respect to its resistance to wear is an important test for aggregates to be used for road construction & pavement construction.

Modulus of elasticity

-> Modulus of elasticity of aggregate depends upon its composition, texture and structure. The modulus of elasticity of aggregate will influence the properties of concrete with respect to shrinkage and elastic behaviour and to very small extent of creep of concrete.
-> Elasticity of aggregate has a decided effect on the elastic property of concrete and that the relation of elasticity of aggregate that of the concrete is not a linear function, but may be expressed as an equation of exponential type.

Specific gravity

-> In concrete technology sp. gravity of aggregates is made use of in design calculation of concrete mixes. avg specific gravity of the rock vary from 2.6 to 2.8

Bulk density

-> Bulk density shows how densely the aggregates is packed when filled in a standard manner.

-> The bulk density depends on the particle size distribution and shape the particles

Absorption and moisture content

-> Some of the aggregates are porous and absorptive. porosity and absorption of aggregates will effect the w/c ratio and hence the workability of concrete.

-> The porosity of aggregates will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

Bulking of aggregates

-> The free moisture content in fine aggregate results in bulking of volume.

-> Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighbouring particles away from it.

-> The extent of bulking can be estimated by a simple test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner.

$$\% \text{ of bulking} = \frac{h_1 - h_2}{h_2} \times 100$$

h_1 = fine aggregate

h_2 = fine aggre with water.

Soundness of aggregate:

-> Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of change in physical conditions.

-> These physical conditions that affect the soundness of aggregate are as the freezing and thawing variation in temperature, alternate wetting and drying under normal condition and drying & wetting in saltwater.

-> Aggregates which are porous, weak and containing any undesirable extraneous matter undergo excessive volume change when subjected to the above condition.

-> Aggregates which undergo more than specified amount of volume change is said to be unsound aggregates.

Alkali Aggregate:

-> For a long time aggregates have been considered as inert materials but later on point was clearly brought out that the aggregates are not fully inert. some of the aggregates contain reactive silica which reacts with alkalies present in cement. i.e sodium oxide and potassium oxide.

-> The reaction starts with attack on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from the alkalies in cement.

-> As a result the alkali silicate gels of unlimited swelling type are formed. when the condition are congenial, progressive manifestation by swelling take place, which results in disruption of concrete with spreading of pattern cracks and eventual failure of concrete structure.

-> The rate of deterioration may be slow or fast depending upon the condition. There were cases where concrete has become unserviceable in about a year time.

THERMAL PROPERTIES :

→ Rock and aggregates possess 3 thermal properties which are significant in establishing the quality of aggregate for concrete construction they are

1) co-efficient of expansion 2) specific heat 3) Thermal conductivity

→ An avg value of the mean thermal co-efficient of expansion of concrete may be taken as $9.9 \times 10^{-6}/°C$ but the range may be from about $5.8 \times 10^{-6}/°C - 14 \times 10^{-6}/°C$ depending upon the type and quantities of the aggregates the mix proportions and other factors.

→ The range of co-efficient of thermal expansion for hydrated cement paste may vary from $10.8 \times 10^{-6}/°C$ to $16.2 \times 10^{-6}/°C$. For mortar it may range from $7.9 \times 10^{-6}/°C$ to $12 \times 10^{-6}/°C$.

→ For common rocks ranges from $0.9 \times 10^{-6}/°C$ to $16 \times 10^{-6}/°C$

SIEVE ANALYSIS

→ This is the name given to the operation of dividing a sample of aggregates into various fractions each consisting of particles of the same size.

→ The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate which are called gradation.

→ The aggregates used for making concrete are normally of the maximum size 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm 600μ, 300μ, and 150μ

→ The aggregates fraction from 80mm - 4.75mm are termed as coarse aggregate and those fraction from 4.75mm - 150μ are termed as fine aggregates.

→ The size 4.75mm is a common fraction appearing both in coarse aggregates and fine aggregates (CA & FA)

→ The material retained on each sieve after shaking, represents the fraction of aggregates coarser than the sieve in question and finer than the sieve above.

→ Sieving is done either manually (or) mechanically

→ In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve. operation should be continued for such time that almost no particle is passing through.

Fineness Modulus :

→ From the sieve analysis the particle size distribution in a sample of aggregates is find out. In this connection a term known as "Fineness Modulus"

→ Fineness Modulus is a good index of coarseness (or) fineness of the material.

→ Fineness Modulus is an empirical factor obtained by adding the cummulative % of aggregates retained on each of the standard sieve ranging from 80-150mm microns and dividing this sum by an arbitrary number 100.

The following limits may be taken as guidance.

	F M
Fine sand	2.2 – 2.6
medium sand	2.6 – 2.9
coarse sand	2.9 – 3.2

→ A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Grading of Aggregates

→ Aggregate comprises about 55% of the volume of mortar and 85% volume of mass concrete.

→ Mortar contains aggregates of size 4.75mm and concrete contains aggregate upto a maximum size of 150mm.

→ It is well known that the strength of concrete is depend upon w/c ratio provided the concrete is workable.

→ One of the most important factor for producing workable concrete is good gradation of aggregates

→ Good grading implies that a sample of aggregates contains all standard fractions of aggregates in required proportion such that the sample contains minimum voids.

→ A sample of well graded aggregates containing minimum voids will require minimum paste to fill up the voids in aggregates

→ Minimum paste will be mean less quantity of water which will furthermean ~~less quantity of cement and less quantity of water~~ increased economy higher strength, lower shrinkage and greater durability.

→ The advantage due to good grading of aggregates can also be viewed from another angle. If concrete is viewed as a two phase material paste phase and aggregate phase it is the paste phase which is vulnerable to all ills of concrete.

→ Paste is weaker than avg aggregate in normal concrete with some exception when very soft aggregates are used.

→ The paste is more permeable than many of the mineral aggregates. It is the paste that is susceptible to deterioration by the attack of aggressive chemicals.

→ In short, it is the paste which is weak link in a mass of concrete. This objective can be achieved by having well graded aggregates. Hence the importance of good grading.

Gap Grading :

→ so far we discussed the grading pattern of aggregates in which all particle size are present in certain portion in a sample of aggregate. such pattern of particle size distribution is also referred as continous grading.

→ originally in the theory of continuous grading, it was assumed that the voids present in the higher size of the aggregates are filled up by the next lower size of aggregate

→ similarly the voids created by lower size are filled up by the lower than those particles and so on

→ it have been seen that the size of voids existing b/w a particular size of aggregate is of the order of 2 (or) 3 size lower than that of fraction. In other words the void size existing b/w 40mm aggregates is of the size equal to 10mm (or) particle size of voids occurs when 20mm aggregate by 4.75mm (or) the size of voids ... along with ... used in order of say 1.18mm (or) ... 20mm aggregate only when 1.18mm aggregate size is used.

Advantages of gap graded concrete:

i) sand required will be of the order of about 26% as against about 40% in the case of continous grading.

ii) specific surface area of the gap graded aggregate will be low because of high % of C.A & low % of F.A.

iii) requires less cement and lower water/cement ratio.

iv) because of point contact b/w C.A & C.A and also on account of lower cement and matrix content the drying shrinkage is reduced.

FRESH CONCRETE

-> Fresh concrete (or) Plastic concrete is a freshly mixed material which can be moulded into any shape.

-> The Relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state.

Workability:

-> 100% compaction of concrete is an important parameter for contributing to the maximum strength. Lack of compaction will result in air voids whose damaging effect on strength and durability is equally (or) more predominant than the presence of capillary cavities.

-> To enable the concrete to be fully compacted with given efforts normally a higher water / cement ratio than that calculated by theoretical consideration may be required. That is to say the function of water is also to lubricate the concrete so that the concrete can be compacted with specified effort forth coming at the site work.

-> The word "workability" (or) 'workable concrete' signifies much wider and deeper meaning than the other terminology "consistency" often used loosely for workability.

-> consistency is a general term to indicate the degree of fluidity (or) the degree of mobility.

-> A concrete which has high consistency and which is more mobile, need not be of right workability for a particular job. every job requires particular workability.

-> A concrete which is required workable for mass concrete for foundation is that not workable for concrete to be used in roof construction or even in roof construction. concrete considered workable when vibrator is used is not workable when concrete is compacted by hand.

→ Stiffness concrete ... workable when used in thin section is not workable when required to be used in thin section. Therefore the word workability assumes full significance of the type of work, thickness of section, extent of reinforcement and mode of compaction.

→ Workability is defined as property of concrete which determines the amount of useful internal work necessary to produce full compaction.

→ Another definition which envelopes a wider meaning is that it is defined as the ease with which concrete can be compacted 100% having regard to mode of compaction and place of deposition.

FACTORS AFFECTING WORKABILITY:

→ Workable concrete is the one which exhibits very little internal friction between particle and particles which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forth coming.

1) Water content
2) Mix proportion
3) Size of aggregates
4) Shape of aggregates
5) Surface texture of aggregates
6) Grading of aggregates
7) Use of admixtures.

→ The above are the factors affecting to the workability of concrete.

Measurement of workability

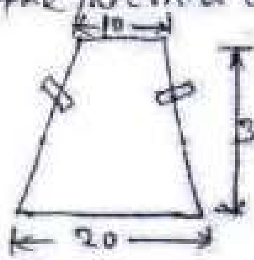
→ The following tests are commonly employed to measure workability

1) Slump test
2) Compaction factor test
3) Flow test
4) Vee bee consistometer test.

1) Slump test

→ Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work.

→ The apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimension under.



All in CM

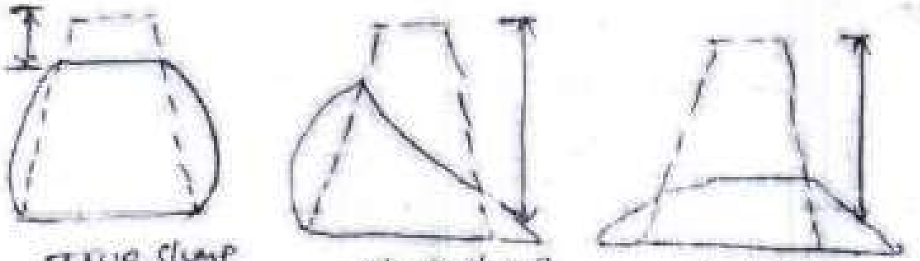
Bottom diameter : 20cm
Top diameter : 10cm
Height : 30cm
Tamping rod : 16mm dia, 0.6m long

→ The mould is placed on a smooth, horizontal, rigid and non absorbent surface. The mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section.

→ After the top layer has been rodded the concrete is struck off level with a trowel and tamping rod.

→ The mould is removed immediately by raising it slowly and carefully in a vertical direction.

→ This allows the concrete to subside. The subsidence is referred as slump of concrete.



→ The pattern of slump is shown in fig. It indicates the characteristic of concrete in addition to the slump cone value.

→ If the concrete slumps evenly it is called true slump.

→ If one half of the cone slides down, it is called shear slump. It is also indicates the concrete is non-cohesive and shows the characteristic of segregation.

→ If the concrete slumps totally collapsed is called collapse.

→ It is seen that the slump test gives fairly good consistent results for a plastic mix. This test is not sensitive for a stiff mix. In case of dry mix, no variation can be detected between mixes of different workability.

Degree of workability	Slump (mm)
Low	25–75
Medium	~~50–100~~ 50–100
High	100–150
Very High	—

2) Compacting factor test

→ The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field.

→ It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to compacted by vibration

Dimension of the compacting factor test.

Upper Hopper A	Dimension (cm)
Top internal dia	25.4
Bottom internal dia	12.7
Internal height	27.9
Lower Hopper B	
Top internal dia	22.7
Bottom internal dia	12.7
Internal height	22.7
Cylinder C	
Internal dia	15.2
Internal height	30.5
Distance b/w hopper	20.3

→ The sample of concrete to be tested is placed in the hopper up to the brim. The trap door is opened so that the concrete falls into the lower hopper. Then the trap door of the lower hopper is opened and the concrete is falls into the cylinder.

→ The exess of concrete remaining above the cylinder is then cut off with the help of plane blades supplied with the apparatus.

→ The out side of the cylinder is wiped clean. The concrete is filled up exactly upto the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as "weight of partially compacted concrete"

→ The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5cm deep. The layers are heavily rammed (or vibrated) as a full compaction. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10 gm. This weight is known as "weight fully compacted concrete"

$$\text{Compaction factor} = \frac{\text{wt of partially compacted concrete}}{\text{wt of fully compacted concrete}}$$

3) Flow test:

→ This is a laboratory test which gives an indication of the Quality of concrete with respect to consistency, cohesiveness and the proneness to segregation.

→ This apparatus consist of flow table about 76cm in diameter.

→ The mould made from smooth metal casting in the form of frustum of a cone is used with the following internal dimensions. The base is 25cm in dia, upper surface 17cm in dia. and height of the cone is 12cm.

→ The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6cm in dia and 61cm long.

→ The top layer is rodded evenly the excess of concrete which has overflowed the mould is removed.

→ The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5mm 15 times in about 15 sec. The

→ The diameter of spread concrete is measured in about 6 directions to the nearest 5mm and the avg spread is noted.

$$\text{Flow \%} = \frac{\text{spread dia in cm} - 25}{25} \times 100.$$

→ The value could range anything from 0 to 150%

4) Vee-Bee consistometer test:

→ This is good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod.

→ Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer.

-> The glass disc attached to the swivel arm is turned and is placed on the top of the concrete in the pot.
-> The electrical vibrator is then switched on and simultaneously a stop watch started. The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.
-> This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete is fully assumes a cylindrical shap the stopwatch is switched off.
-> The time required for the shape of concrete to change from slump cone test to cylindrical shape in seconds is known as vee-bee degree.

SETTING TIME OF CONCRETE:

-> The setting time of concrete depends upon w/c ratio, temperature conditions, type of cement, use of mineral admixtures, use of plasticizers in particular retarding plasticizes.
-> The setting parameter of concrete is more of practical significance for site engineers than setting time of cement
-> when retarding plasticizers are used, the increase in setting time, the duration upto which concrete remains in plastic condition is of special interest.
-> The setting time of concrete is found by penetrometer test
-> The apparatus consist of container which should have minimum lateral dimension of 150mm and minimum depth of 150mm.
-> There are 6 penetration needles with bearing [illegible] area of 645, 323, 161, 65, 32 and 16 mm^2. Each needle stem is scribed circumferentially at a distance of 25mm from the bearing area

→ The test procedure involves the collection of representative sample of concrete in sufficient quantity and sieve it through 4.75mm sieve and the resulting mortar is filled in the container.
→ Compact the mortar by rodding, tapping, rocking or by vibrating. Level the surface and keep it covered to prevent the loss of moisture. Remove bleeding water, if any by means of pipette.
→ Insert a needle of appropriate size, depending upon the degree of setting of mortar in the following manner.
→ Bring the bearing surface of needle in contact with the mortar surface. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5mm, as indicated by the scribe mark.
→ The time taken to penetrate 25mm depth could be about 10sec. Record the force required to produce 25mm penetration and the time of insertion from the time water is added to cement.
→ Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance.
→ For the subsequent penetration avoid the area where the mortar has been disturbed. The clear distance should be two times the diameter of the bearing area. Needle is inserted at least 25mm away from the wall of container.
→ Plot a graph of penetration resistance as ordinate and elapsed time as abscissa, not less than six penetration resistance determination is made.
→ Continue the tests until one penetration resistance of at least 27.6 MPa is reached. Connect the various points by a smooth curve.
→ Penetration resistance equal to 3.5 MPa draw a horizontal line. The point of intersection of this with the smooth curve is read on the X axis which gives the initial setting time. Ily horizontal line is drawn from the penetration resistance of 27.6 MPa and the point it cuts the smooth curve is read on the X axis which gives final set.

SEGREGATION :

→ Segregation can be defined as the seperation of the constituent materials of concrete.

→ A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture.

→ If a sample of concrete exhibits a tendency for seperation of coarse aggregate from the rest of the ingredients that sample is said to be showing the tendency for segregation. Such a concrete is not only going to be weak. lack of homogeneity is also going to induce all undesirable properties in the hardened concrete.

→ Segregation may be of three types
* Coarse aggregate seperating out or setting down from the rest of the matrix.
* The paste (or) matrix seperating from coarse aggregate and ~~material~~
* Water seperating out from the rest of the material being a material of lowest specific gravity.

→ A well made concrete taking into consideration various parameters such as grading, size, shape and surface texture of aggregates with optimum quantity of water makes a cohesive mix. Such concrete will not exhibit any tendency for segregation.

→ The conditions favourable for segregation are as can be seen from the above para. the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation.

→ Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation.

→ Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. If flower alone is excessively vibrated, it is likely that the concrete gets segregated.

→ In the recent time we use concrete with very high slump particularly in RMC. The slump value required at the batching point may be in the order of 150mm and at the pouring point the slump may be around 100mm.

~~segregation~~

→ While finishing concrete floors with a view to achieve a smooth surface masons are likely to work too much with the trowel, float (or) tamping rule immediately on placing concrete. This immediate working on the concrete on placing without any time interval is likely to press the coarse aggregate down which results in the movement of excess of mortar (or) paste to the surface. Segregation caused on this account impairs the homogeneity and serviceability of concrete. The excess mortar at the top cause plastic shrinkage cracks.

→ Segregation is difficult to measure quantitatively but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test (or) the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

BLEEDING:

→ Bleeding is sometimes referred as water gain. This a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete.

→ Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slabs (or) road slabs and when concrete is placed in sunny weather show excessive bleeding.

→ due to bleeding water comes up and accumulates at the surface, sometimes along with this water, certain quantity of cement also comes to the surface.

→ when the surface is worked up with the trowel and floats the aggregates goes down and the cement and water comes up to top surface. This formation of cement paste at the surface is known as "Laitance".

→ In such a cases the top of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season.

→ water while proceeding from bottom to top, makes continuous channels, if the water cement ratio is used more than 0.7 the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

→ The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond b/w the aggregates and the paste.

→ Bleeding rate increases with time up to about one hour or so and thereafter rate decreases but continues more or less till the final setting time of cement.

→ Bleeding presents a very serious problem when slip form paver is used for construction of concrete pavements. If the mix of bleeding water accumulates on the surface of pavement slab the bleeding water flows out over the unsupported sides which causes collapsing of sides.

Method of test for bleeding of concrete

→ This method covers determination of relative quantity of mixing water that will bleed from a sample of freshly mixed concrete.

→ A cylindrical container of approximately 0.01 m³ capacity, having an inside diameter of 250mm and inside height of 280mm is used. A tamping bar similar to the one used for slump test is used. A pipette for drawing off free water from the surface a graduated jar of 100cm³ capacity is required for test.

→ A sample of freshly mixed concrete is obtained. The concrete is filled in 50mm layer for a depth of 250 ± 3 mm (5 layers) and each layer is tamped by giving strokes, and top surface is made smooth by trowelling.

→ The test specimen is weighed and the weight of the concrete is noted. Knowing the total water content in 1 m³ concrete is noted. Knowing the total water content in the cylindrical container of concrete quantity of water in the cylindrical container is also calculated.

→ The cylindrical container is kept in a level surface free from vibration at a temperature of 27°C ± 2°C. It is covered with a lid. Water accumulated at the top is drawn by means of pipette at 10 minutes interval for the first 40 min and at 30 min. interval subsequently till bleeding ceases. To facilitate collection of bleeding water the container may be slightly tilted. All the bleeding water collected in a jar.

$$\text{Bleeding \%} = \frac{\text{Total quantity of bleeding water}}{\text{Total quantity of water in sample of concrete}} \times 100$$

STEPS IN MANUFACTURE OF CONCRETE:

→ The various stages of manufacture of concrete are.

1) Batching
2) Mixing
3) Transporting
4) Placing
5) Compacting
6) Curing
7) Finishing.

1) Batching:

→ The measurement of materials for making concrete is known as "batching".
→ There are two methods of batching.
 i) Volume Batching ii) Weigh Batching.

i) Volume Batching:

– Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume.
→ Cement is always measured by weight, it is never measured in volume. Generally for each batch mix one bag of cement is used. The volume of 1 bag of cement is taken by 35 litres.
→ Gauge boxes are used for measuring the fine and coarse aggregates. The volume of the box is made equal to the volume of 1 bag of cement i.e 35 litres
→ Gauge boxes are generally called farms. They can be made of timber or steel plates.

→ Water is measured either in kg, litres or few of convenient. In this case the two units are same as the density of water is one kg/litre. The quantity of water required is a product of water/cement ratio and the weight of cement.

→ For example if the water/cement ratio of 0.5 is specified the quantity of mixing water is required per bag of cement is 0.5×50 = 25 kg (or litres)

Batch volume of materials for mixes

Grade	cement (kg)	sand (litres)	aggregate (litres)
1:1:2 (M200)	50	35	70
1:1½:3 (M200)	50	52.5	105
1:2:3	50	70	105
1:2:4 (M150)	50	70	140
1:2½:5	50	87.5	175
1:3:6	50	105	210

ii) Weigh Batching:

→ Weigh batching is the correct method of measuring the materials. For important concrete weigh batching is adopted.

→ Use of weigh system in batching facilities accuracy, flexibility and simplicity. Different types of weigh batches are available.

→ The particular type to be used, depends upon the nature of the job. Large weigh batching plants have automatic weighing is one of sophistication and requires qualified and experienced engineers. In this further complication will come to adjust water content to water for the moisture content in the aggregates.

→ In small jobs cement is often proportioned ... it is ... bags assuming the weight of the bag as 50kg. In reality though the cement bag is made of 50kg at the factory due to transportation when the bags are used. In fact the weight of a cement bag at the site is considerably less. Some times the loss of weight becomes more than 5kg. This is one of the sources of error in volume.

→ Batching and weigh batching when the cement is not actually weighed. But in important major concreting jobs, cement is also actually weighed and exact proportion as designed is maintained.

2) Mixing:

→ Through mixing of the material is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency.

→ There are two methods adopted for mixing concrete.

1) Hand mixing.
2) Machine mixing.

1) Hand mixing:

→ Hand mixing is practised for small scale unimportant concrete works.

→ As the mixing cannot be thorough and efficient it is desirable to add 10% more cement to cater for the inferior concrete produced by this method.

2) Machine mixing:

→ Mixing of concrete is almost invariably carried out by machine for reinforced concrete work and for medium (or large) scale mass concrete work.

→ Machine mixing is not only efficient but also economical when the quantity of concrete to be produced is large.

3) Transporting:

→ The methods adopted for transportation of concrete.

i) Mortar pan (ii) Wheel barrow, hand cart

(iii) Crane, Bucket and rope way (iv) Truck mixer & dumper

(v) Belt conveyors (vi) Chute.

vii) Skip and Hoist viii) Transit mixer

ix) Pump and pipeline x) Helicopter.

4) Placing of concrete:

→ It is not enough that a concrete mix correctly designed, batched mixed and transported, it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results.

→ Concrete is invariably laid on foundation bed below the walls (or) columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed.

→ For the construction of road slabs, airfield slabs and ground floor slabs in buildings, concrete is placed in bays. The ground surface on which the concrete is placed must be free from loose earth, pool of water and other organic matters like grass, roots, leaves etc.

→ When concrete is laid in great thickness as in the case of concrete raft for a high rise building (or) in the construction of concrete pier (or) abutment (or) in the construction of mass concrete dam, concrete is placed in layers.

→ Before placing the concrete the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush.

Principal
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5) Compaction :

→ Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In process of mixing, transporting and placing of concrete air is likely to get entrapped in the concrete.

Methods of compaction:

i) Hand compaction

a) Rodding b) Ramming c) Tamping

ii) Compaction by vibration

a) Internal vibrator

b) Formwork vibrator

c) Table vibrator

d) Platform vibrator

e) Surface vibrator

f) Vibratory roller

iii) Compaction by pressure and jolting

iv) Compaction by spinning.

6) Curing :

→ Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately it can be described as the process of maintaining a satisfactory moisture content and a favourable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service.

→ A quick surface drying of concrete results in the movement of moisture from the interior to the surface.

Curing methods:

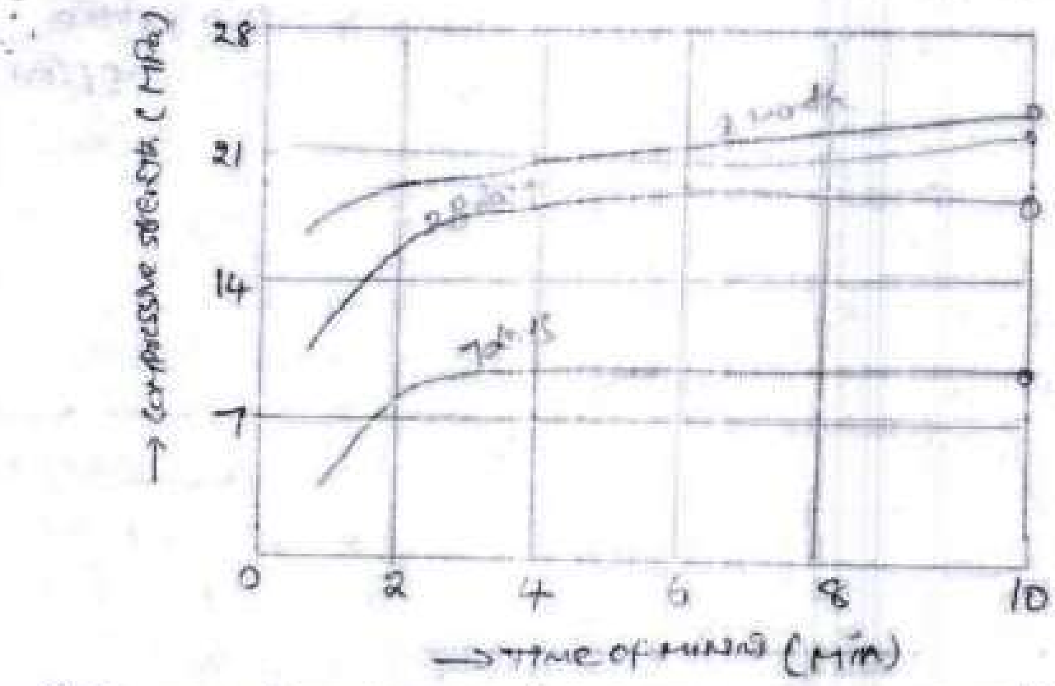
a) Water curing → Immersion, ponding, spraying, wet covering
b) Membrane curing – steam curing, electrical, infra-red radiation
c) Application of heat –

7) FINISHING:

→ Finishing operation is the last operation in making concrete. Finishing in real sense does not apply to all concrete operations, finishing may not be applicable.
→ For mass concreting, finishing may not be applicable, domestic buildings, road pavement, airfield pavement, careful finishing is of great importance.

EFFECT OF TIME & TEMPERATURE ON WORKABILITY:

→ Concrete mixers are generally designed to run at a speed of 15–20 revolutions per minute.
→ For proper mixing it is seen that about 25–30 revolutions are required in a well designed mixer.
→ In the site the normal tendency is to speed up the out turn of concrete by reducing the mixing time. This results in poor quality of concrete. On the other hand, if the concrete is mixed for a comparatively longer time, it is uneconomical from the point of view of rate of production of concrete and fuel consumption. Therefore it is of importance to mix the concrete for such a duration which will accrue optimum benefit.



→ it is seen from the experiment that the quality of concrete in terms of compressive strength will increased with the increase in time of mixing but for mixing time beyond two min the improvement in compressive strength is not very significant. the graph shows the effect of mixing time on strength of concrete.

→ Concrete mixer is not a simple apparatus lot of considerations have gone as input in the design of the mixer drum the shape of drum, the number of blades, inclination of blades with respect to drum surface. the length of blades, the depth of blades, the space b/w the drum and the blades, the space b/w the metal strips of blades and speed of rotation etc. are important to give uniform mixing quality and optimum time of mixing.

→ Generally mixing time is related to the capacity of mixer. the mixing time varies b/w 1½ to 2½ minutes. Bigger the capacity of drum more is the mixing time. However modern high speed pan mixer used in RMC, mixes the concrete in about 15 to 30 secs. one cubic meter (1m3) capacity high speed pan mixer takes only about 2 min. for batching and mixing. The batching plant takes about 12 min. to load a transit mixer of 6m3 capacity.

→ Some times, at site some concrete may not be discharged from the drum and concrete may be kept rotating in the drum for long time. as for instance when some travel (or) dispute takes place with the workers (or) when an anticipated repair (or) modification is required to be done on form work and reinforcement.

→ Long time mixing of concrete will generally result in increase of compressive strength of concrete within limits. Due to mixing over periods the effective water/cement ratio gets reduced.

→ The evaporation of water and formation of excess fines may reduces the workability and hence bring about reduction in strength. The excess of fine may also cause greater shrinkage.

RETEMPERING OF CONCRETE:

→ The process of remixing of concrete if necessary with addition of just the required quantity of water is known as "Retempering of concrete". sometimes a small quantity of extra cement also added while retempering. many specifications do not permit mortar requiring renewed mixing with (or) without addition of cement, aggregate (or) water.

→ The production of concrete of excessive slump (or) adding water in excess of designed water cement ratio to compensate for slump loss resulting from delays in delivery should be prohibited.

→ Retempering of concrete is to wet after initial delay of about one hour as an increase in compressive strength of 2 to 15%.

[signature]

Quality of Mixing water

→ Concrete is a chemically combined mass which is transformed from binding materials and inert material with water.

Functions of water in concrete :-

→ To wet the surface of aggregate to develop adhesion because the cement paste adhers quick and satisfactory to the surface of the aggregates than to a dry surface.

→ To make a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position

→ water is also needed for the hydration of the cementing material to set and harden during the period of curing

→ Quantity of water in the mix plays a vital role on the strength of the concrete, some water which have adverse effect on hardened concrete. Sometimes may not be harmless (or) even beneficial during mixing.

→ The affect on concreting for different types of contamination (or) impurities are described below-

1) Suspended solids :

→ Mixing water with high content of suspended solids should be allowed to stand in a settling tank basin before use as it undesirable to introduce large quantities of clay and silt into the concrete

2) Acidity & Alkalinity :

→ natural water that is slightly acidic are harmless, but presence of humic (or) other organic acids may result adverse effect over the [illegible] which are highly alkaline should also be tested.

3) Algae:-

→ The presence of algae in mixing water causes air entrainments with a consequent loss of strength. The Green (or) brown slime forming algae should be regarded with suspicion and such water should be tested carefully.

4) Sea water:-

→ Sea water contains a total salinity of about 3.5% (78% of the dissolved solids being NaCl and 15% $MgCl_2$ and $MgSO_4$) which produces a slightly higher early strength but a lower long term strength.

→ The loss of strength is usually limited 15% and can therefore be tolerated. Sea water reduces the initial setting time of cement but do not effect final setting time.

5) Chloride:-

→ water containing large amount tends to cause persistent dampness and surface efflorence.

→ The presence of chlorides in concrete containing embedded steel can lead to its corrosion.

6) Moisture content of aggregates:-

→ Aggregates usually contains some surface moisture. Coarse aggregate rarely contains more than 1% of surface moisture but fine aggregate can contain in excess of 10%.

→ This water can represent a substantial proportion of the total mixing water indicating a significant importance in the quantity of water that contributes surface moisture in aggregate.

UNIT-IV
HARDENED CONCRETE

→ The compressive strength of concrete is one of the most important and useful properties of concrete.

→ Compressive strength is also used a qualitative measure for other properties of hardened concrete.

→ No exact quantitative relationship b/w compressive strength and flexural strength, tensile strength, modulus of elasticity, wear resistance, fire resistance or permeability.

→ The compressive strength of concrete is generally determined by testing cubes. When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure.

→ The modern version of original water/cement ratio rule can be given as follows.

1) Ratio of cement to mixing water
2) Ratio of cement to aggregates
3) Grading, surface texture, shape, strength and stiffness of aggregate.
4) Maximum size of aggregate.

Water/cement ratio:

→ Strength of concrete primarily depends upon the strength of cement paste. It has been depends upon the dilution of paste

→ The strength of paste increases with cement content and decreases with air and water content

$$S = \frac{A}{B^x}$$

x = water cement ratio by volume and for 28 days results the constant A & B are 14,000 lbs/sq.in and 7 respectively.

→ Abrams W/C ratio law states that the strength of concrete is only dependent upon W/C ratio provided the mix is workable.

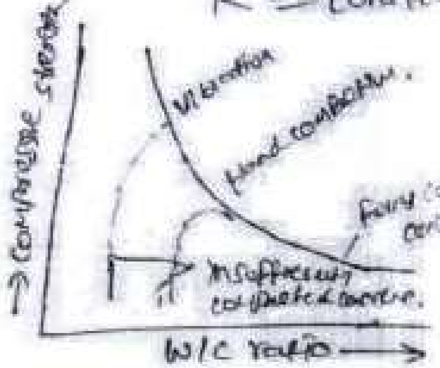
→ According to the strength of concrete paste and concrete in terms of volume fraction of the constituents by the equation

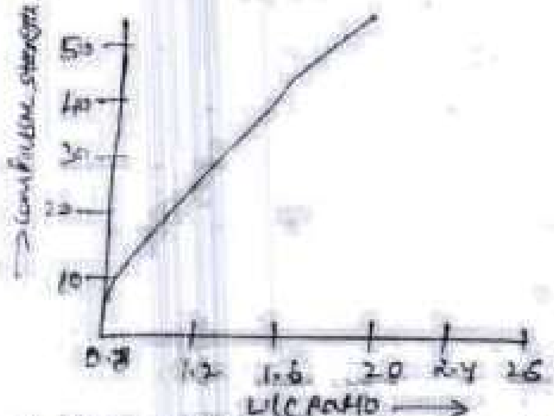
$$S = K\left(\frac{c}{c+e+a}\right)^2$$

where, S = strength of concrete

c, e and a = volume of cement, water and air

K = constant





→ In this expression the volume of air is also included because it is not only the water/cement ratio but also the degree of compaction, which indirectly means the volume of air filled voids in the concrete is taken into account in estimating the strength of concrete.

→ It can be seen that lower water/cement ratio could be used to achieve higher strength, when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio [illegible] when concrete is hand compacted. In both cases when the water/cement ratio is below the practical limit the strength of concrete falls rapidly due to introduction of air voids.

→ The graph showing the relationship b/w the strength and water/cement ratio is approximately hyperbolic in shape. Sometimes it is difficult to interpolate the intermediate value.

Gel/space ratio:

-> Instead of relating the strength to w/c ratio, the strength can be more related to the solid products of hydration of cement to the space available for formation of this product.

-> Gel/space ratio is defined as the ratio of the volume of the hydrated cement space to the sum of the volumes of the hydrated cement and of the capillary pores.

-> Power experiment showed that the strength of concrete bear a specific relationship with the gel/space ratio. He found the relationship to be $240x^3$, where x is the gel/space ratio and 240 represents the intrinsic strength of gel in MPa for the type of cement and specimen used.

-> The relationship b/w the strength and water/cement ratio will hold good primarily for 28 days strength for fully compacted concrete. whereas the relationship b/w the strength and gel/space ratio is independent of age.

-> Gel space ratio can be calculated at any age and for any fraction of cement.

-> The following example show how to calculate gel/space ratio

Calculation of gel/space ratio for complete hydration:

C = weight of cement in gm

V_c = specific volume of cement = 0.319 ml/gm

W_o = volume of mixing water in (ml)

Assuming that 1 ml of cement on hydration will produce 2.06 ml of gel

Volume of gel = $C \times 0.319 \times 2.06$

Space available = $C \times 0.319 + W_o$

$\therefore$ Gel/space ratio = $\frac{\text{Vol. of gel}}{\text{space available}}$

$$x = \frac{0.657C}{0.319C + W_0}$$

Calculation of gel/space ratio for Partial hydration:

α = fraction of cement that has hydrated

Volume of gel = $C \times \alpha \times 0.319 \times 2.06$

Total space available = $C\, V_c \alpha + W_0$

$$\therefore \text{Gel/space ratio} = x = \frac{2.06 \times 0.319 \times C\alpha}{0.319\, C\alpha + W_0} = \frac{0.657C\alpha}{0.319C\alpha + W_0}$$

Ex:

Calculate the Gel/space ratio and the theoretical strength of a sample of concrete made with 500gm of cement with 0.5 W/C ratio, on fully hydration & at 60% hydration.

Ans:

$$\text{Gel/space ratio} = \frac{0.657C}{0.319C + W_0} \qquad \left[\begin{array}{l} W_0 = 0.5 \times 500 \\ W_0 = 250 \end{array}\right]$$

$$x = \frac{0.657 \times 500}{0.319 \times 500 + 250}$$

$$x = 0.8$$

$\therefore$ Theoretical strength of concrete $= 240 \times (0.8)^3$

$= 123$ MPa.

Gel/space ratio for 60% hydration $\quad \alpha = 0.6$

$$x = \frac{0.657C\alpha}{0.319C\alpha + W_0}$$

$$x = \frac{0.657 \times 500 \times 0.6}{0.319 \times 500 \times 0.6 + 250}$$

$$x = 0.57$$

$\therefore$ Theoretical strength of concrete $= 240 \times (0.57)^3$

$= 44.4$ MPa.

Maturity concept of concrete:

→ strength development of concrete depends on both time and temperature. It can be said that strength is a function of summation of product of time and temperature. This summation is called maturity of concrete.

$$\therefore \text{Maturity} = \Sigma(\text{time} \times \text{temp})$$

→ The datum line for computing maturity is −11°C.

→ maturity is measured in °CH (or) °C (Degree centigrade)

→ A sample of concrete cured at 18°C for 28 days taken a fully matured concrete.

$$\text{Maturity} = 28 \times 24 \times (18 - (-11°))$$
$$= 19488°Ch.$$

→ In standard calculations the maturity of fully cured concrete is taken as 19,800°Ch.

→ Maturity concept is useful for estimating the strength of concrete at any other maturity as a percentage of strength of concrete of known maturity.

Strength at any maturity as a % of strength of maturity

$$19{,}800\,°Ch = A + B\log_{10}\frac{(\text{maturity})}{10^3}$$

Plowman's coefficient for maturity Eqn.

Strength after 28 days at 18°C (MPa)	Coefficient	
	A	B
< 17.5	10	68
17.5 − 35.0	21	61
35.0 − 52.5	32	54
52.5 − 70.0	42	46.5

Ex (1)

The strength of a sample of fully matured concrete is found to be 40 MPa. Find the strength of identical concrete at the age of 7 days when cured at an avg. temp. during day time at 20°C and night time 10°C.

Sol

Maturity of concrete at 7 days $= \Sigma(\text{time} \times \text{temp})$

$= 7 \times 12 \times (20-(-11)) + 7 \times 12 \times (10-(-11))$

$= 4368\ ^\circ C\,h$

∴ Strength range of this concrete falls in zone III

∴ $A = 32$, $B = 54$.

% strength of concrete

maturity of 4368°Ch $= A + B \log_{10} \frac{(\text{maturity})}{10^3}$

$= 32 + 54 \log_{10} \frac{(4368)}{10^3}$

$= 66.5\ \%$

∴ strength at 7 days $= 40 \times \frac{66.5}{100}$

$= 26.5$ MPa.

Ex 2 Laboratory experiments conducted at Pune on a particular mix showed a strength of 32.5 MPa for fully matured concrete. Find whether formwork can be removed for an identical concrete placed at Srinagar at the age 15 days when the avg temp. is 5°C. The concrete is likely to subjected stripping stress of 25 MPa.

Sol

maturity of concrete at 15 days $= 15 \times 24 \times (5-(-11))$

$= 5760\ ^\circ C\,h$

concrete falls in $A = 21$, $B = 61$ zone II.

% strength of concrete $= 21 + 61 \log_{10} \frac{(5760)}{10^3}$

$= 67.38\ \%$

∴ strength at 15 days $= 32.5 \times \frac{67.38}{100}$

$= 21.9$ MPa.

Nature of strength of concrete:

→ The paramount influence of voids in concrete on its strength has been repeatedly mentioned and it should be possible to relate this factor to the actual mechanism of failure.
→ For this purpose concrete is considered to be a brittle material even though it exhibits a small amount of plastic action as fracture under static loading takes place at moderately low total strain
→ a strain of 0.001 to 0.005 at failure has been suggested as the limit of brittle behavior.
→ High strength concrete is more brittle than normal strength concrete but there is no quantitative method of expressing the brittleness of concrete whose behavior in practice falls b/w the brittle and the ductile types.

Fracture & failure:

→ Concrete specimens subjected to any state of stress can support loads of upto 40-60% of ultimate without any apparent signs of distress.
→ Below this level any sustained load results in creep strain which is proportional to the applied stress and can be defined in terms of specific creep. Also concrete is below the fatigue limit.
→ Also the load increased above this level soft but distinct noises of internal disruption can be heard until about 70-90% of ultimate small fissures (or) cracks appear on the surface. At this stage sustained loads result in eventual failure.

Strength in Hardened Concrete:

1) Compressive Strength:

→ It is tested in a standard manner which includes full compaction and wet curing for a specified period give results representing the potential quality of the concrete.

→ There are three types of loading in compression test.

i) Uniaxial loading
ii) Biaxial loading
iii) Triaxial loading

→ The uniaxial loading case represents the most conservative system and yields the lowest values in compression.

→ There are three types of failure in compression test.

i) Tension failure (splitting)
ii) Shear failure (sliding)
iii) Combined failure (tension & shear)

2) Tension Strength:

→ Although concrete is not normally designed to resist direct tension the knowledge of tensile strength is of value in estimate the load under which cracking will develop.

→ The absence of cracking is considerable importance in maintaining the continuity of a concrete structure and in many cases in the prevention of corrosion of reinforcement.

→ There are two types of test for strength in tension test.

i.e. i) Direct tension test ii) Splitting tensile strength test

Relation B/w compressive and tensile strength:

→ In Reinforced concrete construction the strength of the concrete in compression is only taken into consideration.

→ The tensile strength of concrete is generally not taken into consideration But the design of concrete pavement slab is often based on the flexural strength of concrete.

→ As measurements and control of compressive strength in field are easier and more convinient, it has been customary to find out the compressive strength for different conditions and to correlate this compressive strength to flexural strength.

→ It is seen that strength of concrete in compression and tension are closely related, but the relationship is not the type of direct proportionality.

→ The two ratios of the strength depends on general level of strength of concrete. For higher compressive strength concrete shows higher tensile strength, but the ratio of increase of tensile strength is of decreasing order.

→ The type of coarse aggregate influences this relationship. Crushed aggregate gives relatively higher flexural strength than compressive strength.

→ The tensile strength of concrete as compared to its compressive strength is more sensitive to improper curing.

→ The use of pozzolanic material increases the tensile strength of concrete.

→ Following statical relation b/w tensile and compressive strength

i) $Y = 15.3X - 9.00$ for 20mm max. size aggregate.

ii) $Y = 14.1X - 10.4$ for 20mm max. size natural gravel

iii) $Y = 9.9X - 0.55$ for 40mm max. size crushed aggregate

iv) $Y = 9.9X - 2.52$ for 40mm max. size natural gravel

where, Y = compressive strength of concrete (MPa)

X = flexural strength of concrete (MPa)

→ There are number of empirical relationship b/w tensile strength and compressive strength of concrete.

Tensile strength = K (compressive strength)^n

K = 6.2 for gravels

K = 10.4 crushed rock

n = 1/2 to 3/4

→ Indian standard IS 456-2000 gives the following relationship b/w the compressive strength and flexural strength

$$\text{flexural strength} = 0.7\sqrt{fck}$$

fck = characteristic compressive strength of concrete in N/mm².

CURING:—

→ The test specimens are stored in place free from vibration, in moist air of at least 90% relative humidity and at a temp. of 27° ± 2°C for 24 hours ± 1/2 hour from the time of addition of water to the dry ingredients.

→ After this period the specimen are marked and removed from the moulds and unless required for test within 24 hours, immediately submerged in clean fresh water (or saturated lime solution and kept there until taken out just prior to test.

→ The water and/or solution in which the specimen are submerged, are renewed every seven days and are maintained at a temp. of 27°C ± 2°C. The specimens are not to be allowed to become dry at any time until they have been tested.

FLEXURAL STRENGTH OF CONCRETE :

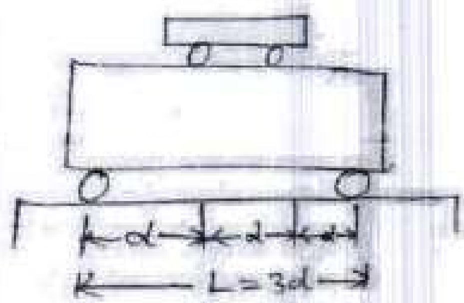
-> Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little independence is placed on the tensile strength of concrete.

Determination of Tensile strength :

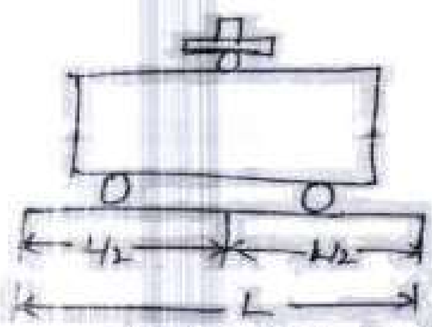
-> Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the pull applied to the concrete.

-> The value of the modulus of rupture depends on the dimension of the beam and manner of loading. The system of loading used in finding out the flexural tension are central point loading and third point loading.

-> In central point loading maximum fibre stress will come below the point of loading where the bending moment is maximum. In case of symmetrical two point loading the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum.



Third - point loading



Centre - point loading.

-> The standard size of specimen are 15×15×70 cm. Alternatively if the largest nominal size of the aggregate does not exceed 20 mm, specimen 10×10×50 cm may be used.

SPLIT TENSILE TEST :

→ This is also called as cylinder splitting tension test (or) "Brazilian test"

→ This test is carried out by placing cylindrical specimen horizontally between the loading surface of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter.

→ When the load is applied along the generatrix an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress of.

$$\frac{2P}{\pi L D}\left[\frac{D^2}{r(D-r)}-1\right]$$

and a horizontal stress of

$$\frac{2P}{\pi L D}$$

P = compressive load
L = length of cylinder
D = diameter.

→ The loading condition produces a high compressive stress immediately below the two generators to which the load is applied. but the larger portion corresponding to depth is subjected to a uniform tensile stress acting horizontally. It is estimated that the compressive stress is acting for about 1/6 depth and remaining 5/6 depth is subjected to tension.

→ In order to reduce the magnitude of the high compression stresses near the points of application of the load, narrow packing strips of suitable material such as plywood are placed b/w the specimen and loading platens of the testing machine. The packing strips should be soft enough to allow distribution of load over a reasonable area, yet narrow and thin enough to prevent large contact area. Normally a plywood strip of 25mm wide, 3mm thick, 30cm long used.

→ The main advantage of this method is that same type of specimen and the same testing machine as are used for the compression test

→ The splitting test is simple to perform and gives more uniform results than other tension tests.

Principal
[illegible]

NON-DESTRUCTIVE TESTING METHODS:

→ In this method as now a powerful method for evaluating existing concrete structures with regard their strength and durability apart from assessment and control of quality of hardened concrete.

→ Though non-destructive testing methods are relatively simple to perform the analysis and interpretation of test results are not so easy. The special knowledge is required to analyse the hardened properties of concrete.

NDT METHODS

1) Schmidt's Rebound hammer
2) Penetration techniques
3) Pullout test
4) Dynamic(or) vibration methods
5) Pulse velocity method.
6) Radioactive & nuclear methods
7) Magnetic & electrical methods

1) Schmidt's Rebound hammer:

→ It is one of the most commonly adopted equipments for measuring the surface hardness.

→ It consist of a spring control hammer that slides on a plunger within a tubular housing. when the plunger is pressed against the surface of concrete, the mass rebound from the plunger. It retracts against the force of the spring.

→ The hammer impacts against the concrete and the spring control mass rebounds, taking the rider with it along the guide scale.

→ The distance travelled by the mass is called the rebound number. It is indicated by the rider moving along a graduated

→ The test was conducted by horizontally, vertically upwards (or) downwards (or) at any intermediate angle.

→ At each angle the rebound number will be different for the same concrete and will require seperate calibration (or) correction chart.

Limitations:

* smoothness of surface under test
* size, shape & rigidity of specimen.
* Age of specimen
* Surface and internal moisture condition of concrete.
* type of coarse aggregate.
* type of cement
* type of mould
* carbonation of concrete surface.

2) Penetration techniques

→ The measurement of hardness by probing techniques was first reported during 1954. Two techniques were used.

→ In one case a hammer known as "simbi" was used to perforate concrete and the depth of borehole was correlated to compressive strength of concrete cubes.

→ In other technique the probing of concrete was achieved by blasting with spit pins and the depth of penetration of the pins was correlated with compressive strength of concrete.

→ The accuracy of this test was found to be ± 15%. However it is further seen that 'simbi' and 'spit pins' were more effected by the arrangement of coarse aggregate, than the tests using rebound hammers.

3) Pullout test:

-> A pullout test measures the force required to pull out from the concrete a specially shaped rod whose enlarged end has been cast into that concrete.

-> The stronger the concrete the more is the force required to pullout. The ideal way to use pullout test in the field would be to incorporate assemblies in the structure.

-> This standard specimen could then be pulled out at any point of time.

-> The force required denotes the strength of concrete. Another way to use pullout test in the field would be to cast one (or) two big blocks of concrete incorporating pullout assemblies.

-> Pullout test could then be performed to assess the strength of concrete.

4) Dynamic (or) Vibration method:

-> This is the important non destructive method in testing concrete strength and other properties.

-> The fundamental principle on which the dynamic (or) vibration methods are based is velocity of sound through a material.

-> A mathematical relationship could be established b/w the velocity of sound through specimen and its resonant frequency and the relationship of these two to the modulus of elasticity of the material.

-> The relationship which are derived for solid mediums considered to be homogeneous, isotropic and perfectly elastic but they may be applied to heterogeneous materials like concrete.

-> The velocity of sound in a solid can be measured by determining the resonant frequency of specimen (or) by recording the time of travel of short pulses of vibration passing through the samples.

-> In NDT of concrete either resonance method (or) pulse velocity techniques could be adopted.

5) Pulse velocity method :

-> This can be of two methods

i) mechanical sonic pulse velocity

ii) ultrasonic pulse velocity.

i) Mechanical sonic pulse velocity:

-> out of these two ultrasonic pulse velocity method has gained considerable popularity all over the world.

-> when mechanical impulses are applied to a solid mass, three different kinds of waves are generated.

-> These are generally known as longitudinal waves, shear waves and surface waves. These three waves travel at different speeds.

-> The longitudinal (or) compressional waves travel about twice as fast as the other two types. Shear (or) transverse waves are not so fast, the surface waves are the slowest.

-> The pulses can be generated either by hammer blows (or) by the use of an electro acoustic transducer. Electro acoustic transducers are preferred as they provide better control on the type and frequency of pulses generated. The instrument used is called "Sonic scope".

ii) Ultrasonic pulse velocity:

-> This method consist of measuring the time of travel of an ultrasonic pulse, passing through the concrete to be tested. The pulse generator circuit consists of electronic circuit for generating pulses and a transducers for transforming these electronic pulses into mechanical energy having vibration frequencies in the range of 15 to 50 kHz.

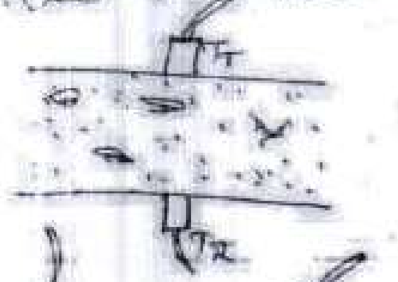
-> The time of travel b/w initial onset and the reception of the pulses is measured electronically. The path length b/w transducer divided by the time of travel gives the avg velocity of wave propagation.

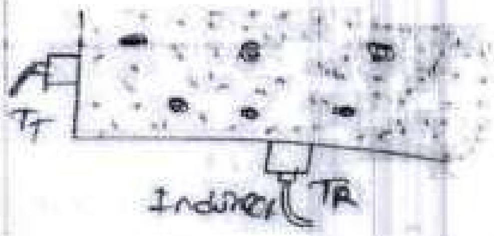
Techniques of measuring pulse velocity through concrete:

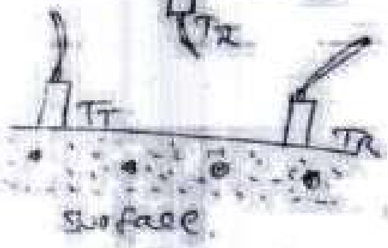
a) Direct transmission

b) Indirect transmission

c) Surface transmission







$T_T = T_R$ = Transducer transmits.

Factors affecting the measurement of pulse velocity:

→ The measurement of pulse velocity is affected by a number of factors regardless of the properties of concrete.

i) Smoothness of contact surface under test.

ii) Influence of path length on pulse velocity.

iii) Temperature of concrete.

iv) Moisture condition of concrete.

v) Presence of reinforcing steel.

b) Radioactive & nuclear methods:

i)

→ The use of X-ray and gamma rays as nondestructive method for testing properties of concrete is relatively new. X-ray and γ-ray both components of high energy region on the electromagnetic spectrum penetrate concrete but undergo attenuation in the process.

→ The degree of attenuation depends on the kind of matter traversed its thickness and the wavelength of the radiation.

→ The intensity of incident γ-rays and the emerging γ-rays after passing through the specimens are measured these two values use for calculating densities of structural members in place.

γ-rays transmission method has been used to measure the thickness and of concrete slabs of known density. γ-radiation sources of known intensity is made to pass and penetrate through the concrete. The intensity at the other face is measured to which thickness of the concrete is calculated.

ii) → Use of nuclear methods for non destructive measurement of some properties of concrete is of recent reason.

→ The techniques have been reported. neutron neutron scattering method for determining the moisture content of concrete and neutron activation analysis for the determination of cement content. these methods are not suitable for finding out the strength of concrete.

7) Magnetic & Electrical Method:

i) → Battery operated magnetic devices that can measure the depth of reinforcement cover in concrete and detect the position of reinforcement bars are now available. The apparatus is known as cover meter.

ii) → Electrical resistivity methods have been used to find out the thickness of concrete pavements.

→ The method is based on the principle that the material offers resistance to the passage of an electric current.

→ A concrete pavement has resistivity characteristic that is different from that of the underlying subgrade layers.

→ A change in the slope of the resistivity (vs) depth curve is used to estimate the depth of concrete pavement.

MODULUS OF ELASTICITY :

→ The stress in steel is 'm' times the stress in concrete. where 'm' is the ratio b/w the modulus of elasticity of steel and concrete. known as modular ratio.

→ The modulus of elasticity can also be determined by subjecting a concrete cube (or cylinder specimen to uniaxial compression and measuring the deformation by means of dial gauges fixed b/w the certain gauge length.

→ Total gauge reading divided by gauge length will give the strain and load applied divided by area of cross section will give the stress

→ The modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formulae for deflection and substituting other parameters. The modulus of elasticity so found out from actual loading is called static modulus of elasticity.

→ Modulus of elasticity may be measured in tension, compression (or) shear.

→ The modulus in tension is equal to modulus in compression.

→ Modulus of elasticity of concrete increases approximately with the square root of the strength.

modulus of Elasticity is $E_c = 5000\sqrt{f_{ck}}$.

→ The modulus of elasticity of light weight concrete is usually between 40 to 80% of the modulus of elasticity of ordinary concrete of the same strength.

→ The relation b/w the modulus of elasticity and strength is not much effected by temperature upto about 230°C since both the properties vary with temperature in approximately the same manner. steam cured concrete shows a slightly lower modulus than water-cured concrete of the same strength.

DYNAMIC MODULUS OF ELASTICITY:

→ The value of E is found out by actual loading of concrete. The value of E is found out by actual loading doesnot truly represent i.e. the static modulus of elasticity doesnot truly represent the elastic behaviour of concrete due to the phenomenon of creep. The elastic modulus of elasticity will get affected more seriously at higher stresses when the effect of creep is more pronounced.

→ The modulus of elasticity can be determined by subjecting the concrete member to longitudinal vibration at their natural frequency.

→ Modulus of elasticity can be calculated from the following relationship

$$E_d = Kn^2L^2\rho$$

E_d = Dynamic modulus of elasticity

K = constant

n = resonant frequency.

L = length of specimen.

ρ = density of concrete.

$$E_d = 4\times10^{-5}\, n^2L^2\rho \text{ GPa.}$$

→ The value of E found out in this method by the velocity of sound (or) frequency of sound is referred as dynamic modulus of elasticity, in contrast to the value of E found out by actual loading of the specimen and from stress-strain relationship which is known as static modulus of elasticity.

→ The value of dynamic modulus of elasticity computed from ultrasonic pulse velocity method is somewhat higher than those determined by static method.

→ This is because the modulus of elasticity as determined by dynamic modulus is unaffected by creep. The creep also doesnot significantly effect the initial tangent modulus in the static method.

→ The value of dynamic modulus and the value of initial tangent modulus to be more (or) less agree with each other. Approximate relationship b/w the two moduli expressed in CP/110 is given by

$$E_c = 1.25\, E_d - 19$$

E_c & E_d are static and dynamic modulus of elasticity

→ For light weight concrete the relationship is

$$E_c = 1.04\, E_d - 4.1$$

poisson's Ratio:

→ poissons ratio is the ratio b/w lateral strain to the longitudinal strain. It is denoted by 'μ'

→ For normal concrete μ = 0.15 to 0.20

→ poissons ratio can be determined from ultrasonic pulse velocity method and by finding out the fundamental resonant frequency of longitudinal vibration of concrete beam.

$$\left(\frac{V}{2nL}\right)^2 = \frac{1-\mu}{(1+\mu)(1-2\mu)}$$

V = pulse velocity

n = resonant frequency

L = length of beam

μ = 0.2 to 0.24

→ Dynamic modulus of elasticity can also be found out from following eqn.

$$E_d = \rho V^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

V = pulse velocity

ρ = density

μ = poissons ratio.

CREEP:

→ Creep can be defined as the "time-dependent" part of the strain resulting from stress.

→ The gradual increase in strain, without increase in stress, with the time is due to creep. From this explanation creep can also be defined as the increase in strain under a static stress.

→ Creep of concrete is approximately linear function of stress upto 30 to 40% of its strength.

Measurement of creep:

→ Creep is usually determined by measuring the change with time in the strain of specimen subjected to constant stress and stored under appropriate condition.

→ It is generally assumed that the creep continues to assume a limiting value after an infinite time under load. It is estimated that 26% of the 20 year creep occurs in 2 weeks. 55% of 20 year creep occurs in 3 months and 76% of 20 year creep occurs in one year.

→ If creep after one year is taken as unity, then the avg value of creep at later ages are.

1.14 after 2 years
1.20 after 5 years
1.26 after 10 years
1.30 after 20 years
1.36 after 30 years.

→ The relation b/w creep (C) and time (t) is

$$C = \frac{t}{a + bt}$$

$$a = 1/C$$

FACTORS AFFECTING CREEP

i) Influence of aggregate:

→ Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However the aggregates influences the creep of concrete through a restraining effect on the magnitude of creep.

→ The grading, the shape, the maximum size of aggregate have been suggested as factors affecting creep.

→ The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep.

ii) Influence of mix proportion:

→ The amount of paste content and its quality is one of the most important factors influencing creep.

→ A poorer paste content structure undergoes higher creep. Therefore it can be said that creep increases in water/cement ratio.

→ In other words creep is inversely proportional to strength of concrete.

iii) Influence of Age:

→ Age at which concrete members is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more.

iv) Effects of Creep:

→ magnitude of creep is depending on many factors the main factors being time and level of stress. In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.

SHRINKAGE:

→ The volume change on account of inherent properties of concrete is known as "shrinkage".

→ One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements due to the shrinkage.

→ It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude.

TYPES OF SHRINKAGE:

1) Plastic shrinkage
2) Drying shrinkage
3) Autogeneous shrinkage
4) Carbonation shrinkage.

1) plastic shrinkage:

→ Loss of water by evaporation from the surface of concrete (or) by the absorption by aggregate (or) subgrade is believed to be the reason of plastic shrinkage

→ The loss of water results in the reduction volume. The aggregate particles (or) the reinforcement comes in the way of subsidence due to which cracks may appear at the surface (or) internally around the aggregate (or) reinforcement.

→ In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind the surface of concrete dries very fast which results in plastic shrinkage.

→ Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation

→ Monomolecular coatings by fog spray that keeps the surface moist.

→ Working at night an effective method of reducing shrinkage.

2) Drying shrinkage:

-> The drying shrinkage is also an ever lasting process when concrete is subjected to drying conditions.

-> The drying shrinkage of the concrete is analogous to the mechanism of drying of timber specimen. The loss of water contained in hardened concrete, does not result in any appreciable dimension change.

-> Cement paste shrinks more than mortar and mortar shrinks more than concrete.

-> The rate of shrinkage decreases rapidly with time. It is observed that 14-34% of the 20 years shrinkage occurs in 2 weeks, 40-80% of the 20 year shrinkage occurs in 3 months, 66-85% of the 20 year shrinkage occurs in one year.

-> The volume fraction of aggregate will have some influence on the total shrinkage. The ratio of shrinkage of concrete (Sc) to shrinkage of neat paste (Sp) depends on the aggregate content in the concrete.

$$S_c = S_p (1-a)^n$$

$$n = 1.2 \text{ \& } 1.7$$

-> The property of swelling when placed in wet condition and shrinking when placed in drying condition is refered as moisture movement in concrete.

3) Autogeneous shrinkage:

-> In a conservative system i.e where no moisture movement to (or) from the paste is permitted when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage.

-> Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of concrete dam.

-> The magnitude of autogeneous shrinkage is 100×10^{-6}.

4) Carbonation Shrinkage

→ Carbonation shrinkage is a phenomenon very recently recognised. Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement.

→ Calcium hydroxide ($Ca(OH)_2$) gets converted to calcium carbonate ($CaCO_3$) and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete only very slowly.

→ The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium.

→ Carbonation of concrete also results in increased strength and reduced permeability.

UNIT-IV

MIX DESIGN

FACTORS AFFECTING THE CHOICE OF MIX PROPORTIONS:

1) Compressive strength
2) Workability
3) Durability
4) Max. nominal size of aggregate
5) Fineness modulus & zone of aggregate
6) Quality control

① Compressive strength:

→ The compressive strength of any material is defined as the resistance to failure under the action of compressive forces. Especially for concrete, compressive strength is an important parameter to determine the performance of the material during service conditions.

→ Concrete mix can be designated (or proportioned) to obtain the required engineering and durability properties as required by the design engineer.

→ Some of the other engineering properties of hardened concrete include elastic modulus, tensile strength, creep co-efficient, density, co-efficient of thermal expansion etc.

Compressive strength of concrete:

→ Concrete specimens are cast and tested under the action of compressive loads to determine the strength of concrete

→ Compressive strength is calculated by dividing the failure load with the area of application load, usually after 28 days of curing.

→ The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water and various admixtures.

→ The ratio of the water to cement is the chief factor for determining concrete strength. The lower the water-cement ratio the higher is the compressive strength.

→ In normal field the concrete strength can vary from 10MPa to 60MPa.

→ For structural the concrete mixes can be designed to obtain very high compressive strength capacity in the range of 500MPa.

→ The compressive strength of concrete is given in terms of the characteristic compressive strength of 150mm size cubes tested at 28 days.

→ The characteristic strength is defined as the strength of the concrete below which not more than 5% of the test results are expected to fall.

PROCEDURE:

→ Specimen stored in water shall be tested immediately on removal from the water and while they are still in the wet condition.

→ Take the dimension of the specimen to the nearest 0.2m.

→ Clean the bearing surface of the testing machine.

→ Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the specimen.

→ Apply the load gradually without shock & continuously at the rate of 40 kg/cm²/min till the specimen fails.

→ Record the max. load and note any unusual features in the type of failure.

2) Workability of Concrete:

→ Workability represents consistency and cohesiveness of concrete.

General consideration for workability

i) Water content:

→ The higher the water content, the higher will be the fluidity of concrete, which is one of the important factors affecting workability.

ii) Aggregate/cement ratio:

→ The higher the a/c ratio, the leaner is the concrete.

→ In lean concrete, less quantity of paste is available for lubrication per unit surface area of aggregate and hence the mobility reduce.

→ In case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

iii) Size of aggregate:

→ The bigger the size of aggregate, the less the surface area hence, less water is required for wetting the surface and paste is required for lubricating the surface to reduce internal friction.

→ For a given quantity of water and paste bigger size of aggregate will give higher workability.

iv) Shape of aggregate:

→ Angular, elongated (or) flaky aggregate makes the concrete very harsh when compared to rounded aggregate (or) cubical shaped aggregates.

→ Being round in shape the frictional resistance is also greatly reduced.

v) Surface texture:

→ Total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume.

→ Rough textured aggregate will show poor workability and smooth (or) glassy textured aggregate will give better workability.

vi) Grading of aggregates:

→ Better the grading, the less is the void content and higher the workability.

→ When the total voids are less, excess paste is available to give better lubricating effect

vii) Use of Admixtures:

→ Use of air entraining agent being surface-active reduces the internal friction between the particles.

→ Plasticizers and super-plasticizers greatly improve the workability many folds.

3) Durability of concrete:

→ Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

→ It is normally refers to the duration of life span of trouble free performance.

Concrete will remain durable if:

→ The cement paste structure is dense and of low permeability

→ Under extreme condition, it has entrained air to resist freeze-thaw cycle.

→ It is made with graded aggregate that are strong and inert

→ The ingredients in the mix contain minimum impurities such as alkalis, chlorides, sulphates and silt.

Factors affecting Durability:

i) Cement content:

→ Mix must be designed to ensure cohesion and prevent segregation and bleeding. If cement is reduced, then at fixed w/c ratio the workability will be reduced leading to inadequate compaction

→ However if water is added to improve workability, water cement ratio increases and results in highly permeable material.

ii) Compaction:

→ The concrete as a whole contain voids can be caused by inadequate compaction. Usually this being governed by compaction equipments used type of formwork, and density of the steel work.

iii) Curing:

→ It is very important to permit proper strength development and moisture retention and to ensure hydration process occur completely.

iv) Cover:

→ Thickness of concrete cover must follow the limits set in codes.

v) Permeability:

→ The higher permeability usually caused by higher porosity

→ A proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete.

Types of Durability of Concrete:

1. Physical durability
2. Chemical durability

1. Physical durability:

→ Freezing and thawing action
→ percolation / permeability of water
→ temperatures stresses.

2. Chemical durability:

→ Alkali aggregate Reaction.
→ Sulphate Attack
→ Chloride Ingress
→ Corrosion of reinforcement.

Causes of durability

1. External causes
2. Internal causes

1. External causes

-> Extreme weathering conditions
-> Extreme temperature.
-> Extreme humidity
-> Abrasion
-> Electrolytic action.

2. Internal causes

-> Physical -> Frost action
-> Chemical -> Alkali aggregate reaction and
corrosion of steel.

4) Max. nominal size of coarse aggregate:

-> The max. nominal size of the coarse aggregate is determined by sieve analysis and is designated by the sieve size higher than the largest size on which 15% or more of the aggregate is retained.

-> The max. nominal size of the aggregate to be used in concrete is governed by the size of the section and spacing of the reinforcement.

-> According to IS:456-2000 and IS:1343-1980, the maximum nominal size of the aggregate should not be more than 1/4th of the max. thickness of the member, and it should be restricted to 5mm less than min. clear distance b/w main bars or 5mm not less than min. clear cover to the reinforcement.

-> The nominal max. size of aggregate, should as large as possible, because more the max. size of the aggregate, smaller is the cement requirement for a particular water/cement ratio.

-> The workability also increases increase in max. size aggregate

→ For the concrete with higher w/c ratio the larger max size of aggregate may be beneficial whereas for high strength concrete 10-20MM size of aggregate is preferable. 7.

5) Quality control:-

→ The strength of concrete varies from batch to batch over a period of time.

→ The source of variability in the strength of concrete may be considered due to variation in the quality of the constituent materials, variations in mix proportions due to batching process, variations in the quality of batching and mixing equipment available, the quality of supervision and workmanship.

→ Controlling the variation is important in lowering the difference b/w minimum strength and characteristic mean strength of the mix and hence reducing the cement content. The factor controlling the difference is quality control.

→ The degree of control is ultimately evaluated by the variation in test results usually expressed in terms of "co-efficient of variation"

→ Most of the mix design procedures are primarily based on the water-cement ratio law and absolute volume system of calculating the amount of materials.

→ According to Abram's law, the strength of fully compacted hardened concrete is approximately inversely proportional to the water content per cubic meter of concrete.

$$\text{Absolute volume} = \frac{\text{Mass of loose dry material}}{\text{Sp. gravity} \times \text{mass of unit of volume of water}}$$

Statical Quality control of concrete:-

-> The aim of Quality control is to limit the variability as much as practicable. Statical quality control method provides a scientific approach to the concrete designer to understand the realistic variability of the materials so as to lay down design specifications with proper tolerance to cater for unavoidable variations.

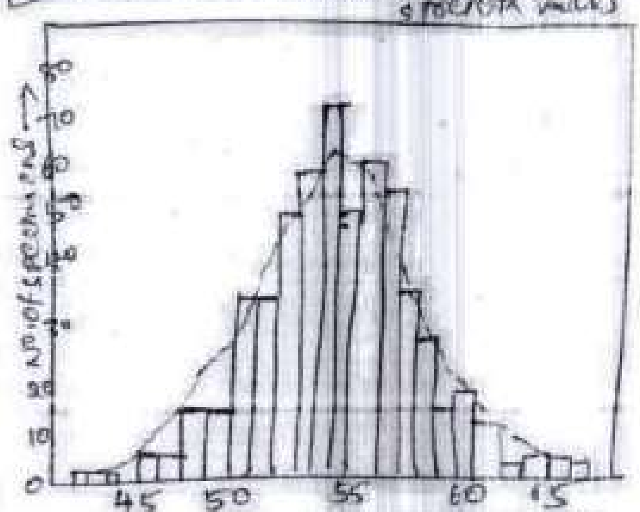
-> The acceptance criteria are based on statical evaluation on the test result of samples taken at random during execution.

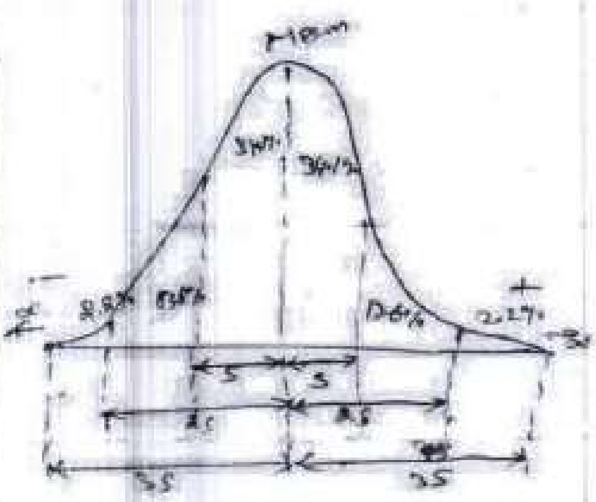
-> The method provides a scientific basis of acceptance which is not only realistic but also restrictive as required by the design requirements for the concrete construction.

-> The quality of concrete will be of immense value for large contracts where the specifications insist on certain minimum requirements. The effort put in will be more than repaid by resulting savings in the overall concreting operations.

-> The compressive strength test cubes from random sampling of a mix exhibit variations, which are inherent in the various operations involved in the making and testing of concrete.

Histogram of strength values





→ If a number of cube test results are plotted on histogram, the results are found to follow a bell shaped curve known as 'normal distribution curve'.

→ The results are said to follow a normal distribution curve about the mean value and if the if they are equally spaced about the mean value and if the largest number of the cubes have a strength closer to the mean value, i.e the largest pair and very few number of results with much greater (or) less value than the mean value.

→ The arithmatic mean (or) the average value of the number of test result gives no indication of the extent of variation of strength. This can be ascertained by relating the individual strength to mean strength and determining the variation from the mean with the help of the properties of normal distribution curve.

Common terminologies:

i) Mean strength:

→ The avg strength obtained by dividing the sum of strength of all the cubes by the number of cubes

$$\bar{x} = \frac{\Sigma x}{n}$$

ii) Variance:

→ This is the measure of variability (or) difference b/w any single observed data from the mean strength.

iii) Standard deviation:

→ This is the root mean square deviation of all the results. (σ)

$$\sigma = \sqrt{\frac{\Sigma (x-\bar{x})^2}{n-1}}$$

iv) Co-efficient of variation:

→ It is an alternative method of expressing the variation of results. This non dimensional measure of variation obtained by dividing the standard deviation by the arithmatic mean.

$$V = \frac{\sigma}{\bar{x}} \times 100$$

Various methods of proportioning mix design

1) Arbitrary proportion
2) Fineness modulus method.
3) Maximum density method
4) Surface area method.
5) Indian Road congress, IRC 44 method.
6) High strength concrete mix design.
7) Mix design based on flexural strength.
8) Road note No 4.
9) ACI committee 211 method.
10) DOE method.
11) Mix design for pumpable concrete.
12) Indian standard recommended method IS 10262-82

→ Out of the above methods, some of them are not very widely used these days because of some difficulties (or) drawbacks in the procedures for arriving at the satisfactory proportions.

→ The ACI committee 211 method, the DOE method and Indian standard recommended methods are commonly used.

→ Since concrete is very commonly placed by pumping these days method of mix design of pumpable concrete has become important.

→ Before we deal with some of the important methods of concrete mix design, it is necessary to get acquainted with statistical quality control methods, which are common to all the methods of mix design.

PROCEDURE FOR CONCRETE [illegible]

1. Determine the mean target strength (f_t) from the specified characteristic compressive strength at 28 days fck and the level of quality control.

$$f_t = f_{ck} + 1.65 S$$

S = standard deviation.

2. Obtain the water cement ratio for the desired mean target using the empirical relationship b/w compressive strength and water cement ratio so chosen is checked against the limiting w/c ratio.

3. Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.

4. Select the water content for the required workability and maximum size of aggregates from table.

5. Determine the % of fine aggregates in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.

6. Adjust the value of water content and % of sand as provided in the table for any difference in workability water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

7. Calculate the cement content from the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability and greater of the two values is adopted.

8. From the quantities of [illegible] of concrete and the % of sand already determined in step 6 and step 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relation,

$$V = \left[W + \frac{C}{S_c} + \frac{1}{P} \frac{f_a}{S_{fa}} \right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-P} \cdot \frac{C_a}{S_{ca}} \right] \times \frac{1}{1000}$$

V = absolute volume of concrete = gross volume (m³) − volume of entrapped air

S_c = sp. gravity of cement

W = mass of water per cubic metre of concrete, kg.

C = mass of cement per cubic metre of concrete, kg

P = ratio of fine aggregate to total aggregate by absolute volume.

C_a = total masses of fine and coarse aggregate [illegible]

S_{fa}, S_{ca} = sp. gravities of saturated surface dry fine and coarse aggregates.

9. Determine the concrete mix proportions for the first trial mix.

10. Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28 days moist curing and check for the strength.

11. Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

PROBLEMS

Q). CONCRETE MIX DESIGN - M50 GRADE CONCRETE

Grade Designation = M50
Type of cement = OPC-43 Grade
Brand of cement = UltraTech
Admixture = silica
Fine aggregate = zone-II

SP. GRAVITY

cement = 3.15
fine aggregate = 2.61
C.A (20mm) = 2.65
C.A (10mm) = 2.66

Min. cement = 400 kg/m3
Max. water/cement Ratio = 0.45.

MIX CALCULATION:

1) TARGET MEAN STRENGTH:-

$f_t = f_{ck} + 1.65 S$

$f_t = 50 + (1.65 \times 5)$

$f_t = 58.25$ MPa.

2) W/C RATIO:-

(IS 10262-2009)

ASSUME W/C = 0.35

3) Calculation of water:-

Approximate water content for 20mm max. size of aggregate = 180 kg/m3 (table no.5, IS 10262)

As plasticizers is proposed we can reduce water content by 20%

100 - 20 = 80% = 0.8

water content = 180 × 0.8 = 144 kg/m3

Verification of cement content :-

W/C ratio = 0.35

Water content / m^3 of concrete = 144 kg

Cement content = $\frac{144}{0.35}$ = 411.4 kg/m^3

Cement content = 412 kg/m^3 (As per contract min.
cement content 400 kg/m^3)

Hence OK.

5) Calculation for C.A & F.A :-

Volume of concrete = 1 m^3

Volume of cement = $\frac{412}{(3.15 \times 1000)}$ = 0.1308 m^3

Volume of water = $\frac{144}{1 \times 1000}$ = 0.1440 m^3

Volume of admixture = $\frac{4.944}{(1.145 \times 1000)}$ = 0.0043 m^3

Total wt of materials except C.A = 0.1308 + 0.1440 + 0.0043
= 0.2791

Volume of CA & FA = 1 − 0.2791 = 0.7209 m^3.

Volume of FA = 0.7209 × 0.33 = 0.2379 m^3 (Assume
33% by volume of total aggregate)

Volume of CA = 0.7209 − 0.2379 = 0.4830 m^3.

Weight of FA = 0.2379 × 2.61 × 1000 = 1288.365 kg/m^3
= 620.91 kg/m^3

Say weight of CA = 1284 kg/m^3.

Principal

Considering 20mm : 10mm = 0.55 : 0.45

20mm = 706 kg

10mm = 578 kg.

Hence mix details / m3

Increasing cement, water, admixture by 2.5% for this operation.

Cement = 413 x 1.025 = 423 kg.

Water = 144 x 1.025 = 147.8 kg

F.A = 621 kg

C.A 20mm = 706 kg

C.A 10mm = 578 kg

Admixture = 1.2% by weight of cement = 5.064 kg.

Water : Cement : F.A : C.A = 0.35 : 1 : 1.472 : 3.043.

Observations from concrete mix design:-

A. Mix was cohesive & homogeneous

B. Slump = 120mm

C. No. of cube casted = 9 nos.

7 days avg compressive strength = 52.07 MPa

28 days avg compressive strength = 62.52 MPa.

UNIT-V

SPECIAL CONCRETE

LIGHT WEIGHT CONCRETE:

→ One of the disadvantages of conventional concrete is the high self weight of concrete.

→ Density of normal concrete is in the order of 2200 to 2600 kg/m³. This heavy self weight will make it to some extent an uneconomical structural material.

→ Attempts have been made in the past to reduce the self weight of concrete to increase the efficiency of concrete as a structural material.

→ The light weight concrete as we call is a concrete whose density varies from 300 to 1850 kg/m³.

→ There are many advantages of having low density. It helps in reduction of dead load, increases the progress of building, and lowers haulage and handling costs.

→ The weight of a building on the foundation is an important factor in design, particularly in the case of weak soil and tall structures.

→ In framed structures, the beams and columns have to carry load of floors and walls. This are made up of light-weight concrete it will result in considerable economy.

→ Another most important characteristic of light weight concrete is the relatively low thermal conductivity, a property which improves with decreasing density.

→ In extreme climatic conditions and also in case of buildings where air conditioning is to be installed, the use of light weight concrete with low thermal conductivity will be of considerable advantage from the point of view of thermal comforts and lower power consumption.

→ The adoption of light weight concrete gives an outlet for industrial wastes such as clinker, flyash, slag etc.

-> Basically there is only one method for making concrete light i.e by the inclusion of air in concrete.

i) By replacing the usual mineral aggregates by cellular porous (or) light weight aggregate.

ii) By introducing gas (or) air bubbles in mortar. This is known as aerated concrete.

iii) By omitting sand fraction from the aggregate. This is called no-fines concrete.

-> A particular type of light-weight concrete called structural light weight concrete is one which is comparatively lighter than conventional concrete but at the same time strong enough to be used for structural purpose.

LIGHT WEIGHT AGGREGATE CONCRETE:

-> Very often light-weight concrete is made by the use of light weight aggregates. We have seen that different light-weight aggregates have different densities.

-> Naturally when this aggregate used, concrete of different densities are obtained. By using expanded perlite (or) vermiculite, a concrete of density as low as 300 kg/m3 can be produced, and by the use of expanded slag, sintered fly ash, bloated clay etc. a concrete of density 1900 kg/m3 can be obtained.

-> The strength of the light weight concrete may also vary from about 0.3N/mm² to 40N/mm². A cement content of 200kg/m³ to about 500 kg/m3 may be used.

-> Strength of light weight concrete depends on the density of concrete. Less porous aggregates which is more heavier in weight produces stronger concrete particularly with higher cement content.

-> The grading of aggregate, the water/cement ratio, the degree of compaction also effect the strength of concrete.

-> Most of the light-weight aggregate with the exception of bloated clay and sintered fly ash are angular in shape and rough in texture they produce harsh mix.

-> The strength of aggregate will also be influenced by the type of fine aggregates. For increasing the strength, for improving the workability and for reducing the water requirement, sometimes natural sand is used instead of crushed sand made out of light-weight aggregate.

-> Most of the light weight aggregates have a high and rapid absorption quality. This is one of the important difficulties in applying the normal mix design procedure to the light weight concrete.

-> Light weight concrete being comparatively porous when used for reinforced concrete, reinforcement may become prone to corrosion. Either the reinforcement must be coated with anticorrosive compound (or) the concrete must be plastered at the surface by normal mortar to inhibit the penetration of air and moisture inside.

Design :

-> Mix design methods applying to normal weight concrete are generally difficult to use with light-weight aggregate concrete. The lack of accurate value of absorption, specific gravity, and free moisture content in the aggregate make it difficult to apply the water/cement ratio accurately for mix proportioning.

-> Light weight concrete mix design is usually established by trial mixes. The proportion of fine to coarse aggregate and the cement and water requirement are estimated based on the previous experience with particular aggregate.

-> Sometimes the aggregate is saturated before mixing so that it ultimately does not suck up the water used for mixing.

-> The quality of concrete does not get altered on account of absorption by aggregate. It has been seen that the strength of the resulting concrete is about 5 to 10 % less than when only aggregate is used for the same content and workability.

Mixing procedure:

→ Mixing procedure for light weight concretes may vary with different types of aggregates. The general practice for structural light weight concrete is to mix the aggregates and about 2/3 of the mixing water for a period upto one minute prior to the addition of cement and the balance mixing water.

→ Mixing is done continuously as required for homogeneity. Usually 2 or more minutes are required to get uniform mixing. In case of some insulating concrete the aggregate is added at the end of mixing to minimise degradation.

Aerated concrete / cellular concrete:

→ Aerated concrete is made by introducing air (or) gas into slurry composed of portland cement (or) lime and finely crushed siliceous filler so that when the mix sets and hardens, a uniformly cellular structure is formed. Though it is called aerated concrete it is not a really not a concrete in the correct sense of the word. It is mixture of water, cement and finely crushed sand.

→ Aerated concrete is also referred as gas concrete, foam concrete, cellular concrete.

→ There are several ways in which aerated concrete can be manufactured.

(a) By the formation of gas by chemical reaction within the mass during liquid (or) plastic state.

(b) By mixing preformed stable foam with the slurry.

(c) By using finely powdered metal.

→ Powdered zinc may also be added in place of aluminium powder. Hydrogen peroxide and bleaching powder have also been used instead of metal powder. But this practice is not widely followed at present.

(b)
→ In the stable foam is mixed with cement and crushed sand slurry thus causing the cellular structure when this gets set and hardened.

→ However this method cannot be employed for decreasing the density of the concrete beyond a certain point and as such the use of air entrainment is not often practised for making aerated concrete.

(c)
→ Gasification method is most widely adopted method using aluminium powder (or) such other similar material. This method is adopted in the large scale manufacture of aerated concrete in the factory where in the whole process is mechanised and the product is subjected to high pressure steam curing. The products are autoclaved.

NO FINES CONCRETE :

→ No fines concrete as the term implies is a kind of concrete from which the fine aggregate fraction has been omitted. This concrete made up of only coarse aggregate, cement and water.

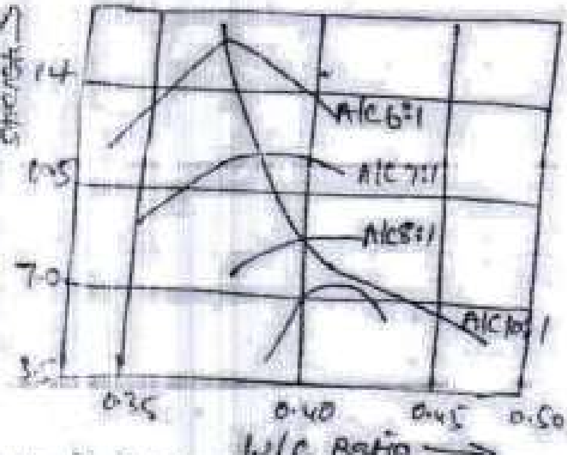
→ Very often only single sized coarse aggregate of size passing through 20mm retained on 10mm is used.

→ No fines concrete is becoming popular because of some of the advantages it posses over the conventional concrete.

→ This single sized aggregates make a good no fines concrete, which in addition to having large voids and hence light in weight also offers an architecturally attractive look.

MIX PROPORTION:

- No fines concrete is generally made with the aggregate/cement ratio from 6:1 to 10:1.
- Aggregates are used normally of size passing through 20mm and retained on 10mm unlike the conventional concrete, in which strength is primarily controlled by the water/cement ratio the strength of fines concrete is dependent on the water/cement ratio, aggregate cement ratio and unit weight of concrete.
- The w/c ratio for satisfactory consistency will vary b/w a narrow range of 0.38 and 0.52
- If too low w/c ratio is adopted the paste will be so dry that aggregates does not get properly stored with paste which result in insufficient.



- On the other hand if the w/c ratio is too high, the paste flows to the bottom of the concrete, particularly when vibrated and fills up the voids b/w the aggregates at the bottom and makes that portion dense.
- No standard method is available, like slump test (or) compacting factor test for measuring the consistency of no-fines concrete.
- No fines concrete when conventional aggregates are used, may show a density of about 1600 to 1900 kg/m3, but when no-fines concrete is made by using light weight aggregate, the density may come to about 360 kg/m3.
- The bond strength of no fines concrete is very low and therefore reinforcement is not used in conjunction with no fines concrete. However if reinforcement is required to be used in no fines concrete, it is advisable to shroud the RC with cement paste to improve the bond and also to protect it from rusting.

HIGH DENSITY CONCRETE:

-> Density of normal concrete is in the order of about 2400 kg/m³

-> The density of light weight concrete will be less than about density 1900 kg/m³.

-> To call the concrete, as high density concrete, it must have unit weight ranging from about 3360 kg/m³ — 3840 kg/m³, which is about 50% higher than the unit weight of conventional concrete.

-> The advent of the nuclear energy industry presents a considerable demand on the concrete technologists.

-> Large scale production of penetrating radiation and radioactive materials are as a result of the use of nuclear reactors, particle accelerator, industrial radiography, and X-ray, γ-ray therapy, require the need of shielding material for the protection of operating personnel against the biological hazards such radiation.

-> Concrete both high density and normal density are effective and economic construction material for permanent shielding purposes.

Types of Radiation and Hazards:

-> There are two general classes of radiation.

1) Electromagnetic waves

2) Nuclear particles

-> Electro magnetic waves the high energy, high frequency waves known as X- and γ-rays are only types which require shielding for the protection of personnel. These are similar to light rays but of higher energy greater penetrating power.

-> Nuclear particles consist of nuclei of atoms (or) fragments thereof. They include neutrons, protons, alfa and beta particles of these all neutrons posses an electric charge.

FIBRE REINFORCED CONCRETE:

→ Fibre reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete.

→ Fibre is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat.

→ The fibre is often described by a convenient parameter called 'aspect ratio' i.e ratio of its length to its diameter.

- The ratio ranges from 50 to 150.

TYPES OF F.R.C

→ Although every type of the fibre has been tried out in cement and concrete, not all of them can be effectively and economically used. Each types of fibre has its characteristic properties and limitations.

→ Some of the fibres could be used are

1) Steel fibres
2) Polypropylene fibres
3) nylons fibres
4) asbestos fibre
5) coir fibre
6) Glass fibre
7) Carbon fibre

1) Steel fibre:

→ It is one of the most commonly used fibre. Generally round fibres are used.

→ They diameter may vary from 0.25 to 0.75 mm. The steel fibre is likely to get rusted and lose some of its strengths. But investigations have shown that the rusting of fibres takes place only at the surface.

a) Polypropylene & nylon fibres:-

-> This fibres are found to be suitable to increase the impact strength. They posses very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to the flexural strength.

b) Asbestos Fibres:-

-> Asbestos is a mineral fibre and has proved to be most successful of all fibres as it can be mixed with Portland cement.

-> Tensile strength of asbestos varies b/w 560 to 980 N/mm². The composite product called asbestos cement has considerably higher flexural strength than the Portland cement paste.

-> For un important fibre concrete, organic fibres like coir, jute, canes, splits are also used.

c) Glass Fibre:

-> It is a recent introduction in making fibre concrete. It has very high tensile strength 1020 - 4080 N/mm².

-> Glass fibres which is originally used in conjuction with cement was found to be affected by alkaline condition of cement.

-> Therefore alkali-resistant glass fibre by trade name "CEM-FIL" has been developed and used. The alkali resistant fibre reinforced concrete shows considerable improvements in durability to the conventional E-glass fibre.

d) Carbon Fibre:

-> Carbon fibre posses very high tensile strength 2110 to 2815 N/mm² and young's modulus. It has been reported that cement composite made with carbon fibre as reinforcement will have very high modulus of elasticity and flexural strength.

-> The use of carbon fibres for structures like cladding, panels, and shells will have promising future.

FACTORS AFFECTING PROPERTIES OF FRC:

-> F.R.C reinforced concrete is the composite material containing fibres in the cement matrix in an orderly manner (or) randomly distributed manner.

-> Its properties would obviously depend upon the efficient transfer of stress between matrix and the fibres, which is largely dependent on the type of fibre, fibre geometry, fibre content, orientation and distribution of the fibres, mixing and compaction techniques of concrete, and size and shape of the aggregate.

1) Relative fibre matrix stiffness:-

-> The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer. Low modulus of fibres such as nylons and polypropylene are therefore unlikely to give strength improvement, but they help in the absorption of large energy and therefore impart greater degree of toughness and resistance to impact.

-> High modulus fibres such as steel, glass and carbon impart strength and stiffness to the composite.

-> A good bond is essential for improving tensile strength of the composite.

-> The interfacial bond could be improved by larger area of contact improving the frictional properties and degree of gripping and by treating the steel fibres with sodium hydroxide (or) acetone.

2) Volume of fibres:-

-> The strength of the composite largely depends on the quantity of fibres used in it. Use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.

3) Aspect ratio of Fibre :-

-> Another important factor which influences the properties and behaviour of the composite is the aspect ratio of the fibre. It has been reported that upto aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75 relative strength and toughness is reduced.

4) Orientation of fibres:

-> One of the differences b/w conventional reinforcement and fibre reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibres are randomly oriented.

-> To see the effect of randomness, mortar specimens reinforced with 0.5% volume of fibres were tested.

5) Workability and compaction of concrete :-

-> Incorporation of steel fibre decreases the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete.

-> The fibre volume which this situation is reached depends on the length and diameter of the fibre.

-> Another consequence of poor workability is non-uniform distribution of the [illegible] fibres. Generally the workability and compaction standard of the mix is improved through increased w/c ratio.

6) Size of coarse aggregate :-

-> Several investigators recommended that the max. size of the coarse aggregate should be restricted to 10mm, to avoid appreciable reduction in strength of the composite.

7) Mixing:-

-> Mixing of fibre reinforced concrete needs careful conditions to avoid balling of fibres, segregation and in general the difficulty of mixing the materials uniformly.

-> Increase in the aspect ratio, volume % and size and quantity of coarse aggregate intensify the difficulties and balling tendencies.

-> A steel fibre content in excess of 2% by volume and an aspect ratio of more than 100 are difficult to mix.

-> The typical proportions for fibre reinforced concrete is

cement content : 325 - 550 kg/m³.

w/c ratio : 0.4 to 0.6

% of sand to total aggregate : 50 to 100%

Max. Aggregate size : 10mm.

Air content : 6 - 9 %

Fibre content : 0.5 - 2.5%

: steel - 1 % 78 kg/m³

Glass - 1% 25 kg/m³

Nylon - 1 % 11 kg/m³.

Applications:

-> Fibre reinforced concrete is increasingly used on account of the advantages of increased static and dynamic tensile strength, energy absorbing characteristics and better fatigue strength.

-> The uniform dispersion of fibres throughout the concrete provides isotropic properties not common to conventionally reinforced concrete.

-> F.R.C has been used on overlays of air field, road pavements, industrial floorings, bridge decks, canal lining, explosive resistant structures, refractory linings etc.

-> F.R.C concrete can also be used for the fabrication of precast like pipes, boats, beams, stair case steps, wall panels, roof panels, manhole covers etc.

Principal
... College of Engineering

POLYMER CONCRETE :-

-> continous research by concrete technologists to understand improve and develop the properties of concrete has resulted in a new type of concrete known as "polymer concrete".

-> The porosity is due to air voids, water voids (or) due to the inherent porosity of gel structure itself on account of the porosity, the strength of concrete is naturally reduced. It is conceived by many research workers that reduction of porosity results in increase of strength of concrete.

-> Therefore process like vibration, pressure application spinning etc. have been practiced mainly to reduce porosity. All these methods have been found to be helpful to a great extent, but none of these methods could really help to reduce the water voids and the inherent porosity of gel which is estimated to be about 28%.

-> The development of concrete - polymer composite material is directed at producing a new material by combining the ancient technology of cement concrete with the modern technology of polymer chemistry.

TYPES OF polymer concrete :

① Polymer impregnated concrete :- is one of the widely used polymer composite. It is nothing but a pre cast conventional concrete, cured and dried in oven, (or) by dielectric heating from which the air in the open cell is removed by vacuum. Then a low viscosity monomer is diffused through the open cell and polymerised by using radiation, application of heat (or) by chemical initiation.

-> Mainly the following types of monomer are used.

a) methylmethacrylate
b) styrene
c) Acrylonitrile
d) t-butyl styrene.
e) other thermoplastic monomers.

-> The amount of monomer that can be loaded into a concrete specimen is limited by the amount of water and air that has occupied the total void space.

-> It is necessary to know the concentration of water and air void in the system to determine the rate of monometer penetration. However the main research effort has been towards obtaining a maximum monomer loading in concrete by the removal of water and air from the concrete by vacuum (or) thermal drying, the latter being more practicable for water removal because of its rapidity.

2) Polymer cement concrete (PCC)

-> Polymer cement concrete is made by mixing cement, aggregates, water and monometers. Such plastic mixture is cast in moulds, cured, dried and polymerised. The monometer that are used in PCC are.

a) polyster-styrene
b) Epoxy-styrene
c) Furans
d) Vinylidene chloride.

-> However the results in obtained by the production of PCC in this way have been disappointing and have shown relatively modest improvement of strength and durability. In many cases, materials poorer than ordinary concrete are obtained.

-> This behaviour is explained by the fact that organic materials are incompatible with aqueous system and sometimes interfere with the alkaline cement hydration process.

3) Polymer concrete :-

-> Polymer concrete is an aggregate bound with a polymer binder instead of portland cement as in conventional concrete.

-> The main technique in producing PC is to minimise void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates.

-> This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume.

-> The graded aggregates are prepacked and vibrated in a mould. Monomer is then diffused up through the aggregates and polymerisation is initiated by radiation (or) chemical means.

-> An important reason for the development of this material is the advantage it offers over conventional concrete where the alkaline portland cement on curing, forms internal voids. water can be entrapped in these voids which on freezing can readily crack the concrete.

-> Polymer concretes tend to be brittle and it is reported that dispersion of fibre reinforcement would improve the toughness and tensile strength of the material.

-> The use of fibrous polyester concrete (FPC) in the compression strength [illegible] of reinforced concrete beams provides a high strength, ductile concrete at reasonable cost.

4) Partially impregnated and surface coated concrete:

-> Partial [illegible] impregnation may be sufficient in situations where the major requirement is surface resistance against chemical and mechanical attack in addition to strength increase.

-> Even with only partial impregnation, significant increases in the strength of original concrete has been obtained.

-> The depth of monomer penetration is dependent upon following.

1) Pore structure of hardened and dried concrete.
2) The duration of soaking.
3) viscosity of the monomer.

Application of polymer impregnated concrete:

1) Prefabricated structural elements.
2) Prestressed concrete
3) Marine works
4) Desalination plants
5) Nuclear power plants
6) Sewage works - pipe & internal work.
7) Ferrocement products
10) Water proofing structures
11) Industrial applications.

SELF COMPACTING CONCRETE:

-> Modern application of self compacting concrete (SCC) is focussed on high performance, better and more reliable and uniform quality.
-> Self compacting concrete has been described as "the most revolutionary development in concrete construction for several decades"
-> Originally developed in Japan to offset a growing shortage of skilled labour, it has proved to be beneficial from the following points.

1) Faster construction
2) Reduction in site manpower
3) Better surface finish
4) Easier placing
5) Improved durability
6) Greater freedom in design
7) Thinner concrete sections
8) Reduced noise level
9) Safer working environment

Material for SCC

Cement: Ordinary Portland cement, 43 or 53 grades can be used.

Aggregates:

→ The maximum size of aggregate is generally limited to 20mm. Aggregate of size 10to12mm is desirable for structures having congested reinforcement. Possible size of aggregate higher than 20mm could also be used.

Mixing water:

→ water quality must be established on the same line as that for using reinforced concrete or prestressed concrete.

chemical admixtures:

→ super plasticizers are an essential component of SCC to provide necessary workability. The new generation super plasticizers termed poly-carboxylated ethers (PCE) is particularly useful for SCC.

Mineral admixtures:

a) Fly ash
b) GGBFS
c) Silica fume
d) stone powder
e) Fibres.

TYPES OF SSC

→ There are three types of SSC

i) Powder type:

→ This is proportioned to give the required self compactability by reducing the water-powder ratio and provide adequate segregation resistance.

→ powdered type SCC made by increasing powder content

ii) Viscosity ~~powder~~ modifying admixtures:

→ by the use of viscosity in SSC by the use of viscosity modifying admixtures to provide segregation

→ ~~increasing powder content and using VMA.~~

iii) combined type :-

-> reduce the water powder ratio.
-> It is made by increasing powder content and using VMA.

MIX DESIGN:

1) Determine the desired air content.
2) Determine the coarse aggregate volume.
3) Determine the sand content.
4) Design the paste composition.
5) Determine the optimum water/powder ratio & super plasticizer dosage in mortar.

TESTS ON CONCRETE:
-> The concrete composition is now determined and the super-plasticizer dosage is finally selected on the bases of tests on concrete.

Guidelines for mix composition:

coarse aggregate <50%
water/powder ratio = 0.8 to 1.0
Total powder content = 400-600 kg/m3.
Sand content = < 40% of the mortar.
Sand <50% of paste volume.
Sand > 50% weight of total aggregate.
free water <200 litres
paste = 40% of the volume of the mix.

SREE VAAGESWARI EDUCATIONAL SOCIETY
VAAGESWARI COLLEGE OF ENGINEERING
(Affiliated to JNTUH, Hyderabad.)
(Approved by AICTE New Delhi & Recognised by the Govt. of Telangana State)

COURSE FILE FOR

CONCRETE TECHNOLOGY

PREPARED BY

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DEPARTMENT OF CIVIL ENGINEERING

COURSE FILE

SUBJECT	:	CONCRETE TECHNOLOGY
NAME	:	RAJESH K
DESIGNATION	:	ASST. PROFESSOR
REGULATION	:	R 18
COURSE CODE	:	CE511PE
YEAR / SEMESTER	:	III / I
DEPARTMENT	:	CIVIL ENGINEERING
ACADEMIC YEAR	:	2020-2021

COURSE FILE CONTENTS

Part-1

S.No.	Topics		
1	Vision, Mission, PEO's, PO's & PSO'S		
	a). Vision		
	b). Mission		
	c). Program Educational Objectives (PEO'S)		
	d). Program Outcomes (PO'S)		
	e). Program Specific Outcomes (PSO'S)		
2	CT Syllabus (University Copy) FOR THE ACADEMIC YEAR 2020-2021		
3	Course Objectives, Course Outcomes And Topic Outcomes		
	a). Course Objectives		
	b). Course Outcomes		
	c). Topic Outcomes		
4	Course Prerequisites		
5	Course Information Sheet (CIS)		
	a). Course Description		
	b). Syllabus		
	c). Gaps in Syllabus		
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	e). Web Sources-References		
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6	Teaching Schedule		
7	Unit Wise Hand Written notes		
8	OHP/LCD SHEETS /CDS/DVDS/PPT (Soft/Hard copies)		
9	University Previous Question papers		
10	MID exam Descriptive Question Papers		
11	Assignment topics with materiels		
12	Tutorial topics and Questions		
13	Unit wise-Question bank		
	1	Two marks question with answers	5 questions
	2	Three marks question with answers	5 questions
	3	Five marks question with answers	5 questions
	4	Objective question with answers	10 questions
	5	Fill in the blanks question with answers	10 questions
14	Course Attainment		
15	CO-PO Mapping		

1. Vision, Mission, PEO's, PO's & PSOs

a). Vision of Civil Engineering Department

- To give the world new age civil engineers who can transform the society with their creative vibe for the sustainable development by instilling scientific temper with ethical human outlook.

b). Mission of Civil Engineering Department

- To make the department a Centre of excellence in the field of civil engineering and allied research
- To promote innovative and original thinking in the minds of budding engineers to face the challenges of future.

c). Program Educational Objectives of Civil Engineering Department

PEO1	Graduates will utilize the foundation in Engineering and Science to improve lives and livelihoods through a successful career in Civil Engineering or other fields
PEO2	Graduates will become effective collaborators and innovators, leading or participating in efforts to address Social, Technical and Business Challenges
PEO3	Graduates will engage in Life-Long Learning and professional development through Self-Study, continuing education or graduate and professional studies in engineering & Business

d) Program Outcomes of Civil Engineering Department

PO1	**Fundamental engineering analysis skills:** An ability to apply knowledge of computing, mathematical foundations, algorithmic principles, and civil engineering theory in the modelling and design of to civil engineering problems.
PO2	**Information retrieval skills:** An ability to design and conduct experiments, as well as to analyze and interpret data.

Principal

PO3	**Creative skills:** An ability to design, implement, and evaluate a system, process, component, or program to meet desired needs, within realistic constraints such as economic, environmental, social, political, health and safety, manufacturability, and sustainability. Graduates have design the competence.
PO4	**Teamwork:** An ability to function effectively on multi-disciplinary teams.
PO5	**Engineering problem solving skills:** An ability to analyze a problem, and identify, formulate and use the appropriate computing and engineering requirements for obtaining its solution.
PO6	**Professional integrity:** An understanding of professional, ethical, legal, security and social issues and responsibilities. Graduates must understand the principles of ethical decision making and can interpret the ASCE Code of Ethics. Graduates will understand the proper use of the work of others (e.g., plagiarism, copyrights, and patents). Graduates will understand the special duty they owe to protect the public's health, safety and welfare by virtue of their professional status as engineers in society.
PO7	**Speaking / writing skills:** An ability to communicate effectively, both in writing and orally. Graduates are able to produce engineering reports using written, oral and graphic methods of communication.
PO8	**Engineering impact assessment skills:** The broad education necessary to analyze the local and global impact of computing and engineering solutions on individuals, organizations, and society.
PO9	**Social awareness:** Knowledge of contemporary issues. Students are aware of emerging technologies and current professional issues.
PO10	**Practical engineering analysis skills:** An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
PO11	**Software hardware interface:** An ability to apply design and development principles in the construction of software and hardware systems of varying complexity.
PO12	**Successful career and immediate employment:** An ability to recognize the importance of professional development by pursuing postgraduate studies or face competitive examinations that offer challenging and rewarding careers in Civil Engineering

e). Program Specific Outcomes (PSO'S)

PSO	DESCRIPTION
PSO1	Educating students with fundamental mathematical, scientific, and engineering knowledge to have a significant and positive long-term impact on the field of Civil Engineering.
PSO 2	Emphasizing the importance of working in a team effectively and to communicate properly within the team to achieve the desired outcome.
PSO 3	Motivate students in learning to learn and the ability to keep learning for a life-time to increase their professionalism, update and deepen their knowledge through the development of the profession.

2. SYLLABUS UNIVERSITY COPY

CE511PE: CONCRETE TECHNOLOGY (Professional Elective – I)

B.Tech. III Year I Sem.

L	T/P/D	C
3	0/0/0	3

Pre-Requisites: Building Materials

Course Objectives: The objectives of the course are to

- **Know** different types of cement as per their properties for different field applications.
- **Understand Design** economic concrete mix proportion for different exposure conditions and intended purposes.
- **Know** field and laboratory **tests** on concrete in plastic and hardened stage.

Course Outcomes: After the completion of the course student should be able to

- **Determine** the properties of concrete ingredients i.e. cement, sand, coarse aggregate by conducting different tests. Recognize the effects of the rheology and early age properties of concrete on its long-term behavior.
- **Apply** the use of various chemical admixtures and mineral additives to design cement-based materials with tailor-made properties
- **Use** advanced laboratory techniques to characterize cement-based materials.
- **Perform** mix design and engineering properties of special concretes such as high-performance concrete, self-compacting concrete, and fibre reinforced concrete.

UNIT I

Cement: Portland cement – chemical composition – Hydration, Setting of cement – Structure of hydrated cement – Tests on physical properties – Different grades of cement. Admixtures: Types of admixtures – mineral and chemical admixtures.

UNIT - II

Aggregates: Classification of aggregate – Particle shape & texture – Bond, strength & other mechanical properties of aggregate – Specific gravity, Bulk density, porosity, adsorption & moisture content of aggregate – Bulking of sand – Deleterious substance in aggregate – Soundness of aggregate – Alkali aggregate reaction – Thermal properties – Sieve analysis – Fineness modulus – Grading curves – Grading of fine, Manufactured sand and coarse Aggregates – Gap graded aggregate – Maximum aggregate size- Properties Recycled aggregate.

UNIT – III

Fresh Concrete: Workability – Factors affecting workability – Measurement of workability by different tests – Setting times of concrete – Effect of time and temperature on workability – Segregation & bleeding – Mixing, vibration and revibration of concrete – Steps in manufacture of concrete – Quality of mixing water.

UNIT - IV

Hardened Concrete: Water / Cement ratio – Abram's Law – Gel/space ratio – Gain of strength of concrete – Maturity concept – Strength in tension and compression – Factors affecting strength – Relation between compression and tensile strength - Curing.

Testing of Hardened Concrete: Compression tests – Tension tests – Factors affecting strength – Flexure tests – Splitting tests – Pull-out test, Non-destructive testing methods – codal provisions for NDT.

ELASTICITY, CREEP & SHRINKAGE – Modulus of elasticity – Dynamic modulus of elasticity – Posisson's ratio – Creep of concrete – Factors influencing creep – Relation between creep & time – Nature of creep – Effects of creep – Shrinkage – types of shrinkage.

UNIT – V

Mix Design: Factors in the choice of mix proportions – Durability of concrete – Quality Control of concrete – Statistical methods – Acceptance criteria – Proportioning of concrete mixes by various methods – BIS method of mix design.

Special Concretes: Introduction to Light weight concrete – Cellular concrete – No-fines concrete – High density concrete – Fibre reinforced concrete – Polymer concrete – High performance concrete – Self compacting concrete.

TEXT BOOKS:

1. Concrete Technology by M.S. Shetty, – S. Chand & Co.; 2004
2. Concrete Technology by A.R. Santhakumar, 2nd Edition, Oxford university Press, New Delhi
3. Concrete Technology by M. L. Gambhir. – Tata Mc. Graw Hill Publishers, New Delhi

REFERENCE BOOKS:

1. Properties of Concrete by A. M. Neville – Low priced Edition – 4th edition
2. Concrete: Micro structure, Properties and Materials – P.K. Mehta and J.M. Monteiro, Mc-Graw Hill Publishers

IS Codes:

IS 383
IS 516
IS 10262 - 2009

3. COURSE OBJECTIVES, COURSE OUTCOMES AND TOPIC OUTCOMES

a). COURSE OBJECTIVES

(i) Student should be able to differentiate the materials that can be effectively used for preparing concrete.

(ii) Student should be able to design, prepare and work with the concrete

(iii) The mechanism of hydration and potential hydration with the concrete heat of hydration kinetic. Shrinkage and its potential to generate cracks in concrete, including chemical, autogen, drying, and carbonation shrinkage.

(iv) The basic principles of mix designing various types of concrete as well as curing technology required for each of the following types.

(v) High performance concrete, ultra high strength concrete, self-compacting concrete, under water.

b). COURSE OUTCOMES

CO1: Identify Quality Control tests on concrete making materials

CO2: Understand the durability requirements of fresh concrete

CO3: Identify Quality Control tests hardened concrete

CO4: Design concrete mixes as per IS and ACI codes

CO5: Understand the need for special concretes

c). TOPIC OUTCOMES

S. No.	Topic to be covered	Topic Outcome (At the end of this topic student will be able to)
L1	**UNIT-I: Cement** Introduction on concrete technology course.	Define cement, aggregates and water.
L2	History of port land cement and Manufacturing process of Portland cement	Various methods and stages of cement manufacturing.
L3	Chemical composition & Bogies compounds of Portland cement	Various chemical composition and compounds.
L4	Hydration of cement, Structure of hydrate cement and setting time of cement	Illustrate cement hydration and consistency of cement
L5	Test on physical properties of cement.	Explain physical properties test of

S. No.	Topic to be covered	Topic Outcome (At the end of this topic student will be able to)
		cement
L6	Different grades of cement.	Describe the cement grades.
L7	Admixtures and types of admixtures, mineral and chemical admixtures	Define admixture, Classify the admixture types – List out the different types of mineral and chemical admixtures
L8	**UNIT-II: Aggregates** Introduction on Aggregates and Classification of aggregate, Particle shape and texture, Bond strength	Define aggregates- Classify aggregates based on their particle shape and texture, bond strength
L9	Mechanical properties of aggregate: Specific gravity, Bulk density, porosity, absorption and moisture content of aggregate.	Define specific gravity, bulk density and porosity. Conclude its importance in mix design. aggregate mechanical properties
L10	Bulking of aggregate and Soundness of aggregate	Demonstrate bulking of sand. Explain soundness of aggregate
L11	Alkali aggregate reaction, Thermal properties	Discuss deleterious substances in aggregates and its effect on properties of concrete. Define and alkali aggregate reaction and its effect on concrete properties. Explain thermal properties of aggregates
L12	Sieve analysis, Fineness modulus, Grading curves,	Demonstrate sieve analysis of aggregates and discuss importance of maximum size of aggregates. Determine fineness modulus, Prepare grading curves to make aggregates correction in design mix.
L13	Grading of fine and coarse Aggregates, Gap graded aggregate, Maximum aggregate size	Examine grading of fine and coarse aggregates; discuss gap graded and maximum aggregate sizes.
L14	**UNIT-III: Fresh Concrete** Introduction of workability and factors affecting workability	Explain properties of concrete define workability and list out factors effecting of workability.
L15	Measurement of workability by different tests, Setting time of concrete	Demonstrate workability test to measure it.
L16	Effect of time and temperature on workability	Define concrete setting, discuss about time and temperature effect on workability.

S. No.	Topic to be covered	Topic Outcome (At the end of this topic student will be able to)
L17	Segregation and bleeding of concrete	Define segregation & bleeding. Demonstrate concrete mixing and vibration.
L18	Steps in manufacture of concrete, Mixing and vibration of concrete	List out concrete manufacturing steps; describe the water quality and its importance in quality of concrete.
L19	Quality of mixing water	Quality of mixing water in concrete.
	MID EXAMINATION-II	
L20	**UNIT-IV: Hardened Concrete** Introduction on hardened concrete, water/cement ratio, Abram's law	Define Water/Cement ratio, Abram's law.
L21	Gel space ratio, nature of strength of concrete	Calculate gel-space ratio to predict concrete strength.
L22	Maturity concept in concrete and problems	Explain concrete strength natures and discuss maturity of concrete to calculate concrete strength.
L23	Strength in tension and compression, factors affecting strength	List out factors effecting concrete strength.
L24	Relation between compression and tensile strength, curing	Distinguish between concrete compressive and tensile strength
L25	Testing of hardened concrete-compression test and tensile strength	Demonstrate compression and tension test of concrete.
L26	Flexural test and splitting test	Explain flexure, splitting tensile and pull out test of concrete.
L27	NDT methods and codal provisions	Explain Non-destructive testing, Name it with codal provisions.
L28	Modulus of elasticity, dynamic modulus of elasticity and poisons ratio	Define elasticity, creep and shrinkage of concrete. Explain experimental process to determine modulus of elasticity.
L29	Creep of concrete, factors influencing creep of concrete, relation between creep and time	Define dynamic modulus of elasticity; differentiate static and dynamic modulus of elasticity. Show the relation between creep and time, list out the effects of creep on concrete strength.
L30	Nature of creep, effects of creep	Explain concrete creep and list out factors effecting on concrete creep.
L31	Shrinkage and types of shrinkage	Define shrinkage and list out types of shrinkages.

L32	**Unit-V: Mix Design & Special Concrete** Factors in the choice of mix proportion	Define mix design and its importance in concrete strength. List out the factors to choose the mix proportions.
L33	Durability of concrete	Define concrete durability.
L34	Quality control of concrete, Statistical quality control of concrete	Explain concrete quality control; demonstrate statistical quality control and acceptance criteria.
L35	Proportioning of concrete mix by normal concretes by BIS method	Select concrete mix proportions for normal concrete.
L36	Normal Mix design problem	Design a mix design as per BIS method and conclude the concrete mix proportions.
L37	Normal Mix design problem	Design a M20 or M25 concrete mix for local available materials.
L38	Proportioning of concrete mix by pump able concretes by BIS method	Select concrete mix proportions for pump able concrete.
L39	Pumpable Mix design problem	Design a mix design as per BIS method and conclude the concrete mix proportions.
L40	Proportioning of concrete mix by pump able concretes by ACI method	Select concrete mix proportions for pump able concrete.
L41	ACI mix design problem	Select concrete mix proportions for ACI Method.
L42	Introduction to Light weight concrete	Define special concretes. Explain light weight concrete and list out the merits and demerits of it.
L43	Cellular concretes	Define cellular concrete. Explain preparation produce of cellular and its applications in construction industry.
L44	No fines concrete	Define no fine concrete. Explain preparation produce of no fines concrete and its applications in construction industry.
L45	Fiber reinforced concrete	Define fiber reinforced concrete. Explain the ingredient of its importance in FRC.
L46	Polymer concrete and types of polymer concrete	Define polymer concrete. Explain the ingredient of its importance in polymer concrete
L47	Self-compacting concrete	Demonstration of self-compacting concrete, list out the test to conclude self-compacting concrete.
L48	High density concrete	Demonstration high density concrete, list out the test to conclude high density concrete

4. COURSE PRE–REQUISITES

1. Ingredients of concrete
2. Elements of building components
3. Characteristics of cement, fine aggregate and coarse aggregates

5. COURSE INFORMATION SHEET

5 a).COURSE DESCRIPTION:

PROGRAMME: B. Tech. (Civil Engineering)	DEGREE: BTECH
COURSE: CONCRETE TECHNOLOGY	YEAR: III SEM: I CREDITS: 4
COURSE CODE: CE511PE REGULATION: R18	COURSE TYPE: CORE
COURSE AREA/DOMAIN: Theory	CONTACT HOURS: 4+0 (L+T)) hours/Week.
CORRESPONDING LAB COURSE CODE (IF ANY): YES	LAB COURSE NAME: CONCRETE TECHNOLOGY LAB

5. b). SYLLABUS:

Unit	Details	Hours
I	**Cement:**Portland cement – chemical composition – Hydration, Setting of cement – Structure of hydrate cement – Test on physical properties – Different grades of cement. Admixtures: Types of admixtures – mineral and chemicaladmixtures	7
II	**Aggregate:**Classification of aggregate – Particle shape & texture –, strength & other mechanical properties of aggregate – Specific gravity, Bulk density, porosity, adsorption & moisture content of aggregate – Bulking of sand – Deleterious substance in aggregate – Soundness of aggregate – Alkali aggregate reaction – Thermal properties – Sieve analysis – Fineness modulus – Grading curves – Grading of fine & coarse Aggregates – Gap graded aggregate – Maximum aggregate size	8
III	**Fresh Concrete:** Workability – Factors affecting workability – Measurement of workability bydifferenttests–Settingtimesofconcrete–Effectoftimeandtemperatureonworkability– Segregation & bleeding – Mixing and vibration of concrete – Steps in manufacture of concrete – Quality of mixing Water	7
IV	**Hardened Concrete :** Water / Cement ratio – Abram's Law – Gel/space ratio – Nature of strength of concrete – Maturity concept – Strength in tension & compression – Factors affecting strength – Relation between compressive & tensile strength - Curing. **Testing of Hardened Concrete:** Compression tests – Tension tests– Flexure tests – Splitting tests – Pull-out test, Non-destructive testing methods – codal provisions for NDT. Elasticity, Creep & Shrinkage – Modulus of elasticity – Dynamic modulus of elasticity – Poisson's ratio – Creep of concrete – Factors influencing creep – Relation between creep & time – Nature of creep – Effects of creep – Shrinkage –types of shrinkage	12

V	**Mix Design:** Factors in the choice of mix proportions – Durability of concrete – Quality Control of concrete – Statistical methods – Acceptance criteria – Proportioning of concrete mixes by– BIS method and ACI mix design. **Special Concretes:** Introduction to light weight concrete – Cellular concrete – No-fines concrete – High density concrete – Fibre reinforced concrete – Polymer concrete – High performance concrete – Self compacting concrete.	18
	Contact classes for syllabus coverage	52
	Total No. of classes	52

5.c). GAPS IN THE SYLLABUS - TO MEET INDUSTRY/PROFESSION REQUIREMENTS:

NIL

5.d). TOPICS BEYOND SYLLABUS/ ADVANCED TOPICS:

NIL

5. e). WEB SOURCE REFERENCES:

Sl. No	Name of book/ website
a.	nptel.ac.in/courses/112104121/1
b.	https://www.youtube.com/watch?v=cx5gPKp9CEc&list=PLbMVogVj5nJQU7M0LdA77p_XaaWBJniNc
c.	http://www.civilenggforall.com/2015/09/concrete-technology-theory-and-practice-by-ms-shetty-free-download-pdf-civilenggforall.html

5. f). DELIVERY/INSTRUCTIONAL METHODOLOGIES:

☑ CHALK & TALK	☑ STUD. ASSIGNMENT	☑ WEB RESOURCES
☑ LCD/SMART BOARDS	☑ STUD. SEMINARS	☐ ADD-ON COURSES

5.g). ASSESSMENT METHODOLOGIES-DIRECT

☑ ASSIGNMENTS	☑ STUD. SEMINARS	☑ TESTS/MODEL EXAMS	☑ UNIV. EXAMINATION
☐ STUD. LAB PRACTICES	☐ STUD. VIVA	☐ MINI/MAJOR PROJECTS	☐ CERTIFICATIONS
☐ ADD-ON COURSES	☐ OTHERS		

5.h). ASSESSMENT METHODOLOGIES - INDIRECT

☑ ASSESSMENT OF COURSE OUTCOMES (BY FEEDBACK, ONCE)	☑ STUDENT FEEDBACK ON FACULTY (TWICE)
☐ ASSESSMENT OF MINI/MAJOR PROJECTS BY EXT. EXPERTS	☐ OTHERS

5.i). TEXT / REFERENCE BOOKS:

T/R	BOOK TITLE/AUTHORS/PUBLICATION
Text Book	Properties of concrete / A.M.Neville / Pearson 5th edition
Text Book	Concrete technology / M.S.Shetty / S.Chand&co
Text Book	Concrete technology / Job Thomas / Cengage Learning
Reference Book	Concrete technology / M.L Gmbhir / Tata Mc.Grawhill
Reference Book	Concrete: Micro structure. Properties and materials/P.K.Mehta and J.M. Monteiro, McGraw Hill Publishers.

6. TEACHING SCHEDULE

Subject	CONCRETE TECHNOLOGY					
Text Books (to be purchased by the Students)						
Book 1	Concrete Technology by M.S. Shetty					
Book 2	Properties of concrete by A.M. Neville					
Reference Books						
Book 3	Concrete technology / Job Thomas / Cengage Learning					
Book 4	Concrete Technology by M.L Gambhir					
Unit	Topic	Chapters Nos				No of classes
		Book 1	Book 2	Book 3	Book 4	

	Introduction on concrete technology course.	1	1	4	2	
	History of port land cement and Manufacturing of process of Portland cement	1	1	4	2	
	Chemical composition & Bogies compounds of Portland cement	1	1	4	2	
I	Hydration of cement, Structure of hydrate cement and setting time of cement	1	1	4	2	
	Test on physical properties of cement.	1	2	4	2	
	Test on physical properties of cement.	1	2	4	2	
	Different grades of cement.	1	2	4	2	
	Admixtures and types of admixtures,	5	5	5	5	
	mineral and chemical admixtures	5	5	5	5	
II	Introduction on Aggregates and Classification of aggregate, Particle shape and texture, Bond strength.	3	3	4	3	
	Mechanical properties of aggregate: Specific gravity, Bulk density, porosity, absorption and moisture content of aggregate.	3	3	4	3	
	Bulking of aggregate and Soundness of aggregate	3	3	4	3	

	Alkali aggregate reaction, Thermal properties	3	3	4	3	
	Sieve analysis, Fineness modulus, Gradingcurves,	3	3	4	3	
	Grading of fine and coarse Aggregates, Gap graded aggregate, Maximum aggregate size	3	3	4	3	
	Introduction of workability and factors affecting workability	6	4	6	6	
	Measurement of workability by different tests, Setting time of concrete	6	4	6	6	
III	Effect of time and temperature on workability	6	8	6	6	
	Segregation and bleeding of concrete	6	4	6	6	
	Steps in manufacture of concrete, Mixing and vibration of concrete	6	4	6	11	
	Quality of mixing water	5	4	-	6	
IV	Introduction on hardened concrete, water/cement ratio, Abram's law	7	6	2	8	
	Gel space ratio, nature of strength of concrete	7	6	2	8	
	Maturity concept in concrete and problems	7	6	2	8	
	Strength in tension and compression, factors affecting strength	7	6	2	8	
	Relation between compression and tensile strength, curing	7	6	2	8	
	Testing of hardened concrete-compression test and tensile strength	10	12	5	8	
	Testing of hardened concrete-Flexural test and splitting test	10	12	5	8	
	NDT methods and codal provisions	7	12	5	8	

	Modulus of elasticity, dynamic modulus of elasticity and poisons ratio	8	9	3	8	
	Creep of concrete, factors influencing creep of concrete, relation between creep and time	8	9	3	8	
	Nature of creep, effects of creep	8	9	3	8	
	Shrinkage and types of shrinkage	8	9	3	8	
	Factors in the choice of mix proportion	11	14	7	10	
	Durability of concrete	11	10	7	10	
	Quality control of concrete, Statistical quality control of concrete	-	14	7	9	
	Proportioning of concrete mix by normal concretes by BIS method	11	14	11to15	10	
	Normal Mix design problem	11	14	11to15	10	
	Normal Mix design problem	11	14	11to15	10	
	Proportioning of concrete mix by pump able concretes by BIS method	11	14	11to15	10	
V	Pumpable Mix design problem	11	14	11to15	10	
	Proportioning of concrete mix by pump able concretes by ACI method	11	14	11to15	10	
	ACI mix design problem	11	14	11to15	10	
	Introduction to Light weight concrete	12	14	11to15	14	
	Cellular concretes	12	13	11to15	14	
	No fines concrete	12	13	11to15	14	
	Fibre reinforced concrete	12	13	11to15	14	
	Polymer concrete	12	13	11to15	14	

	Self-compacting concrete	12	13	11to15	14	
	High density concrete	12	13	11to15	14	
Contact classes for syllabus coverage					60	
Total No. of classes					60	

7. UNIT WISE HAND WRITTEN NOTES

UNIT-I

CEMENTS & ADMIXTURES

HISTORY OF PORTLAND CEMENT :-

-> The history of cementing materials is as old as the history of engineering construction.

-> Some kind of cementing materials were used by Egyptians, Romans and Indians in their ancient constructions.

-> Egyptians mostly used cementing materials obtained by burning gypsum

-> Analysis of mortar from Great pyramid showed that it contained 81.5% calcium sulphate and only 9.5% carbonate.

-> The early Greeks and Romans used cementing materials obtained by burning limestones.

-> The Greeks and Romans later became aware of the fact that certain volcanic ash, when mixed with lime and sand yields mortar possessing superior strength and better durability in fresh or salt water.

-> Roman builders used volcanic ash found near to Pozzuoli village near in Italy. This volcanic ash is mostly siliceous in nature thus acquired the name pozzolana, Later on the name pozzolana was applied to any other material natural or artificial having nearly the same composition as that of volcanic ash found at Pozzuoli.

-> In India powdered brick named surkhi has been used in ~~[illegible]~~ The Indian practice through many and long continued usage of lime mortar with or without the addition of surkhi yielded strong and impervious mortar which confirmed the secret of superiority of Roman mortar.

→ Roman added ... better workability. Hemoglobin is a powerful air entraining agent and plasticiser, which perhaps is yet another reason for the durability of Roman construction.

→ When we come to more recent times, the most important advance in the knowledge of cements, the further to the discoveries and manufacture of all modern cements is undoubtedly the investigations carried out by John Smeaton. When he was called upon to rebuild the Eddystone Light house in 1756, he made extensive enquiries into the state of an existing in those days and also conducted experiments with a view of find out the best material to withstand the severe action of sea water that yielded better lime possessing superior hydraulic properties.

→ In spite of the success of this experiment, the use of hydraulic lime made little progress and the old practice of mixture of lime and pozzolana remained popular in long period.

→ The story of the investigation of portland cement is however attributed to Joseph Aspdin, a Leeds builder and brick layer, even though similar procedures had been adopted by other inventors.

→ In early period cement was used for making mortar only. Later the use of cement was extended for making concrete.

→ In India, portland cement was first manufactured in 1904 near Madras by the South India Industries Ltd. But this venture failed. Later Indian Cement Co. Ltd, was established at Porbandar, the company was able to deliver about 1000 tons of portland cement.

→ During the first five year plan cement production from India rise from 2.69 million to 4.6 million tons.

MANUFACTURING OF PORTLAND CEMENT :-

→ The raw materials required for manufacture of portland cement are calcareous materials such as limestone (or) chalk and argillaceous materials such as shale (or) clay.

→ The process of manufacture of cement consists of grinding the raw materials, mixing them intimately in certain portion depending upon their purity and composition and burning them in a kiln at a temperature of about 1300 to 1500°C at which temperature the materials sinters and partially fuses to form nodular shaped clinker.

→ The clinker is cooled and ground to fine powder with addition of about 3 to 5% of gypsum. the product formed by using this procedure is portland cement.

→ There are two process known as "wet" and "dry" process depending upon whether the mixing and grinding of raw materials is done in wet (or) dry conditions.

→ With a little change in the above process we have the semi-dry process also where the raw materials are ground dry and then mixed with about 10-14% of water and further burnt to clinkering temperature.

→ For many years the wet process remained popular because of the possibility of more accurate control in the mixing of raw materials.

→ The dry process requires much less fuel as the materials are already in a dry state. whereas in the wet process the slurry contains about 35-50% of water.

WET PROCESS

→ In wet process the limestone brought from the quarries is first crushed to smaller fragments.

→ Then it is taken to a ball (or) tube mill where it is mixed with clay (or) shale as the case may be ground to a fine consistency of slurry with addition of water.

→ The slurry is a liquid of creamy consistency with water content of about 35-50% where in particles crushed to the fineness of Indian Standard sieve number 9, are held in suspension.

→ The slurry is pumped to slurry tanks (or) basins where it is kept in an agitated condition by means of rotating arms with chains (or) blowing compressed air from the bottom to prevent settling of limestone and clay particles.

→ The composition of slurry is tested to give the required chemical composition and corrected periodically in the tube mill and also in the slurry tank by blending slurry from different storage tanks.

→ Finally the corrected slurry is stored in storage tanks and kept in homogeneous condition by agitation of slurry.

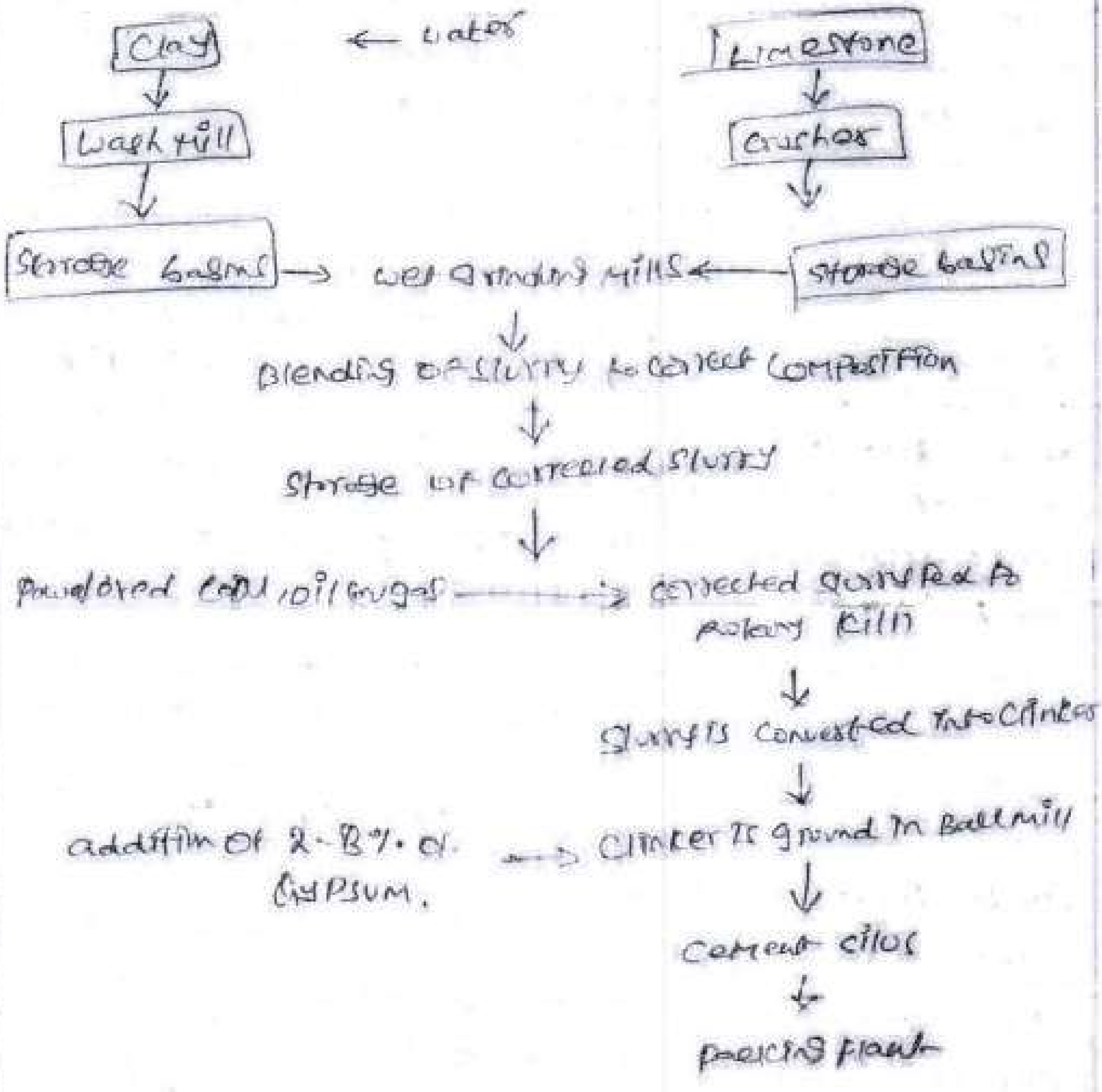
→ The corrected slurry is sprayed on to the upper end of rotary kiln against hot heavy hanging chains.

→ The rotary kiln is an important component of a cement factory. It is a steel cylinder of diameter anything from 3 mts to 8 m lined with refractory materials, mounted on roller bearings capable of rotating about its own axis at a specified speed.

→ The length of rotary kiln may vary from 30 to 60 mm.
→ The slurry on being sprayed against a hot surface of flexible chains loses moisture and became flakes.
→ The flakes peel off and fall on the floor. The rotation of rotary kiln causes the flakes to move from the upper end towards the lower end of the kiln subjects itself to higher and higher temperature.
→ The kiln is fired from the lower end. The fuel is either powered coal oil or natural gas. By the time the material downs to the lower end of rotary kiln, the dry materials undergoes a series of chemical reactions. Until finally in the hottest part of the kiln where the temperature is in the hottest part of the kiln, where the temperature is in order of 1500°C about 20 to 30% of the material get fused.
→ Lime silica and alumina get recombined. The fused mass fuse into nodular form of size 3mm to 20mm known as clinker.
→ The clinker drops into a rotary cooler where it is cooled under controlled conditions.
→ The clinker is stored in silos or bins. The clinker weighs about 1100 to 1300 gms per litre. The litre weight of clinker indicates the quality of clinker.
→ The cooled clinker is then ground in a ball mill with the addition of 3 to 5% of gypsum in orders to prevent flash-setting of cement.
→ A ball mill consists of several compartments charged with progressively smaller hardened steel balls. The particles are crushed to the required fineness are separated by currents of air and taken to storage silos from where

the cement is bagged (or) filled into containers for bulk supply.

WET PROCESS



DRY PROCESS

→ In the dry and semi dry process the raw materials are crushed dry and fed in correct proportions into grinding mill where they are dried and reduced to a very fine powder.

→ The dry powder leaves the raw meal is ... ... blended and corrected for its right composition and mixed by means of compressed air. The aerated powder tends to behave almost like liquid and in about one hour of aeration a uniform mixture is obtained.

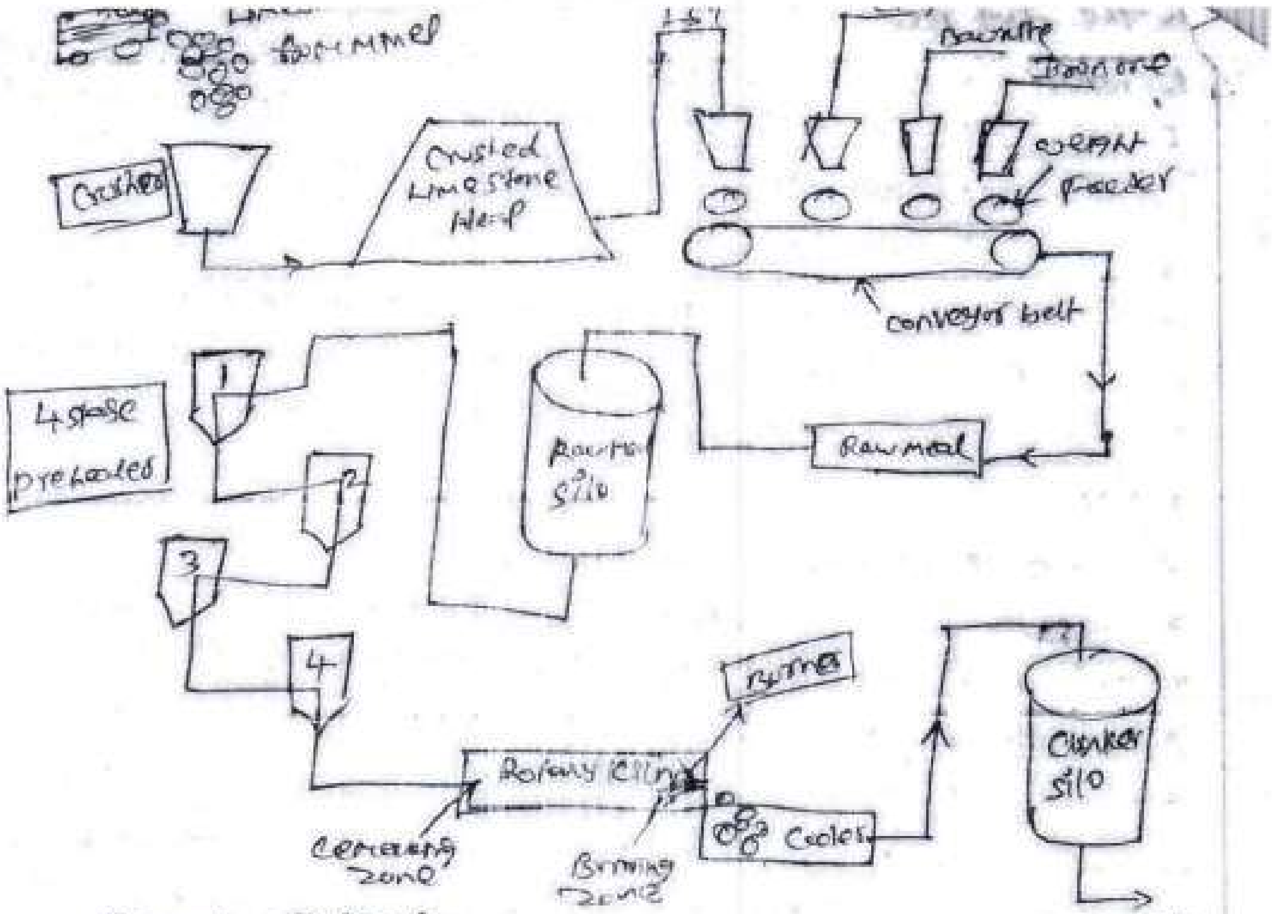
→ The blended meal is further sieved and fed into a rotating disc called granulator. A quantity of water about 12% by weight is added to make the blended meal into pellets.

→ The equipment used in the dry process kilns comparatively smaller. The process is quite economical. The total consumption of coal is this method is only about 100kg when compared to the requirement of about 350 kg for producing a ton of cement in the wet process.

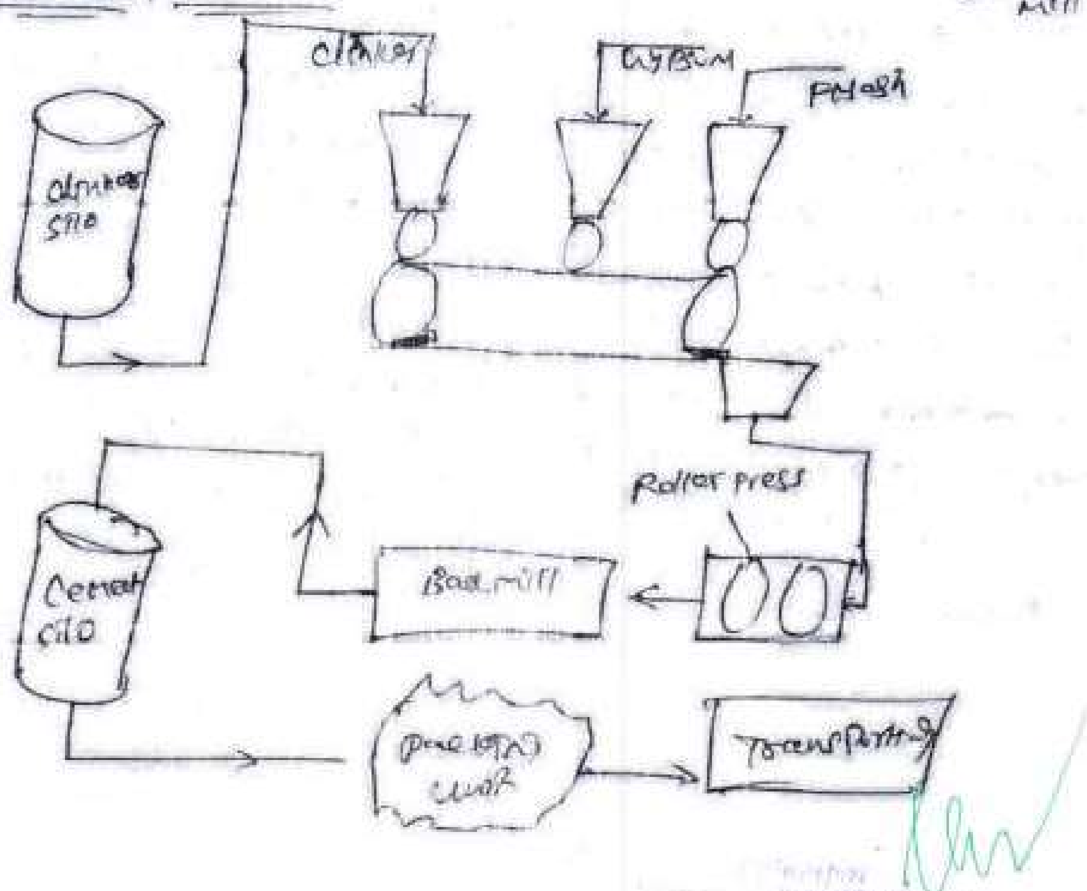
→ During March 1998 in India there were 173 large plants operating, out of which 49 plants used wet process, 115 plants used dry process and 9 plants used semi-dry process.

→ The methods are commonly employed for direct control of quantity of clinker. The first method involves reflected light optical microscopy of polished and etched section of clinker, followed by point count of areas occupied by various compounds.

→ For moderate cooling it is implied that from about 1200°C the clinker is brought to about 500°C in about 15 minutes and from the 500°C the temperature is brought down to normal atmospheric temperature in about 10 minutes.



Cement Mill Section



Chemical composition

→ The raw materials used for the manufacture of cement consists mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds.

→ The relative composition of these oxides composition are responsible for influencing the various properties of cement.

Oxide	% Content
CaO	60–67
SiO_2	17–25
Al_2O_3	3–8
Fe_2O_3	0.5–6
MgO	0.1–4
Alkalies	0.4–1.3
SO_3	1.3–3.0

Approximate oxide composition limits of ordinary portland cement.

→ As mentioned earlier the oxides present in the raw materials when subjected to high clinkering combine with each other to form complex compounds.

→ The identification of the major compound is largely based on RH Bogue's work and hence it is called Bogue's compounds. The four compounds usually re- garded as major compounds.

BOGUE'S COMPOUNDS

Name of Compounds	Formula	Abbreviated Formula	%
Tricalcium silicate	$3CaO\,SiO_2$	C_3S	54.1
Dicalcium silicate	$2CaO\,SiO_2$	C_2S	16.6
Tricalcium Aluminate	$3CaO\,Al_2O_3$	C_3A	10.8
Tetracalcium Alumino ferrite	$4CaO\,Al_2O_3\,Fe_2O_3$	C_4AF	9.1

→ Tricalcium silicate and dicalcium silicate are the most important compounds responsible for strength. Together constitute 70-80% of cement. The average C_3S content in modern cement is about 45% and C_2S is about 25%. The sum of the contents of C_3A and C_4AF has decreased slightly in modern cement.

→ An increase in lime content beyond a certain value makes it difficult to combine with other compounds and free lime will exist in the clinker which causes unsoundness in cement.

→ An increase in silica content at the expense of the content of alumina and ferric oxide will make the cement difficult to fuse and form clinker.

→ Cements with a high (early) total alumina and high ferric oxide content is favourable to the production of early strength in cement.

→ Bogue's compounds C_3S, C_2S, C_3A, C_4AF are sometimes called as Alite, Belite, Celite, and Felite respectively.

HYDRATION OF CEMENT:

→ Anhydrous cement does not bind fine and coarse aggregate. It acquires adhesive property only when mixed with water.

→ The chemical reaction that take place between cement and water is refered as hydration of cement.

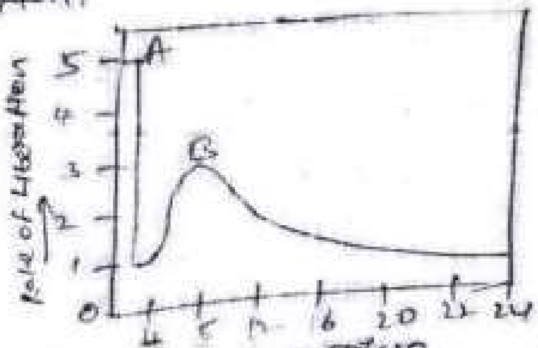
→ On account of hydration certain products are formed. These products are important because they have cementing (or) adhesive value.

→ The hydration of cement is visualised in two ways. The first is "through solution" mechanism. In this cement compounds dissolve to produce a supersaturated solution from which different hydrated products get precipitate.

→ The second possibility is that water attacks cement compounds in the solid state converting the compounds into hydrated products starting from the surface and proceeds to the interior of the compounds with time.

→ It is probable that both "through solution" and "solid state" type of mechanism may occur during the course of reactions between the cement and water.

→ The former mechanism is predominate in the early stages of hydration in view of large quantities of water being available and then later mechanism may operate during the later stages of hydration.



Heat liberation from a setting cement

STRUCTURE OF HYDRATED CEMENT

→ To understand the behaviour of concrete its necessary to acquaint ourselves with structure of hydrated hardened cement paste.

→ If the concrete is considered to be a two phase material namely the paste phase and the aggregate phase, the understanding of the paste phase will become more important as it influences the behaviour of the concrete to a much greater extent.

→ The strength, permeability, durability, drying, shrinkage, elastic properties the creep and volume change properties of the concrete are much influenced by the paste structure.

→ So to understand the concrete it is important that we have a deep understanding of the structure of the hydrated hardened cement paste.

Transition zone :

→ Transition zone which represents the interfacial region between the particles of coarse aggregate and hardened cement paste.

→ Transition zone is generally a plane of weakness and therefore has far greater influence on the mechanical behaviour of concrete.

→ Although transition zone is composed of same bulk cement, paste the quality of paste in the transition zone is of poor quality. Firstly due to internal bleeding, water accumulation below elongated, flaky and large pieces of aggregates. This reduces the bond between paste and aggregate in general.

→ Due to drying shrinkage (or) temperature variation, the transition zone develops microcracks even before a structure is loaded. When structure is loaded at high stressed levels, these micro cracks propagate and bigger cracks are formed resulting in failure bond. Therefore transition zone generally the weakest part of the chain is considered strength limiting phase in concrete.

→ The techniques used to study the structure of cement paste include measurements of setting time, compressive strength, quantity of heat of hydration evolved etc.

→ Measurements of heat evolved during the exothermic reactions also give valuable insight into the nature of hydration reactions, since approximately 50% of total heat liberation occurs during 3 days of hydration, a continuous record of heat liberation during this time is extremely useful in understanding the degree of hydration and the resultant structure of hardening cement paste.

→ The mechanical properties of the hardened concrete depends more on the physical structure of the product of hydration than on the chemical composition of the cement.

→ For simplicity's sake we will consider only the structure of the paste phase. Fresh cement paste is a plastic mass consisting of water and cement. With the lapse of time, say one hour, the hardening paste consists of hydrates of various compounds, unhydrated cement particles and water. With further lapse of time the quantity of unhydrated cement left in the paste decreases and the hydrates of the various compounds increase

TEST ON PHYSICAL PROPERTIES

Testing of cement

testing of cement can be brought under two categories

1) Field testing
2) Laboratory testing

Field testing

→ It is sufficient to test the cement in field when it is used for minor works. The following are the field tests.

a) open the bag and take a good look at a cement. There should not be any visible lumps. The colour of the cement should normally be greenish grey.

b) Thrust your hand into the cement bag it must give a cool feeling. there should not be any lumps inside.

c) take a pinch of cement and feel b/w the fingures it should give a smooth and not a gritty feeling.

d) Take a hand full of cement and throw it on a bucket full of water the particles should not float for sometimes before they sink.

Laboratory tests

The following tests are usually conducted in the lab

i) Fineness test
ii) setting time test
iii) Soundness test.
iv) Strength test.

i) Fineness test:-

→ The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat.

-> Fineness cement offers greater surface area for hydration and hence faster development of strength. The disadvantage of fine grinding is that it is susceptible to air set and early deterioration.
-> Max no of particles in a sample of cement should have a size less than 100 microns and the smallest particles may have a size about 1.5 µ
-> Fineness of cement is tested by sieving.

Sieve test
-> Weigh correctly 100 grams of cement and take it on a standard IS sieve No 9 (90 microns). Break down the ~~lumps~~ air-set lumps in the sample with fingers. Continuously sieve the sample giving circular and vertical motion for a period of 15 min. Mechanical sieving devices may also be used. Weigh the residue left on the sieve this weight should not exceed 10% of ordinary cement.

ii) Setting time test
-> An arbitrary division has been made for the setting time of cement as initial setting time and final setting time. It is difficult to draw a rigid line b/w these two arbitrary division. For convenience initial setting time is regarded as the time elapsed b/w the moment that the water is added to cement to the time that the paste starts losing its plasticity.
-> The final setting time is the time elapsed b/w the moment the water is added to cement and the time when the paste has completely lost its plasticity has attained sufficient firmness to resist certain define pressure.
-> Initial setting time is normally 30 min and final setting time should not be more than 10 hrs.
-> For initial and final setting time test is tested by the Vicat's apparatus.

Initial setting time

-> take about 500gms of cement sample and gauge it with 0.85 times the water required to produce cement paste of standard consistency 0.85P.

-> The paste shall be gauged and filled into the vicat mould in specific manner with in 3-5 min.

-> start the stop watch the instant water is added to the cement.

-> lower the needle gently and bring it in contact with the surface of the test block and quickly release. Allow it to penetrate into the test block.

-> In beginning the needle will completely pierce through the test block. But after sometimes when the paste starts losing its plasticity, the needle may penetrate only to a depth of 33-35mm from top.

-> The period elapsing b/w the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35 from the top is taken as initial setting time.

Final setting time

-> Replace the needle of the vicat apparatus by a circular attachment. The cement shall be considered as finally set when upon lowering the attachment gently cover the surface of the test block, the centre needle makes an impression, while the circular cutting edge of the attachment fails to do so. In other words the paste has attained such hardness that the centre needle does not pierce through the paste more than 0.5 mm.

(iii) Soundness test

→ It is very important that cement after setting shall not undergoes any appreciable change of volume. certain cement have been found to undergo a large expansion after setting causing disruption of the set and hardened mass.

→ The apparatus consists of small split cylinder of spring brass or other suitable metal. It is 30mm in diameter and 30mm high on either side of split are attached two indicator arms 165mm long with pointed ends.

→ cement is gauged with 0.78 times the water required for standard consistency 0.78P. in a standard manner and filled into the mould kept on a glass plate.

→ The mould is covered on the top with another glass plate. the whole assembly is immersed in water at a temp. of 27°C – 32°C and kept there for 24hrs

→ Measure the distance b/w the indicator points. Submerge the mould again in water. Heat the water and bring to boiling point in about 25–30 min. keep it boiling for 3hrs.

→ Remove the mould from the water allow it to cool and measure the distance b/w the indicator points.

→ The difference b/w these two measurements represents the expansion of cement. This must not exceed 10mm for ordinary Portland cement. If in case the expansion is more than 10mm as tested above the cement is said to be unsound.

(iv) Strength test

→ The compressive strength of hardened cement is the most important of all the properties

→ Strength of cement is indirectly found on cement sand mortar in specific proportions

→ Take 555 gms of standard sand, 185 gms of cement (1:3) in a non porous enamel tray and mix them with a trowel for one minute, then add water of quantity $\frac{P}{4} + 3$ percent of combined weight of cement and sand and mix the three ingredients thoroughly until the mixture is of uniform colour.

→ The time of mixing should not be less than 3 minutes nor more than 4 minutes.

→ Immediately after mixing, the mortar is filled into a cube mould of size 7.06 cm. The area of the face of the cube will be equal to 50 sq cm. Compact the mortar either by hand compaction in standard specified manner (or) in the vibrating equipment for 2 minutes.

→ Keep the compacted cube in the mould at a temp of 27°C ± 2°C and at least 90% relative humidity for ~~the through~~ 24 hrs.

→ After 24 hrs the cubes are removed from the mould and immersed in clean fresh water until taken out for testing.

TYPES OF CEMENT (GRADES OF CEMENT)

1) Ordinary portland cement.
2) Rapid hardening cement
3) Extra rapid hardening cement
4) Sulphate resisting cement
5) Portland slag cement
6) Quick setting cement

7) Super sulphated cement
8) Low heat cement
9) Portland pozzolana cement
10) Air entraining cement
11) Coloured cement (white cement)
12) Hydrophobic cement
13) Masonary cement
14) Expansive cement
15) Oil well cement
16) Rediset cement
17) Concrete sleeper grade cement
18) High alumina cement
19) Very high strength cement

ADMIXTURES :

→ Admixture is defined as a material, other than cement, water and aggregates that is used as ingredient of concrete and is added to the batch immediately before (or) during mixing. Additive is a material which is added at the time of grinding cement clinker at the cementory.

→ These days concrete is using for wide varities of purposes to make it suitable in different condition. In these conditions ordinary (cement) concrete may fail to exhibit the required quality performance (or) durability in such cases, admixtures is used to modify the properties of ordinary concrete so as to make it more suitable for any situation.

→ A few type of admixtures called water reducers (or) high range water reducers, generally ~~referred as~~ plasticizers (or) super plasticizers.

Types of Admixtures

(1) Chemical Admixtures

1) Plasticizers (water reducers)

2) Super plasticizers

3) Retarders and Retarding plasticizers

4) Accelerators and Accelerating plasticizers

5) Air Entraining Admixtures

(2) Mineral Admixtures

6) Pozzolanic (or) Mineral admixtures

7) Damp-proofing and water proofing admixtures

8) Gas forming admixtures

9) Air detraining admixtures

10) Alkali aggregate expansion inhibiting admixtures.

11) Workability admixtures

12) Grouting admixtures

13) Corrosion inhibiting admixtures

14) Bonding admixtures

15) Colouring admixtures

Construction Chemicals

1) Concrete curing compounds
2) Polymer Bonding Agents
3) Mould Releasing Agents
4) Protective and Decorative Coatings
5) Installation Aids
6) Surface Retarders
7) Bond aid for proofing
8) Guniting Aid.

AGGREGATES:- Unit - II

→ aggregates are important constituents in concrete. they give body to the concrete, reduce shrinkage and effect economy.

→ they aggregates occupy 70-80% of volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.

Classification of aggregates

→ Aggregates are classified as
1) Normal aggregates
2) Lightweight aggregates
3) Heavy weight aggregates.

→ In this chapter properties of normal aggregates will be discuss.

→ Normal weight aggregates further classified as Natural and artificial aggregates

Natural	Artificial
Sand,	Broken brick,
Gravel,	Air cooled slag,
Crushed rock such as	sintered flyash,
Granite, Quartzite, Basalt,	Bloated clay
Sand stone.	

→ aggregates can be classified on the basis of the size of the aggregates as coarse aggregates and fine aggregates

Particle Shape & Texture of Aggregates

SHAPE:

→ The shape of aggregate is an important characteristic since it affects the workability of concrete. It is difficult to really measure the shape of irregular body like concrete aggregate which are derived from various rocks.

→ One of the methods of expressing the angularity qualitatively is by a figure called angularity number.

→ This is based on % voids in the aggregate after compaction in a specified manner.

→ A quantity of single sized aggregates are ~~considered~~ is ~~standard~~ filled into metal cylinder of 3 lit capacity. The aggregates are compacted in a standard manner and % of voids is found out.

→ The void is found out can be knowing the sp.gravity of aggregates and bulk density (or) by pouring water to the cylinder to bring the level of water upto the brim. If the voids is 33% the angularity of such aggregates is considered zero. If the void is 44% the angularity no of such aggregate is considered 11.

→ The normal aggregates which are suitable for making the concrete may have angularity number anything from 0 to 11.

→ Angularity number zero represents the most practicable rounded aggregates and the number 11 indicates the most angular aggregates that could be tolerated for making concrete not so unduly harsh and uneconomical.

TEXTURE:

→ Surface texture is the property the measure of which depends upon the relative degree to which particle surfaces are polished (or) dull, smooth (or) rough.

→ Rough textured aggregates develops higher bond strength in tension than smooth textured aggregates

Strength of aggregate

→ When the cement paste is of good quality and its bond with ~~the aggregate~~ ~~...~~ is satisfactory, then the mechanical properties of rock (or) aggregates will influence the strength of concrete.

→ The test for strength of aggregate is required to be made in the following statements (or) situations.

i) For production of high strength & extra high strength concrete.

ii) When contemplating to use aggregates manufacture from weathered rocks.

iii) Aggregates manufactured by industrial process.

Aggregate crushing value

→ Strength of rock is found out by making a test specimen of cylinder shape of size 25mm dia and 25mm height.

→ The cylinder is subjected to compressive stress. Different rock samples are found to give different compressive strength varying from a min of 45 MPa – 545 MPa.

→ As said earlier the compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete. For this reason assessment of strength of the aggregate is made by using a sample of bulk aggregate in standardised manner. The test is known as "aggregate crushing value test".

Aggregate Impact value

→ With respect to concrete aggregates, toughness is usually considered the resistance of the material to failure by impact.

→ Several attempts to develop a method of test for aggregates impact value have been made.

→ The most successful is the one in which a sample of standard aggregates kept in a mould is subjected to 15 blows of a metal hammer of weight 14 kgs falling from a height of 38cms.

→ The quantity of finer materials resulting from pounding will indicate the toughness of the sample of aggregates.

→ The ratio of the fines formed to the weight of the total sample taken is expressed as a %.

Aggregate Abrasion Value

→ Apart from testing aggregates with respect to crushing value, impact resistance testing the aggregate with respect to its resistance to wear is an important test for aggregates to be used for road construction & pavement construction.

Modulus of Elasticity

→ Modulus of elasticity of aggregate depends upon its composition, texture and structure. The modulus of elasticity of aggregate will influence the properties of concrete with respect to shrinkage and elastic behaviour and to very small extent of creep of concrete.

→ Elasticity of aggregate has a decided effect on the elastic property of concrete and that the relation of elasticity of aggregate that of the concrete is not a linear function, but may be expressed as an equation of exponential type.

Specific gravity

→ In concrete technology sp. gravity of aggregates is made use of in design calculation of concrete mixes. Avg specific gravity of the rock vary from 2.6 to 2.8

Bulk density

→ Bulk density shows how densely the aggregates is packed when filled in a standard manner.

→ The bulk density depends on the particle size distribution and shape the particles

Absorption and moisture content

→ Some of the aggregates are porous and absorptive. porosity and water absorption of aggregates will effect the w/c ratio and hence the workability of concrete.

→ The porosity of aggregates will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

Bulking of aggregates

→ The free moisture content in fine aggregate results in bulking of volume

→ free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighbouring particles away from it.

→ The extent of bulking can be estimated by a simple test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner.

$$\% \text{ of bulking} = \frac{h_1 - h_2}{h_2} \times 100$$

h_1 = fine aggregate

h_2 = fine aggregate with water.

Soundness of aggregate:

-> Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of change in physical conditions.

-> These physical conditions that affect the soundness of aggregate are as the freezing and thawing, variation in temperature, alternate wetting and drying under normal condition and drying & wetting in salt water.

-> Aggregates which are porous, weak and containing any undesirable extraneous matter undergo excessive volume change when subjected to the above condition.

-> Aggregates which undergo more than specified amount of volume change is said to be unsound aggregates.

Alkali Aggregate:

-> For a long time aggregates have been considered as inert materials but later on point was clearly brought out that the aggregates are not fully inert. Some of the aggregates contain reactive silica, which reacts with alkalies present in cement. i.e. sodium oxide and potassium oxide.

-> The reaction starts with attack on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from the alkalies in cement.

-> As a result the alkali silicate gels of unlimited swelling type are formed. When the condition are congenial, progressive manifestation by swelling take place, which results in disruption of concrete with spreading of pattern cracks and eventual failure of concrete structure.

-> The rate of deterioration may be slow or fast depending upon the condition. There were cases where concrete has become unserviceable in about a year time.

THERMAL PROPERTIES :

→ Rock and aggregates possess 3 thermal properties which are significant in establishing the quality of aggregate for concrete construction they are:

1) co-efficient of expansion 2) specific heat 3) Thermal conductivity

→ An avg value of the mean thermal co-efficient of expansion of concrete may be taken as $9.9\times10^{-6}/^\circ C$ but the range may be from about $5.6\times10^{-6}/^\circ C - 14\times10^{-6}/^\circ C$ depending upon the type and quantities of the aggregates the mix proportions and other factors.

→ The range of co-efficient of thermal expansion for hydrated cement paste may vary from $10.8\times10^{-6}/^\circ C$ to $16.2\times10^{-6}/^\circ C$. For mortar it may range from $7.9\times10^{-6}/^\circ C$ to $12\times10^{-6}/^\circ C$.

→ For common rocks ranges from $0.9\times10^{-6}/^\circ C$ to $16\times10^{-6}/^\circ C$

SIEVE ANALYSIS

→ This is the name given to the operation of dividing a sample of aggregates into various fractions each consisting of particles of the same size.

→ The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate which are called gradation.

→ The aggregates used for making concrete are normally of the maximum size 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm 600µ, 300µ, and 150µ

→ The aggregates fraction from 80mm–4.75mm are termed as coarse aggregate and those fraction from 4.75mm–150µ are termed as fine aggregates.

→ The size 4.75mm is a common fraction appearing both in coarse aggregates and fine aggregates (CA & FA)

→ The material retained on each sieve after shaking, represents the fraction of aggregates coarser than the sieve in question and finer than the sieve above.

→ Sieving is done either manually (or) mechanically

→ In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve. operation should be continued for such time that almost no particle is passing through.

Fineness Modulus:

→ from the sieve analysis the particle size distribution in a sample of aggregates is find out. In this connection a term known as "Fineness Modulus"

→ Fineness modulus is a good index of coarseness (or) fineness of the material.

→ Fineness modulus is an empirical factor obtained by adding the cumulative % of aggregates retained on each of the standard sieve ranging from 80mm-150 microns and dividing this sum by an arbitrary number 100.

The following limits may be taken as guidance.

	F M
Fine sand	— 2.2 – 2.6
Medium sand	— 2.6 – 2.9
Coarse sand	— 2.9 – 3.2

→ A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Grading of Aggregates

→ Aggregate comprises about 55% of the volume of mortar and 85% volume of mass concrete.

→ Mortar contains aggregates of size 4.75mm and concrete contains aggregate upto a maximum size of 150mm.

→ It is well known that the strength of concrete is depend upon w/c ratio provided the concrete is workable.

→ One of the most important factor for producing workable concrete is good gradation of aggregates

→ Good grading implies that a sample of aggregates contains all standard fractions of aggregates in required proportion such that the sample contains minimum voids.

→ A sample of well graded aggregates containing minimum voids will require minimum paste to fill up the voids in aggregates

→ Minimum paste will be mean less quantity of water which will furthermean ~~less quantity of cement and less quantity of water~~ increased economy higher strength, lower shrinkage and greater durability.

→ The advantage due to good grading of aggregates can also be viewed from another angle. If concrete is viewed as a two phase material paste phase and aggregate phase it is the paste phase which is vulnerable to all ills of concrete.

→ Paste is weaker than avg aggregate in normal concrete with some exception when very soft aggregates are used.

→ The paste is more permeable than many of the mineral aggregates. It is the paste that is susceptible to deterioration by the attack of aggressive chemicals.

→ In short, it is the paste which is weak link in a mass of concrete. This objective can be achieved by having well graded aggregates. Hence the importance of good grading.

Gap Grading :

→ sofar we discussed the grading pattern of aggregates in which all particle size are present in certain portion in a sample of aggregate. such pattern of particle size distribution is also referred as continous grading.

→ originally in the theory of continuous grading, it was assumed that the voids present in the higher size of the aggregates are filled up by the next lower size of aggregate

→ similarly the voids created by lower size are filled up by the lower than those particles and so on

→ It have been seen that the size of voids existing b/w a particular size of aggregate is of the order of 2 (or) 3 size lower than that of fraction. In other words the void size existing b/w 40mm aggregates is of the size equal to 10mm (or) particle size of voids occurs when 20mm aggregate by 4.75mm (or) the size of voids of say 1.18mm (or) 0.6 ∴ along with ... used in order of say 1.18mm (or) 0.6, ∴ along with 20mm aggregate only when 1.18mm aggregate size is used.

Advantages of gap graded concrete:

i) sand required will be of the order of about 26% as against about 40% in the case of continous grading.

ii) specific surface area of the gap graded aggregate will be low because of high % of C.A & low % of F.A.

iii) Requires less cement and lower water/cement ratio.

iv) Because of point contact b/w C.A & C.A and also on account of lower cement and matrix content the drying shrinkage is reduced.

UNIT-III a

FRESH CONCRETE

-> Fresh concrete (or) plastic concrete is a freshly mixed material which can be moulded into any shape.

-> The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state.

Workability:

-> 100% compaction of concrete is an important parameter for contributing to the maximum strength. Lack of compaction will result in air voids whose damaging effect on strength and durability is equally (or) more predominant than the presence of capillary cavities.

-> To enable the concrete to be fully compacted with given efforts normally a higher water / cement ratio than that calculated by theoretical consideration may be required. That is to say the function of water is also to lubricate the concrete so that the concrete can be compacted with specified effort forth coming at the site work.

-> The word "workability" (or) workable concrete" signifies much wider and deeper meaning than the other terminology "consistency" often used loosely for workability.

-> Consistency is a general term to indicate the degree of fluidity (or) the degree of mobility.

-> A concrete which has high consistency and which is more mobile, need not be of right workability for a particular job. every job requires particular workability.

-> A concrete which is required workable for mass concrete for foundation is that not workable for concrete to be used in roof construction or even in roof construction. concrete considered workable when vibrator is used is not workable when concrete is hand compacted by hand.

→ similar concrete ... workable when used in a thin section is not workable when required to be used in thin section. Therefore the word workability assumes full significance of the type of work, thickness of section, extent of reinforcement and mode of compaction.

→ Workability is defined as property of concrete which determines the amount of useful internal work necessary to produce full compaction.

→ Another definition which envelopes a wider meaning is that it is defined as the ease with which concrete can be compacted 100% having regard to mode of compaction and place of deposition.

FACTORS AFFECTING WORKABILITY:

→ Workable concrete is the one which exhibits very little internal friction between particle and particles which overcomes the frictional resistance offered by the form work surface or reinforcement contained in the concrete with just the amount of compacting efforts forth coming.

1) Water Content
2) Mix proportion
3) Size of aggregates
4) Shape of aggregates
5) Surface texture of aggregates
6) Grading of aggregates
7) Use of admixtures.

→ The above are the factors affecting to the workability of concrete.

MEASUREMENT OF WORKABILITY

→ The following test are commonly employed to measure workability

1) Slump test

2) Compaction factor test

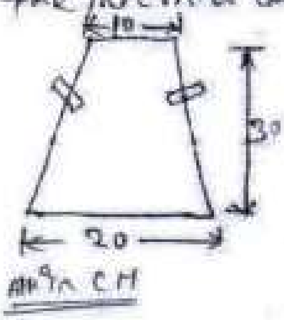
3) Flow test

4) Vee bee consistometer test.

1) Slump test

→ Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory (or) at site of work.

→ The apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimension under.



Bottom diameter : 20cm

Top diameter : 10cm

Height : 30cm

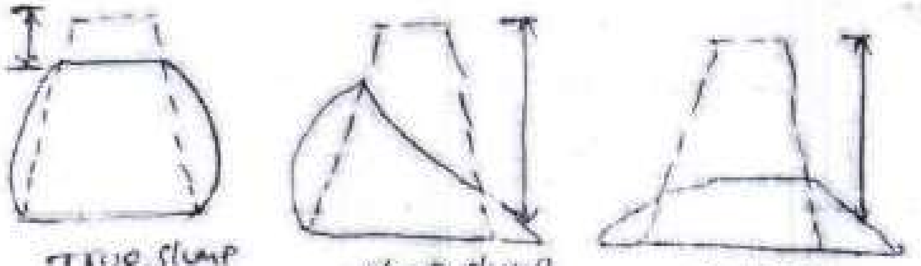
Tamping rod : 16mm dia, 0.6m long

→ The mould is placed on a smooth horizontal, rigid and non absorbent surface the mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod taking care to distribute the strokes evenly over the cross section.

→ After the top layer has been rodded the concrete is struck off level with a trowel and tamping rod.

→ The mould is removed immediately by raising it slowly and carefully in a vertical direction.

→ This allows the concrete to subside. The subsidence is referred as slump of concrete.



→ The pattern of slump is shown in fig. It indicates the characteristic of concrete in addition to the slump cone value.
→ If the concrete slumps evenly it is called true slump.
→ If one half of the cone slides down, it is called shear slump. It is also indicates the concrete is non-cohesive and shows the characteristic of segregation.
→ If the concrete slumps totally collapsed is called collapse.
→ It is seen that the slump test gives fairly good consistent results for a plastic mix. This test is not sensitive for a stiff mix. In case of dry mix, no variation can be detected between mixes of different workability.

Degree of workability	Slump (mm)
Low	25–75
Medium	~~50–100~~ 50–100
High	100–150
Very high	—

2) Compacting factor test

→ The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field.
→ It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to compacted by vibration

Dimension of the compacting factor test.

Upper hopper A	Dimension (cm)
Top internal dia	25.4
Bottom internal dia	12.7
Internal height	27.9
Lower hopper B	
Top internal dia	22.9
Bottom internal dia	12.7
Internal height	22.9
Cylinder C	
Internal dia	15.2
Internal height	30.5
Distance b/w hopper	20.3

→ The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap door is opened so that the concrete falls into the lower hopper. Then the trap door of the lower hopper is opened and the concrete is falls into the cylinder.

→ The excess of concrete remaining above the cylinder is then cut off with the help of plane blades supplied with the apparatus.

→ The outside of the cylinder is wiped clean. The concrete is filled up exactly upto the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as "weight of partially compacted concrete"

→ The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5cm deep. The layers are heavily rammed or vibrated as a full compaction. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10gm. This weight is known as "weight fully compacted concrete"

$$\text{Compaction factor} = \frac{\text{wt of partially compacted concrete}}{\text{wt of fully compacted concrete}}$$

3) Flow test:

→ This is a laboratory test which gives an indication of the Quality of concrete with respect to consistency, cohesionless and the proneness to segregation.

→ This apparatus consist of flow table about 76cm in diameter.

→ The mould made from smooth metal casting in the form of frustum of a cone is used with the following internal dimens. The base is 25cm in dia, upper surface 17cm in dia. and height of the cone is 12cm.

→ The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6cm in dia and 61cm long.

→ The top layer is rodded evenly the excess of concrete which has overflowed the mould is removed.

→ The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5mm 15 times in about 15 sec. The

→ The diameter of spread concrete is measured in about 6 directions to the nearest 5mm and the avg spread is noted.

$$\text{Flow \%} = \frac{\text{spread dia in cm} - 25}{25} \times 100.$$

→ The value could range anything from 0 to 150%

4) Vee-Bee consistometer test:

→ This is good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod.

→ slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer.

-> The glass disc attached to the swivel arm is turned and is placed on the top of the concrete in the pot.
-> The electrical vibrator is then switched on and simultaneously a stop watch started. The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape.
-> This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete is fully assumes a cylindrical shap the stopwatch is switched off.
-> The time required for the shape of concrete to change from slump cone test to cylindrical shape in seconds is known as Vee-Bee degree.

SETTING TIME OF CONCRETE:

-> The setting time of concrete depends upon w/c ratio, temperature conditions, type of cement, use of mineral admixtures, use of plasticizers in particular retarding plasticizers.
-> The setting parameter of concrete is more of practical significance for site engineers than setting time of cement.
-> When retarding plasticizers are used, the increase in setting time, the duration upto which concrete remains in plastic condition is of special interest.
-> The setting time of concrete is found by penetrometer test.
-> The apparatus consist of container which should have minimum lateral dimension of 150mm and minimum depth of 150mm.
-> There are 6 penetration needles with bearing area of 645, 323, 161, 65, 32 and 16 mm^2. Each needle stem is scribed circumferentially at a distance of 25mm from the bearing area.

→ The test procedure involves the collection of representative sample of concrete in sufficient quantity and sieve it through 4.75mm sieve and the resulting mortar is filled in the container.
→ Compact the mortar by rodding, tapping, rocking or by vibrating.
Level the surface and keep it covered to prevent the loss of moisture. Remove bleeding water, if any by means of pipette.
→ Insert a needle of appropriate size, depending upon the degree of setting of mortar in the following manner.
→ Bring the bearing surface of needle in contact with the mortar surface. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5mm, as indicated by the scribe mark.
→ The time taken to penetrate 25mm depth could be about 10 sec. Record the force required to produce 25mm penetration and the time of inserting from the time water is added to cement.
→ Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance.
→ For the subsequent penetration avoid the area where the mortar has been disturbed. The clear distance should be two times the diameter of the bearing area. Needle is inserted at least 25mm away from the wall of container.
→ Plot a graph of penetration resistance as ordinate and elapsed time as abscissa, not less than six penetration resistance determination is made.
→ Continue the tests until one penetration resistance of at least 27.6 MPa is reached. Connect the various points by a smooth curve.
→ Penetration resistance equal to 3.5 MPa draw a horizontal line. The point of intersection of this with the smooth curve is read on the X axis which gives the initial setting time. Ily horizontal line is drawn from the penetration resistance of 27.6 MPa and the point it cuts the smooth curve is read on the X axis which gives final set.

SEGREGATION :

→ Segregation can be defined as the separation of the constituent materials of concrete.

→ A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture.

→ If a sample of concrete exhibits a tendency for separation of coarse aggregate from the rest of the ingredients, that sample is said to be showing the tendency for segregation. Such a concrete is not only going to be weak, lack of homogeneity is also going to induce all undesirable properties in the hardened concrete.

→ Segregation may be of three types

* Coarse aggregate separating out or settling down from the rest of the matrix.
* The paste (or) matrix separating from coarse aggregate and ~~material~~
* Water separating out from the rest of the material being a material of lowest specific gravity.

→ A well made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregates with optimum quantity of water makes a cohesive mix. Such concrete will not exhibit any tendency for segregation.

→ The conditions favourable for segregation are as can be seen from the above para, the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation.

→ Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation.

→ Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. If trowel action is excessively vibrated, it is likely that the concrete gets segregated.

→ In the recent time we use concrete with very high slump particularly in RMC. The slump value required at the batching point may be in the order of 150mm and at the pouring point the slump may be around 100mm.

~~Segregation~~

→ While finishing concrete floors with a view to achieve a smooth surface masons are likely to work too much with the trowel, float (or tamping rule) immediately on placing concrete. This immediate working on the concrete on placing without any time interval is likely to press the coarse aggregate down which results in the movement of excess of mortar (or paste) to the surface. Segregation caused on this account impairs the homogeneity and serviceability of concrete. The excess mortar at the top causes plastic shrinkage cracks.

→ Segregation is difficult to measure quantitatively but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test (or) the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

BLEEDING:

→ Bleeding is sometimes referred as water gain. This a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity amongst all the ingredients of concrete.

→ Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slabs (or) road slabs and when concrete is placed in sunny weather show excessive bleeding.

→ due to bleeding water with it accumulates at the surface sometimes along with this water, certain quantity of cement also comes to the surface.

→ when the surface is worked up with the trowel and floats the aggregates goes down and the cement and water comes up to top surface. This formation of cement paste at the surface is known as "Laitance".

→ In such a cases the top of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season.

→ water while traveling from bottom to top, makes continuous channels, if the water cement ratio is used more than 0.7 the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

→ The bleeding water is likely to accumulate below the aggregate. This accumulation of water create of water voids and reduces the bond b/w the aggregates and the paste.

→ Bleeding rate increases with time up to about one hour or so and thereafter rate decreases but continues more or less till the final setting time of cement.

→ Bleeding presents a very serious problem when slip form paver is used for construction of concrete pavements. If the mix of bleeding water accumulates on the surface of pavement slab the bleeding water flows out over the unsupported sides which causes collapsing of sides.

Method of test for bleeding of concrete

→ This method covers determination of relative quantity of mixing water that will bleed from a sample of freshly mixed concrete.

→ A cylindrical container of approximately 0.01 m³ capacity, having an inside diameter of 250mm and inside height of 280mm is used. A tamping bar similar to the one used for slump test is used. A pipette for drawing off free water from the surface a graduated jar of 100cm³ capacity is required for test.

→ A sample of freshly mixed concrete is obtained the concrete is filled in 50mm layer for a depth of 250 ± 3 mm (5 layers) and each layer is tamped by giving strokes, and top surface is made smooth by trowelling.

→ The test specimen is weighed and the weight of the concrete is noted. Knowing the total water content in 1 m³ concrete. quantity of water in the cylindrical container of concrete is also calculated.

→ The cylindrical container is kept in a level surface free from vibration at a temperature of 27°C ± 2°C it is covered with a lid. water accumulated at the top is drawn by means of pipette at 10 minutes interval for the first 40 min and at 30 min. interval subsequently till bleeding cease. To facilitate collection of bleeding water the container may be slightly tilted. All the bleeding water collected in a jar.

$$\text{Bleeding \%} = \frac{\text{Total quantity of bleeding water}}{\text{Total quantity of water in sample of concrete}} \times 100$$

STEPS IN MANUFACTURE OF CONCRETE:

→ The various stages of manufacture of concrete are.

1) Batching
2) Mixing
3) Transporting
4) Placing
5) Compacting
6) Curing
7) Finishing.

1) Batching:

→ The measurement of materials for making concrete is known as "batching".

→ There are two methods of batching.

i) Volume Batching ii) Weigh Batching.

i) Volume Batching:

— Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume.

→ Cement is always measured by weight, it is never measured in volume. Generally for each batch mix one bag of cement is used. The volume of 1 bag of cement is taken by 35 litres.

→ Gauge boxes are used for measuring the fine and coarse aggregates. The volume of the box is made equal to the volume of 1 bag of cement i.e 35 litres

→ Gauge boxes are generally called farmas. They can be made of timber (or) steel plates.

-> water is ... expect in kg, litres or ... be convenient. In this case the two units are same as the density of water is one kg/litre. The quantity of water required is a product of water/cement ratio and the weight of cement.

-> For example if the water/cement ratio of 0.5 is specified the quantity of mixing water is required per bag of cement is 0.5x50 = 25 kg (or litres)

Batch volume of materials for mixes

Grade	Cement (kg)	Sand (litres)	aggregate (litres)
1:1:2 (M200)	50	35	70
1:1½:3 (M200)	50	52.5	105
1:2:3	50	70	105
1:2:4 (M150)	50	70	140
1:2½:5	50	87.5	175
1:3:6	50	105	210

ii) weigh Batching:

-> weigh batching is the correct method of measuring the materials. For important concrete weigh batching is adopted.

-> use of weigh system in batching facilities accuracy, flexibility and simplicity. Different types of weigh batches are available.

-> The particular type to be used, depends upon the nature of the job. large weigh batching plants have automatic weighing is one of sophistication and requires qualified and experienced engineers. In this further complication will come to adjust water content to water for the moisture content in the aggregates.

-> In small jobs cement is often proportioned ... it is assumed ... bags assuming the weight of the bag as 50kg. In reality though the cement bag is made of 50kg at the factory due to transportation when the bags are used. In fact the weight of a cement bag at the site is considerably less. Some times the loss of weight becomes more than 5kg. This is one of the sources of error in volume.

-> Batching and weigh batching when the cement is not actually weighed. But in important major concreting jobs, cement is also always weighed and exact proportion as designed is maintained.

2) Mixing:

-> Through mixing of the material is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency.

-> There are two methods adopted for mixing concrete.

1) Hand mixing.
2) Machine mixing.

1) Hand mixing:

-> Hand mixing is practised for small scale unimportant concrete works.

-> As the mixing cannot be thorough and efficient, it is desirable to add 10% more cement to cater for the inferior concrete produced by this method.

2) Machine mixing:

-> Mixing of concrete is almost invariably carried out by machine for reinforced concrete work and for medium (or large scale mass concrete work.

-> Machine mixing is not only efficient but also economical when the quantity of concrete to be produced is large.

3) Transporting:

→ The methods adopted for transportation of concrete.

i) Mortar pan (ii) Wheel barrow, Hand cart

iii) Crane, Bucket and rope way iv) Truck mixer & dumper

v) Belt conveyors vi) Chute.

vii) Skip and Hoist viii) Transit mixer

ix) Pump and pipeline x) Helicopter.

4) Placing of concrete:

→ It is not enough that a concrete mix correctly designed, batched mixed and transported, it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results.

→ Concrete is invariably laid on foundation bed below the walls (or) columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed.

→ For the construction of road slabs, airfield slabs and ground floor slabs in buildings, concrete is placed in bays. The ground surface on which the concrete is placed must be free from loose earth, pool of water and other organic matters like grass, roots, leaves etc.

→ When concrete is laid in great thickness as in the case of concrete raft for a high rise building (or) in the construction of concrete pier for abutment (or) in the construction of mass concrete dam, concrete is placed in layers.

→ Before placing the concrete the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush.

5) Compaction:

→ Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In process of mixing, transporting and placing of concrete air is likely to get entrapped in the concrete.

Methods of compaction:

i) Hand compaction

a) Rodding b) Ramming c) Tamping

ii) Compaction by vibration

a) Internal vibrator
b) Formwork vibrator
c) Table vibrator
d) Platform vibrator
e) Surface vibrator
f) Vibratory roller

iii) Compaction by pressure and jolting

iv) Compaction by spinning.

6) Curing:

→ Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately it can be described as the process of maintaining a satisfactory moisture content and a favourable temp. in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service.

→ A quick surface drying of concrete results in the movement of moisture from the interior to the surface.

Curing Methods:

a) Water curing → Immersion, ponding, spraying, wet covering

b) Membrane curing – steam curing, electrical, infra-red radiation

c) Application of heat –

7) FINISHING:

→ Finishing operation is the last operation in making concrete. Finishing in real sense does not apply to all concrete operations, may not be applicable.

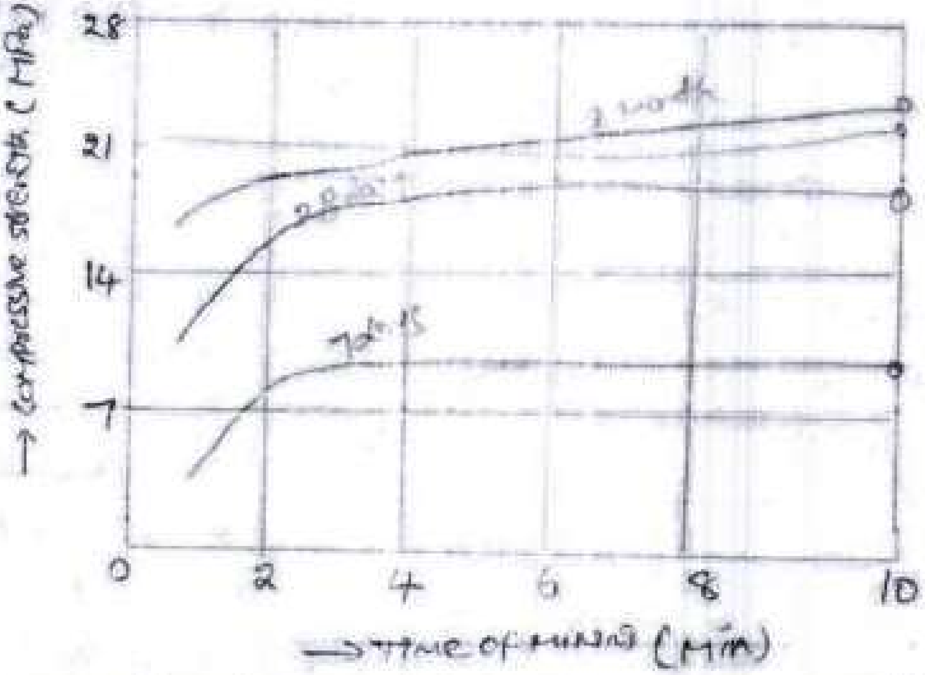
→ For a beam concreting, finishing may not be applicable, domestic buildings, road pavement, airfield pavement, careful finishing is of great importance.

EFFECT OF TIME & TEMPERATURE ON WORKABILITY:

→ Concrete mixers are generally designed to run at a speed of 15–20 revolutions per minute.

→ For proper mixing it is seen that about 25–30 revolutions are required in a well designed mixer.

→ In the site the normal tendency is to speed up the mixing time. The out turn of concrete by reducing the mixing time on the other hand, it results in poor quality of concrete. On the other hand, if the concrete is mixed for a comparatively longer time, it is uneconomical from the point of view of rate of production of concrete and fuel consumption, therefore it is of importance to mix the concrete for such a duration which will accrue optimum benefit.



→ It is seen from the experiment that the quality of concrete in terms of compressive strength will increased with the increase in time of mixing but for mixing time beyond two min the improvement in compressive strength is not very significant. The graph shows the effect of mixing time on strength of concrete.

→ Concrete mixer is not a simple apparatus. Lot of considerations have gone as input in the design of the mixer. The shape of drum, the number of blades, inclination of blades with respect to drum surface, the length of blades, the depth of blades, the space b/w the drum and the blades, the space b/w the metal strips of blades and speed of rotation etc. are important to give uniform mixing quality and optimum time of mixing.

→ Generally mixing time is related to the capacity of mixer. The mixing time varies b/w 1½ to 2½ minutes. Bigger the capacity of drum more is the mixing time. However modern high speed pan mixer used in RMC, mixes the concrete in about 15 to 30 secs. One cubic meter (1m3) capacity high speed pan mixer takes only about 2 min. for batching and mixing. The batching plant takes about 12 min. to load a transit mixer of 6m3 capacity.

→ Some times, at site some concrete may not be discharged from the drum and concrete may be kept rotating in the drum for long time. as for instance when some travel (or) dispute takes place with the workers (or) when an anticipated repair (or) modification is required to be done on form work and reinforcement.

→ Long time mixing of concrete will generally result in increase of compressive strength of concrete within limits. Due to mixing over periods the effective water/cement ratio gets reduced.

→ The evaporation of water and formation of excess fines may reduces the workability and hence bring about reduction in strength. The excess of fine may also cause greater shrinkage.

RETEMPERING OF CONCRETE:

→ The process of remixing of concrete if necessary with addition of just the required quantity of water is known as "Retempering of concrete". Sometimes a small quantity of extra cement also added while retempering. Many specifications do not permit mortar requiring renewed mixing with (or) without addition of cement, aggregate (or) water.

→ The production of concrete of excessive slump (or) adding water in excess of designed water cement ratio to compensate for slump loss resulting from delays in delivery should be prohibited.

→ Retempering of concrete is too wet after a delay of about one hour as an increase in compressive strength of 2 to 15%.

Quality of Mixing water

→ Concrete is a chemically combined mass which is transformed from binding materials and inert material with water.

Functions of water in concrete:-

→ To wet the surface of aggregate to develop adhesion because the cement paste adhers quick and satisfactory to the surface of the aggregates than to a dry surface.

→ To make a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position

→ water is also needed for the hydration of the cementing material to set and harden during the period of curing

→ Quantity of water in the mix plays a vital role on the strength of the concrete, some water which have adverse effect on hardened concrete. sometimes may not be harmless (or) even beneficial during mixing.

→ The affect on concreting for different types of contamination (or) impurities are described below-

1) Suspended solids:

→ Mixing water with high content of suspended solids should be allowed to stand in a settling tank basin before use as it undesirable to introduce large quantities of clay and silt into the concrete

2) Acidity & Alkalinity:

→ natural water that is slightly acidic are harmless, but presence of humic (or) other organic acids may result adverse effect over the hardening of concrete. Waters which are highly alkaline should also be tested.

3) Algae:-

→ The presence of algae in mixing water causes air entrainments with a consequent loss of strength. The Green (or) brown slime forming algae should be regarded with suspicion and such water should be tested carefully.

4) Sea water:-

→ Sea water contains a total salinity of about 3.5% (78% of the dissolved solids being NaCl and 15% $MgCl_2$ and $MgSO_4$) which produces a slightly higher early strength but a lower long term strength.

→ The loss of strength is usually limited 15% and can therefore be tolerated. Sea water reduces the initial setting time of cement but do not effect final setting time.

5) Chloride:-

→ Water containing large amount tends to cause persistent dampness and surface efflorence.

→ The presence of chlorides in concrete containing embedded steel can lead to its corrosion.

6) Moisture content of aggregates:-

→ Aggregates usually contains some surface moisture. Coarse aggregate rarely contains more than 1% of surface moisture but fine aggregate can contain in excess of 10%.

→ This water can represent a substantial proportion of the total mixing water indicating a significant importance in the quantity of water that contributes surface moisture in aggregate.

UNIT-III
HARDENED CONCRETE

→ The compressive strength of concrete is one of the most important and useful properties of concrete.

→ Compressive strength is also used a qualitative measure for other properties of hardened concrete.

→ No exact quantitative relationship b/w compressive strength and flexural strength, tensile strength, modulus of elasticity, wear resistance fire resistance or permeability.

→ The compressive strength of concrete is generally determined by testing cubes. When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure.

→ The modern version of original water/cement ratio rule can be given as follows.

1) Ratio of cement to mixing water
2) Ratio of cement to aggregates
3) Grading, surface texture, shape, strength and stiffness of aggregate.
4) Maximum size of aggregate.

Water/Cement ratio:

→ Strength of concrete primarily depends upon the strength of cement paste. It has been depends upon the dilution of paste

→ The strength of paste increases with cement content and decreases with air and water content

$$S = \frac{A}{B^x}.$$

x = water cement ratio by volume and for 28 days results the constant A & B are 14,000 lbs/sq.in and 7 respectively.

→ Abrams W/C ratio law states that the strength of concrete is only dependent upon W/C ratio provided the mix is workable.

→ According to the strength of concrete paste and concrete in terms of volume fraction of the constituents by the equation

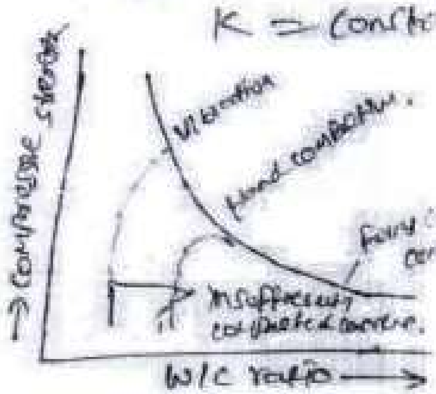
$$S = K\left(\frac{c}{c+e+a}\right)^2$$

where,

S = strength of concrete

c, e and a = volume of cement, water and air

K = constant



→ In this expression the volume of air is also included because it is not only the water/cement ratio but also the degree of compaction, which indirectly means the volume of air filled voids in the concrete is taken into account in estimating the strength of concrete.

→ It can be seen that lower water/cement ratio could be used when the concrete is vibrated to achieve higher strength, whereas comparatively higher water/cement ratio is required when concrete is hand compacted. In both cases when the water/cement ratio is below the practical limit the strength of concrete falls rapidly due to introduction of air voids.

→ The graph showing the relationship b/w the strength and water/cement ratio is approximately hyperbolic in shape. Sometimes it is difficult to interpolate the intermediate value.

Gel/space ratio:

→ Instead of relating the strength to w/c ratio, the strength can be more related to the solid products of hydration of cement to the space available for formation of this product.

→ Gel/space ratio is defined as the ratio of the volume of the hydrated cement space to the sum of the volumes of the hydrated cement and of the capillary pores.

→ Power experiment showed that the strength of concrete bear a specific relationship with the gel/space ratio. He found the relationship to be $240x^3$, where x is the gel/space ratio and 240 represents the intrinsic strength of gel in MPa for the type of cement and specimen used.

→ The relationship b/w the strength and water/cement ratio will hold good primarily for 28 days strength for fully compacted concrete, whereas the relationship b/w the strength and gel/space ratio is independent of age.

→ Gel space ratio can be calculated at any age and for any fraction of cement.

→ The following example show how to calculate gel/space ratio

Calculation of gel/space ratio for complete hydration:

C = weight of cement in gm

V_c = specific volume of cement = 0.319 ml/gm

W_o = volume of mixing water in (ml)

Assuming that 1 ml of cement on hydration will produce 2.06 ml of gel

Volume of gel = $C \times 0.319 \times 2.06$

Space available = $C \times 0.319 + W_o$

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$\therefore$ Gel/space ratio $= \frac{\text{vol of gel}}{\text{space available}}$

$$x = \frac{0.657C}{0.319C + W_0}$$

Calculation of gel/space ratio for Partial hydration:

α = fraction of cement that has hydrated

Volume of gel $= C \times \alpha \times 0.319 \times 2.06$

Total space available $= C V_c \alpha + W_0$

$\therefore$ Gel/space ratio $= x = \frac{2.06 \times 0.319 \times C\alpha}{0.319 C\alpha + W_0} = \frac{0.657C\alpha}{0.319C\alpha + W_0}$

Ex:

Calculate the gel/space ratio and the theoretical strength of a sample of concrete made with 500gm. of cement with 0.5 w/c ratio, on fully hydration & at 60% hydration.

Ans: Gel/space ratio $= \frac{0.657C}{0.319C + W_0}$ $[W_0 = 0.5 \times 500,\ W_0 = 250]$

$$x = \frac{0.657 \times 500}{0.319 \times 500 + 250}$$

$$x = 0.8$$

$\therefore$ Theoretical strength of concrete $= 240 \times (0.8)^3$

$= 123$ MPa.

Gel/space ratio for 60% hydration $\alpha = 0.6$

$$x = \frac{0.657C\alpha}{0.319C\alpha + W_0}$$

$$x = \frac{0.657 \times 500 \times 0.6}{0.319 \times 500 \times 0.6 + 250}$$

$$x = 0.57$$

$\therefore$ Theoretical strength of concrete $= 240 \times (0.57)^3$

$= 44.4$ MPa.

Maturity concept of concrete:

→ strength development of concrete depends on both time and temperature. It can be said that strength is a function of summation of product of time and temperature. This summation is called maturity of concrete.

$$\therefore \text{Maturity} = \Sigma (\text{time} \times \text{temp})$$

→ The datum line for computing maturity is $-11°C$.

→ maturity is measured in °CH (or) 0°C (Degree centigrade)

→ A sample of concrete cured at 18°C for 28 days taken a fully matured concrete.

$$\text{maturity} = 28 \times 24 \times (18-(-11°))$$
$$= 19488°Ch.$$

→ In standard calculations the maturity of fully cured concrete is taken as 19,800°Ch.

→ Maturity concept is useful for estimating the strength of concrete at any other maturity as a percentage of strength of concrete of known maturity.

strength at any maturity as a % of strength of maturity

$$19{,}800\,°Ch = A + B\log_{10}\frac{(\text{maturity})}{10^3}$$

Plowman's coefficient for maturity eqn.

Strength after 28 days at 18°C (MPa)	Coefficient	
	A	B
< 17.5	10	68
17.5 – 35.0	21	61
35.0 – 52.5	32	54
52.5 – 70.0	42	46.5

Ex (1)

The strength of a sample of fully matured concrete is found to be 40 MPa find the strength of identical concrete at the age of 7 days when cured at an avg. temp. during day time at 20°C and night time 10°C.

Sol

Maturity of concrete at 7 days = Σ(time × temp)

$= 7 \times 12 \times (20-(-11)) + 7 \times 12 \times (10-(-11))$

$= 4368\ °C\,h$.

∴ Strength range of this concrete falls in zone III

∴ A = 32, B = 54.

% strength of concrete

maturity of 4368 °Ch $= A + B \log_{10} \frac{(\text{maturity})}{10^3}$

$= 32 + 54 \log_{10} \frac{(4368)}{10^3}$

$= 66.5\%$

∴ strength at 7 days $= 40 \times \frac{66.5}{100}$

= 26.5 MPa.

Ex 2 Laboratory experiments conducted at Pune on a particular mix showed a strength of 32.5 MPa for fully matured concrete. Find whether formwork can be removed for an identical concrete placed at Srinagar at the age 15 days when the avg temp. is 5°C. The concrete is likely to sustain a stripping stress of 25 MPa.

Sol Maturity of concrete at 15 days $= 15 \times 24 \times (5-(-11))$

$= 5760\ °C\,h$.

Concrete falls in A = 21, B = 61 Zone II.

% strength of concrete $= 21 + 61 \log_{10} \frac{(5760)}{10^3}$

= 67.38 %

∴ strength at 15 days $= 32.5 \times \frac{67.38}{100}$

= 21.9 MPa.

Nature of strength of concrete:

→ The paramount influence of voids in concrete on its strength has been repeatedly mentioned and it should be possible to relate this factor to the actual mechanism of failure.

→ For this purpose concrete is considered to be a brittle material even though it exhibits a small amount of plastic action as fracture under static loading takes place at moderately low total strain.

→ a strain of 0.001 to 0.005 at failure has been suggested as the limit of brittle behavior.

→ High strength concrete is more brittle than normal strength concrete but there is no quantitative method of expressing the brittleness of concrete whose behavior in practice falls b/w the brittle and the ductile types.

Fracture & failure:

→ Concrete specimens subjected to any state of stress can support loads of upto 40-60% of ultimate without any apparent signs of distress.

→ Below this level any sustained load results in creep strain which is proportional to the applied stress and can be defined in terms of specific creep. Also concrete is below the fatigue limit.

→ Also the load increased above this level soft but distinct noises of internal disruption can be heard until about 70-90% of ultimate small fissures (or) cracks appear on the surface. At this stage sustained loads result in eventual failure.

Strength in hardened concrete:

1) Compressive strength:

→ It is tested in a standard manner which includes full compaction and wet curing for a specified period give results representing the potential quality of the concrete.

→ There are three types of loading in compression test.

i) Uniaxial loading
ii) Biaxial loading
iii) Triaxial loading

→ The uniaxial loading case represents the most conservative system and yields the lowest values in compression.

→ There are three types of failure in compression test.

i) Tension failure (splitting)
ii) Shear failure (sliding)
iii) Combined failure (tension & shear)

2) Tension strength:

→ Although concrete is not normally designed to resist direct tension the knowledge of tensile strength is of value in estimating the load under which cracking will develop.

→ The absence of cracking is considerable importance in maintaining the continuity of a concrete structure and in many cases in the prevention of corrosion of reinforcement.

→ There are two types of test for strength in tension test.

i) Direct tension test ii) Splitting tensile strength test

Relation B/w compressive and tensile strength:

-> In Reinforced concrete construction the strength of the concrete in compression is only taken into consideration.

-> The tensile strength of concrete is generally not taken into consideration. But the design of concrete Pavement slab is often based on the flexural strength of concrete.

-> As measurements and control of compressive strength in field are easier and more convinient, it has been customary to find out the compressive strength for different conditions and to correlate this compressive strength to flexural strength.

-> it is seen that strength of concrete in compression and tension are closely related, but the relationship is not the type of direct proportionality.

-> The two ratios of the strength depends on general level of strength of concrete. For higher compressive strength concrete shows higher tensile strength, but the ratio of increase of tensile strength is of decreasing order.

-> The type of coarse aggregate influences this relationship. crushed aggregate gives relatively higher flexural strength than compressive strength.

-> The tensile strength of concrete as compared to its compressive strength is more sensitive to improper curing.

-> The use of pozzolanic material increases the tensile strength of concrete.

-> Following Statical Relation b/w tensile and compressive strength

i) $y = 15.3x - 9.00$ for 20mm max. size aggregate.

ii) $y = 14.1x - 10.4$ for 20mm max. size natural gravel

iii) $y = 9.9x - 0.55$ for 40mm max. size crushed aggregate

iv) $y = 9.8x - 2.52$ for 40mm max. size natural gravel

where, y = compressive strength of concrete (MPa)

x = flexural strength of concrete (MPa)

→ There are number of empirical relationship b/w tensile strength and compressive strength of concrete.

$$\text{Tensile strength} = K\,(\text{compressive strength})^n$$

K = 6.2 for gravels

K = 10.4 crushed rock

n = 1/2 to 3/4

→ Indian Standard IS 456-2000 gives the following relationship b/w the compressive strength and flexural strength

$$\text{Flexural strength} = 0.7\sqrt{f_{ck}}$$

f_{ck} = characteristic compressive strength of concrete in N/mm².

CURING:-

→ The test specimens are stored in place free from vibration, in moist air of at least 90% relative humidity and at a temp. of 27° ± 2°C for 24 hours ± 1/2 hour from the time of addition of water to the dry ingredients.

→ After this period the specimen are marked and removed from the moulds and unless required for test within 24 hours, immediately submerged in clean fresh water or saturated lime solution and kept there until taken out just prior to test.

→ The water and/or solution in which the specimen are submerged, are renewed every seven days and are maintained at a temp. of 27°C ± 2°C. The specimens are not to be allowed to become dry at any time until they have been tested.

FLEXURAL STRENGTH OF CONCRETE :

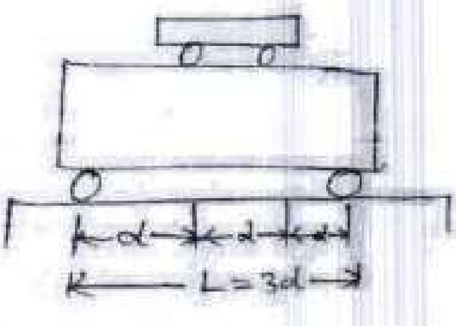
-> Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little independence is placed on the tensile strength of concrete.

Determination of Tensile strength :

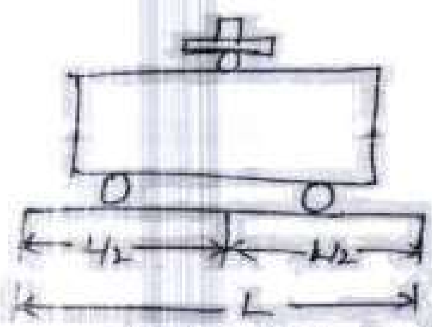
-> Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the pull applied to the concrete.

-> The value of the modulus of rupture depends on the dimension of the beam and manner of loading. The system of loading used in finding out the flexural tension are central point loading and third point loading.

-> In central point loading maximum fibre stress will come below the point of loading where the bending moment is maximum. In case of symmetrical two point loading the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum.



Third - point loading



Centre - point loading.

-> The standard size of specimen are 15×15×70cm. Alternatively if the largest nominal size of the aggregate does not exceed 20mm, specimen 10×10×50cm may be used.

SPLIT TENSILE TEST :

→ This is also called as cylinder splitting tension test (or) "Brazilian test"

→ This test is carried out by placing cylindrical specimen horizontally between the loading surface of a compression testing machine and the load is applied until failure of the cylinder, along the vertical diameter.

→ When the load is applied along the generatrix an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress of .

$$\frac{2P}{\pi LD}\left[\frac{D^2}{r(D-r)}-1\right]$$

and a horizontal stress of

$$\frac{2P}{\pi LD}$$

P = compressive load
L = length of cylinder
D = diameter.

→ The loading condition produces a high compressive stress immediately below the two generators to which the load is applied. But the larger portion corresponding to depth is subjected to a uniform tensile stress acting horizontally. It is estimated that the compressive stress is acting for about 1/6 depth and remaining 5/6 depth is subjected to tension.

→ In order to reduce the magnitude of the high compression stresses near the points of application of the load, narrow packing strips of suitable material such as plywood are placed b/w the specimen and loading platens of the testing machine. The packing strips should be soft enough to allow distribution of load over a reasonable area, yet narrow and thin enough to prevent large contact area. Normally a plywood strip of 25mm wide, 3mm thick, 30cm long used.

→ The main advantage of this method is that same type of specimen and the same testing machine as are used for the compression test

→ The splitting test is simple to perform and gives more uniform results than other tension tests.

NON-DESTRUCTIVE TESTING METHODS:

→ In this method as now a powerful method for evaluating existing concrete structures with regard their strength and durability apart from assessment and control of quality of hardened concrete.

→ Though non-destructive testing methods are relatively simple to perform the analysis and interpretation of test results are not so easy. The special knowledge is required to analyse the hardened properties of concrete.

NDT METHODS

1) Schmidt's Rebound hammer
2) Penetration techniques
3) Pullout test
4) Dynamic (or) vibration methods
5) Pulse velocity method.
6) Radioactive & nuclear methods
7) Magnetic & electrical methods

1) Schmidt's Rebound hammer:

→ It is one of the most commonly adopted equipments for measuring the surface hardness.

→ It consist of a spring control hammer that slides on a plunger within a tubular housing. When the plunger is pressed against the surface of concrete, the mass rebound from the plunger. It retracts against the force of the spring.

→ The hammer impacts against the concrete and the spring control mass rebounds, taking the rider with it along the guide scale.

→ The distance travelled by the mass is called the rebound number. It is indicated by the rider moving along a graduated

-> The test was conducted by horizontally, vertically — upwards (or) downwards (or) at any intermediate angle.

-> At each angle the rebound number will be different for the same concrete and will require seperate calibration (or) correction chart.

Limitations:

* smoothness of surface under test
* size, shape & rigidity of specimen.
* Age of specimen
* Surface and internal moisture condition of concrete.
* type of coarse aggregate.
* type of cement
* type of mould
* carbonation of concrete surface.

2) Penetration techniques:

-> The measurement of hardness by probing techniques was first reported during 1954. Two techniques were used.

-> In one case a hammer known as "Simbi" was used to perforate concrete and the depth of borehole was correlated to compressive strength of concrete cubes.

-> In other technique the probing of concrete was achieved by blasting with spit pins and the depth of penetration of the pins was correlated with compressive strength of concrete.

-> The accuracy of this test was found to be ± 15%. However it is further seen that 'simbi' and 'spit pins' were more effected by the arrangement of coarse aggregate, than the tests using rebound hammers.

3) Pullout test:

-> A pullout test measures the force required to pull out from the concrete a specially shaped rod whose enlarged end has been cast into that concrete.

-> The stronger the concrete the more is the force required to pullout. The ideal way to use pullout test in the field would be to incorporate assemblies in this structure.

-> This standard specimen could then be pulled out at any point of time.

-> The force required denotes the strength of concrete. Another way to use pullout test in the field would be to cast one (or) two big blocks of concrete incorporating pullout assemblies.

-> Pullout test could then be performed to assess the strength of concrete.

4) Dynamic (or) Vibration method:

-> This is the important non destructive method in testing concrete strength and other properties.

-> The fundamental principle on which the dynamic (or) vibration methods are based is velocity of sound through a material.

-> A mathematical relationship could be established b/w the velocity of sound through specimen and its resonant frequency and the relationship of these two to the modulus of elasticity of the material.

-> The relationship which are derived for solid mediums considered to be homogeneous, isotropic and perfectly elastic but they may be applied to heterogeneous materials like concrete.

-> The velocity of sound in a solid can be measured by determining the resonant frequency of specimen (or) by recording the time of travel of short pulses of vibration passing through the samples.

-> In NDT of concrete either resonance method (or) pulse velocity techniques could be adopted.

5) Pulse velocity method:

→ This can be of two methods

i) Mechanical sonic pulse velocity

ii) Ultrasonic pulse velocity.

i) Mechanical sonic pulse velocity:

→ Out of these two ultrasonic pulse velocity method has gained considerable popularity all over the world.

→ When mechanical impulses are applied to a solid mass, three different kinds of waves are generated.

→ These are generally known as longitudinal waves, shear waves and surface waves; these three waves travel at different speeds.

→ The longitudinal (or) compressional waves travel about twice as fast as the other two types. Shear (or) transverse waves are not so fast; the surface waves are the slowest.

→ The pulses can be generated either by hammer blows (or) by the use of an electro acoustic transducer. Electro acoustic transducers are preferred as they provide better control on the type and frequency of pulses generated. The instrument used is called "Sonic scope".

ii) Ultrasonic pulse velocity:

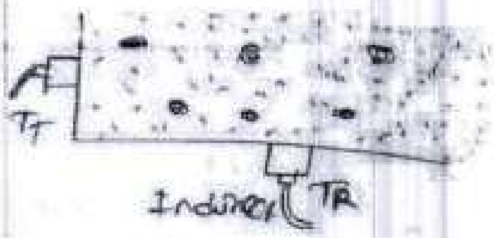
→ This method consist of measuring the time of travel of an ultrasonic pulse, passing through the concrete to be tested. The pulse generator circuit consists of electronic circuit for generating pulses and a transducer for transforming these electronic pulses into mechanical energy having vibration frequencies in the range of 15 to 50 kHz.

→ The time of travel b/w initial onset and the reception of the pulse is measured electronically. The path length b/w transducer divided by the time of travel gives the avg velocity of wave propagation.

Techniques of measuring pulse velocity through concrete:

a) Direct transmission
b) Indirect transmission
c) Surface transmission

Direct



Indirect

Surface.

TT = TR = Transducer transmits.

Factors affecting the measurement of pulse velocity:

-> The measurement of pulse velocity is affected by a number of factors regardless of the properties of concrete.

i) Smoothness of contact surface under test.
ii) Influence of path length on pulse velocity.
iii) Temperature of concrete.
iv) Moisture condition of concrete.
v) Presence of reinforcing steel.

b) Radioactive & Nuclear methods:

i)
-> The use of X-ray and gamma rays as nondestructive method for testing properties of concrete is relatively new. X-ray and γ-ray both components of high energy region on the electromagnetic spectrum penetrate concrete but undergo attenuation in the process.

-> The degree of attenuation depends on the kind of matter traversed its thickness and the wavelength of the radiation.

-> The intensity of incident γ-rays and the emerging γ-rays after passing through the specimens are measured. These two values use for calculating density of structural concrete members.

γ-rays transmission method has been used to measure the thickness ~~and~~ of concrete slabs of known density. γ-radiation sources of known intensity is made to pass and penetrate through the concrete. The intensity at the other face is measured from this thickness of the concrete is calculated.

ii) → Use of nuclear methods for non destructive measurement of some properties of concrete is of recent region.

→ Two techniques have been reported, namely neutron-scattering method for determining the moisture content of concrete and neutron activation analysis for the determination of cement content. These methods are not suitable for finding out the strength of concrete.

7) Magnetic & Electrical method:

i) → Battery operated magnetic devices that can measure the depth of reinforcement cover in concrete and detect the position of reinforcement bars are now available. The apparatus is known as cover meter.

ii) → Electrical resistivity methods have been used to find out the thickness of concrete pavements.

→ The method is based on the principle that the material offers resistance to the passage of an electric current.

→ A concrete pavement has resistivity characteristic that is different from that of the underlying subgrade layers.

→ A change in the slope of the resistivity vs depth curve is used to estimate the depth of concrete pavement.

MODULUS OF ELASTICITY :

→ The stress in steel is 'm' times the stress in concrete. where 'm' is the ratio b/w the modulus of elasticity of steel and concrete. known as Modular ratio.

→ The modulus of elasticity can also be determined by subjecting a concrete cube (or cylinder specimen) to uniaxial compression and measuring the deformation by means of dial gauges fixed b/w the certain gauge length.

→ Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross section will give the stress.

→ The modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formulae for deflection and substituting other parameters. The modulus of elasticity so found out from actual loading is called static modulus of elasticity.

→ Modulus of elasticity may be measured in tension, compression (or) shear.

→ The modulus in tension is equal to modulus in compression.

→ Modulus of elasticity of concrete increases approximately with the square root of the strength.

$$\text{Modulus of Elasticity } E_c = 5000\sqrt{f_{ck}}$$

→ The modulus of elasticity of light weight concrete is usually between 40 to 80% of the modulus of elasticity of ordinary concrete of the same strength.

→ The relation b/w the modulus of elasticity and strength is not much effected by temperature upto about 230°C since both the properties vary with temperature in approximately the same manner. Steam cured concrete shows a slightly lower modulus than water-cured concrete of the same strength.

DYNAMIC MODULUS OF ELASTICITY:

→ The value of E is found out by actual loading of concrete. i.e. the static modulus of elasticity does not truly represent the elastic behaviour of concrete due to the phenomenon of creep. The elastic modulus of elasticity will get affected more seriously at higher stresses when the effect of creep is more pronounced.

→ The modulus of elasticity can be determined by subjecting the concrete member to longitudinal vibration at their natural frequency.

→ Modulus of elasticity can be calculated from the following relationship

$$E_d = K n^2 L^2 \rho$$

E_d = Dynamic modulus of elasticity

K = constant

n = resonant frequency.

L = length of specimen.

ρ = density of concrete.

$$E_d = 4 \times 10^{-5} n^2 L^2 \rho \text{ GPa.}$$

→ The value of E found out in this method by the velocity of sound (or) frequency of sound is referred as dynamic modulus of elasticity, in contrast to the value of E found out by actual loading of the specimen and from stress-strain relationship which is known as static modulus of elasticity.

→ The value of dynamic modulus of elasticity computed from ultrasonic pulse velocity method is somewhat higher than those determined by static method.

→ This is because the modulus of elasticity as determined by dynamic modulus is unaffected by creep. The creep also doesnot significantly effect the initial tangent modulus in the static method.

→ The value of dynamic modulus and the value of initial tangent modulus to be more or less agree with each other. Approximate relationship b/w the two moduli expressed in Ga/m² is given by

$$E_c = 1.25\, E_d - 19$$

E_c & E_d are static and dynamic modulus of elasticity

→ For light weight concrete the relationship is

$$E_c = 1.04\, E_d - 4$$

Poisson's Ratio:

→ Poisson's ratio is the ratio b/w lateral strain to the longitudinal strain. It is denoted by 'μ'

→ For normal concrete μ = 0.15 to 0.20

→ Poisson's ratio can be determined from ultrasonic pulse velocity method and by finding out the fundamental resonant frequency of longitudinal vibration of concrete beam.

$$\left(\frac{V}{2nL}\right)^2 = \frac{1-\mu}{(1+\mu)(1-2\mu)}$$

V = pulse velocity
n = resonant frequency
L = length of beam
μ = 0.2 to 0.24

→ Dynamic modulus of elasticity can also be found out from following eqn.

$$E_d = \rho V^2 \frac{(1+\mu)(1-2\mu)}{(1-\mu)}$$

V = pulse velocity
ρ = density
μ = poisson's ratio.

CREEP:

→ Creep can be defined as the "time-dependent" part of the strain resulting from stress.

→ The gradual increase in strain, without increase in stress, with the time is due to creep. From this explanation creep can also be defined as the increase in strain under a sustained stress.

→ Creep of concrete is approximately linear function of stress upto 30 to 40% of its strength.

Measurement of creep:

→ Creep is usually determined by measuring the change with time in the strain of specimen subjected to constant stress and stored under appropriate condition.

→ It is generally assumed that the creep continues to assume a limiting value after an infinite time under load. It is estimated that 26% of the 20 year creep occurs in 2 weeks. 55% of 20 year creep occurs in 3 months and 76% of 20 year creep occurs in one year.

→ If creep after one year is taken as unity, then the avg value of creep at later ages are.

1.14 after 2 years

1.20 after 5 years

1.26 after 10 years

1.30 after 20 years

1.36 after 30 years.

→ The relation b/w creep (C) and time (t) is

$$C = \frac{t}{a + bt}$$

$$a = 1/C$$

FACTORS AFFECTING CREEP

i) Influence of aggregate:

→ Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However the aggregates influences the creep of concrete through a restraining effect on the magnitude of creep.

→ The bonding, the shape, the maximum size of aggregate have been suggested as factors affecting creep.

→ The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep.

ii) Influence of mix proportion:

→ The amount of paste content and its quality is one of the most important factors influencing creep.

→ A poorer paste content structure undergoes higher creep. Therefore it can be said that creep increases in water/cement ratio.

→ In other words creep is inversely proportional to strength of concrete.

iii) Influence of Age:

→ Age at which concrete members is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more.

iv) Effects of Creep:

→ Magnitude of creep is dependent on many factors the main factors being time and level of stress. In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.

SHRINKAGE:

→ The volume change on account of inherent properties of concrete is known as "shrinkage".

→ One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements, due to the shrinkage.

→ It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude.

TYPES OF SHRINKAGE:

1) Plastic shrinkage
2) Drying shrinkage
3) Autogeneous shrinkage
4) Carbonation shrinkage.

1) plastic shrinkage:

→ Loss of water by evaporation from the surface of concrete (or) by the absorption by aggregate (or) subgrade is believed to be the reason of plastic shrinkage

→ The loss of water results in the reduction volume the aggregate particles (or) the reinforcement comes in the way of subsidence due to which cracks may appear at the surface (or) internally around the aggregate (or) reinforcement.

→ In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind the surface of concrete dries very fast which results in plastic shrinkage.

→ Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation

→ monomolecular coatings by fog spray that keeps the surface moist.

→ working at night an effective method of reducing shrinkage.

2) Drying shrinkage:

-> The drying shrinkage is also an ever lasting process when concrete is subjected to drying conditions.

-> The drying shrinkage of the concrete is analogous to the mechanism of drying of timber specimen. The loss of water contained in hardened concrete, does not result in any appreciable dimension change.

-> Cement paste shrinks more than mortar and mortar shrinks more than concrete.

-> The rate of shrinkage decreases rapidly with time it is observed that 14-34% of the 20 years shrinkage occurs in 2 weeks, 40-80% of the 20 year shrinkage occurs in 3 months, 66-85% of the 20 year shrinkage occurs in one year.

-> The volume fraction of aggregate will have some influence on the total shrinkage. The ratio of shrinkage of concrete (Sc) to shrinkage of neat paste (Sp) depend on the aggregate content in the concrete.

$$S_c = S_p (1-a)^n$$

$$n = 1.2 \text{ \& } 1.7$$

-> The property of swelling when placed in wet condition and shrinking when placed in drying condition is refered as moisture movement in concrete.

3) Autogeneous shrinkage:

-> In a conservative system i.e where no moisture movement to (or) from the paste is permitted when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage.

-> Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of concrete dam.

-> The magnitude of autogeneous shrinkage is 100×10^{-6}.

4) Carbonation Shrinkage

→ Carbonation shrinkage is a phenomenon very recently recognised. Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement.

→ Calcium hydroxide ($Ca(OH)_2$) gets converted to calcium carbonate ($CaCO_3$) and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete only very slowly.

→ The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium.

→ Carbonation of concrete also results in increased strength and reduced permeability.

UNIT-IV

MIX DESIGN

FACTORS AFFECTING THE CHOICE OF MIX PROPORTIONS:

1) Compressive strength
2) Workability
3) Durability
4) Max. nominal size of aggregate
5) Fineness modulus & zone of aggregate
6) Quality control

① Compressive strength:

→ The compressive strength of any material is defined as the resistance to failure under the action of compressive forces. Especially for concrete, compressive strength is an important parameter to determine the performance of the material during service conditions.

→ Concrete mix can be designated and proportioned to obtain the required engineering and durability properties as required by the design engineer.

→ Some of the other engineering properties of hardened concrete include elastic modulus, tensile strength, creep co-efficient, density, co-efficient of thermal expansion etc.

Compressive strength of concrete:

→ Concrete specimens are cast and tested under the action of compressive loads to determine the strength of concrete

→ Compressive strength is calculated by dividing the failure load with the area of application load, usually after 28 days of curing.

→ The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water and various admixtures.

→ The ratio of the water to cement is the chief factor for determining concrete strength. The lower the water-cement ratio the higher is the compressive strength.

→ In normal field the concrete strength can vary from 10MPa to 60MPa.

→ For structural the concrete mixes can be designed to obtain very high compressive strength capacity in the range of 500MPa.

→ The compressive strength of concrete is given in terms of the characteristic compressive strength of 150mm size cubes tested at 28 days.

→ The characteristic strength is defined as the strength of the concrete below which not more than 5% of the test results are expected to fall.

PROCEDURE:

→ Specimen stored in water shall be tested immediately on removal from the water and while they are still in the wet condition.

→ Take the dimension of the specimen to the nearest 0.2m.

→ Clean the bearing surface of the testing machine.

→ Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the specimen.

→ Apply the load gradually without shock & continuously at the rate of 40kg/cm²/min. till the specimen fails.

→ Record the max. load and note any unusual features in the type of failure.

2) Workability of concrete:

→ Workability represents consistency and cohesiveness of concrete.

General consideration for workability

i) Water content:

→ The higher the water content, the higher will be the fluidity of concrete, which is one of the important factors affecting workability.

ii) aggregate/cement ratio:

→ The higher the a/c ratio, the leaner is the concrete.

→ In lean concrete, less quantity of paste is available for lubrication per unit surface area of aggregate and hence the mobility reduce.

→ In case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

iii) size of aggregate:

→ The bigger the size of aggregate, the less the surface area, hence less water is required for wetting the surface and paste is required for lubricating the surface to reduce internal friction.

→ For a given quantity of water and paste bigger size of aggregate will give higher workability.

iv) shape of aggregate:

→ Angular, elongated (or) flaky aggregate makes the concrete very harsh when compared to rounded aggregate (or) cubical shaped aggregates.

→ Being round in shape the frictional resistance is also greatly reduced.

v) surface texture:

→ Total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume.

→ Rough textured aggregate will show poor workability and smooth (or) glassy textured aggregate will give better workability.

vi) Grading of aggregates:

→ Better the grading, the less is the void content and higher the workability.

→ When the total voids are less, excess paste is available to give better lubricating effect.

vii) Use of Admixtures:

→ Use of air entraining agent being surface-active reduces the internal friction between the particles.

→ Plasticizers and super-plasticizers greatly improve the workability many folds.

3) Durability of concrete:

→ Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

→ It is normally refers to the duration of life span of trouble free performance.

Concrete will remain durable if:

→ The cement paste structure is dense and of low permeability

→ Under extreme condition, it has entrained air to resist freeze-thaw cycle.

→ It is made with graded aggregate that are strong and inert

→ The ingredients in the mix contain minimum impurities such as alkalis, chlorides, sulphates and silt.

Factors affecting Durability:

i) Cement content:

→ Mix must be designed to ensure cohesion and prevent segregation and bleeding. If cement is reduced, then at fixed w/c ratio the workability will be reduced leading to inadequate compaction

→ However if water is added to improve workability, water cement ratio increases and results in highly permeable material.

ii) Compaction:

→ The concrete as a whole contain voids can be caused by inadequate compaction. usually this being governed by compaction, equipments used type of formwork, and density of the steel work.

iii) Curing:

→ It is very important to permit proper strength development aid moisture retention and to ensure hydration process occur completely.

iv) Cover:

→ Thickness of concrete cover must follow the limits set in codes.

v) Permeability:

→ The higher permeability usually caused by higher porosity

→ A proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete.

Types of Durability of Concrete:

1. Physical durability
2. Chemical durability

1. Physical durability:

→ freezing and thawing action
→ percolation / permeability of water
→ Temperatures stresses.

2. Chemical durability:

→ Alkali aggregate Reaction.
→ Sulphate Attack
→ Chloride ingress
→ corrosion of reinforcement.

Causes of durability

1. External causes
2. Internal causes

1. External causes

→ Extreme weathering condition
→ Extreme temperature.
→ Extreme humidity
→ Abrasion
→ Electrolytic Action.

2. Internal causes

→ Physical → Frost action
→ Chemical → Alkali aggregate reaction and
corrosion of steel.

4) Max. nominal size of coarse Aggregate:

→ The max. nominal size of the coarse aggregate is determined by sieve analysis and is designated by the sieve size higher than the larger size on which 15% or more of the aggregate is retained.

→ The max. nominal size of the aggregate to be used in concrete is governed by the size of the section and spacing of the reinforcement.

→ According to IS: 456-2000 and IS: 1343-1980 the maximum nominal size of the aggregate should not be more than 1/4th of the max. thickness of the member, and it should be restricted to 5mm less than min. clear distance b/w main bars of 5mm not less than min. clear cover to the reinforcement.

→ The nominal max. size of aggregate, should as large as possible, because more the max. size of the aggregate, smaller is the cement requirement for a particular water/cement ratio.

→ The workability also increases increase in max. size aggregate

-> For the concrete with higher w/c ratio the larger max size of aggregate may be beneficial whereas for high strength concrete 10-20MM size of aggregate is preferable. 7.

5) Quality control:-

-> The strength of concrete varies from batch to batch over a period of time.

-> The source of variability in the strength of concrete may be considered due to variation in the quality of the constituent materials, variations in mix proportions due to batching process, variations in the quality of batching and mixing equipment available, the quality of supervision and workmanship.

-> Controlling the variation is important in lowering the difference b/w minimum strength and characteristic mean strength of the mix and hence reducing the cement content. The factor controlling the difference is quality control.

-> The degree of control is ultimately evaluated by the variation in test results usually expressed in terms of "co-efficient of variation"

-> Most of the mix design procedures are primarily based on the water-cement ratio law and absolute volume system of calculating the amount of materials.

-> According to Abram's law, the strength of fully compacted hardened concrete is approximately inversely proportional to the water content per cubic meter of cement.

$$\text{Absolute volume} = \frac{\text{mass of loose dry material}}{\text{sp. gravity} \times \text{mass of unit of volume of water}}$$

Statical Quality Control of Concrete:-

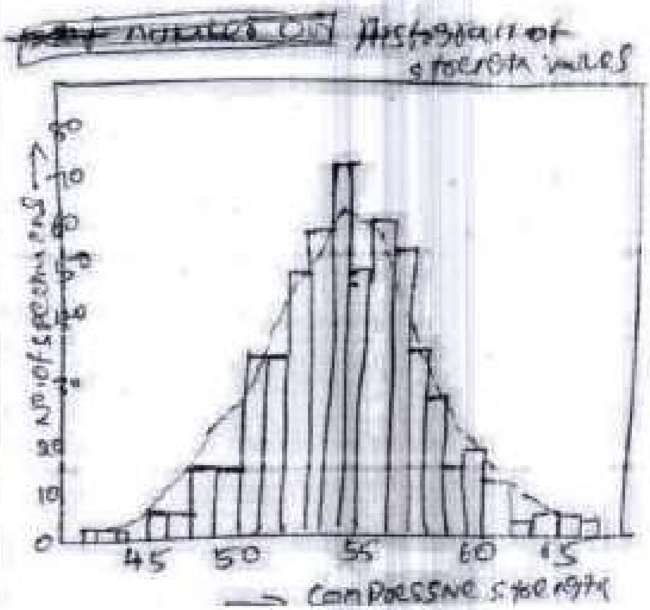
-> The aim of Quality control is to limit the variability as much as practicable. Statical quality control method provides a scientific approach to the concrete designer to understand the realistic variability of the materials so as to lay down design specifications with proper tolerance to cater for unavoidable variations.

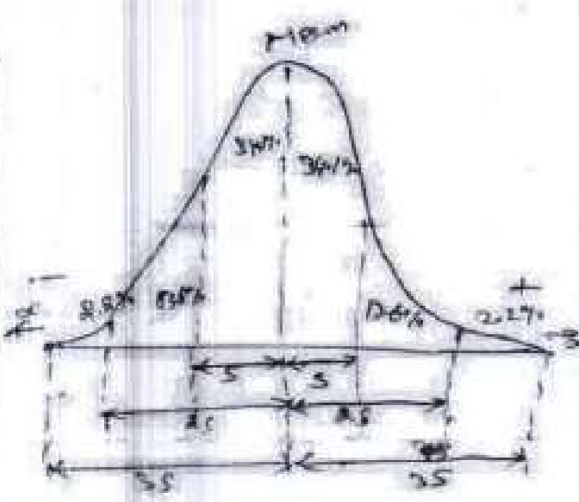
-> The acceptance criteria are based on statical evaluation on the test result of samples taken at random during execution.

-> The method provides a scientific basis of acceptance which is not only realistic but also restrictive as required by the design requirements for the concrete construction.

-> The quality of concrete is will be of immense value for large contracts where the specifications insist on certain minimum requirements. The effort put in will be more than repaid by resulting savings in the overall concreting operations.

-> The compressive strength test cubes from random sampling of a mix, exhibit variations, which are inherent in the various operations involved in the making and testing of concrete.





→ If a number of cube test results are plotted on histogram, the results are found to follow a bell shaped curve known as 'normal distribution curve'. 5

→ The results are said to follow a normal distribution curve if they are equally spaced about the mean value and if the largest number of the cubes have a strength close to the mean value, i.e. the largest part and very few number of results with much greater (or) less value than the mean value.

→ The arithmetic mean (or) the average value of the number of test results gives no indication of the extent of variation of strength. This can be ascertained by relating the individual strength to mean strength and determining the variation from the mean with the help of the properties of normal distribution curve.

Common terminologies:

i) Mean strength:

→ The avg strength obtained by dividing the sum of strength of all the cubes by the number of cubes

$$\bar{x} = \frac{\Sigma x}{n}$$

ii) Variance:

→ This is the measure of variability (or) difference b/w any single observed data from the mean strength.

iii) Standard deviation:

→ This is the root mean square deviation of all the results. (σ)

$$\sigma = \sqrt{\frac{\Sigma (x-\bar{x})^2}{n-1}}$$

iv) Co-efficient of variation:

→ It is an alternative method of expressing the variation of results. This non dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean.

$$V = \frac{\sigma}{\bar{x}} \times 100$$

1

Various methods of proportioning mix design

1) Arbitrary proportion
2) Fineness modulus method.
3) Maximum density method
4) Surface area method.
5) Indian Road congress, IRC 44 method.
6) High strength concrete mix design.
7) Mix design based on flexure strength.
8) Road note No 4.
9) ACI comittee 211 method.
10) DOE method.
11) Mix design for pumpable concrete.
12) Indian standard recommended method IS 10262-82

→ out of the above methods, some of them are not very widely used these days because of some difficulties (or) drawbacks in the procedures for arriving at the satisfactory proportions.

→ The ACI comittee 211 method, the DOE method and Indian standard recommended methods are commonly used.

→ Since concrete is very commonly placed by pumping these days method of mix design of pumpable concrete has become important.

→ Before we deal with some of the important methods of concrete mix design, it is necessary to get acquainted with statical quality control methods, which are common to all the methods of mix design.

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PROCEDURE FOR CONCRETE MIX DESIGN (IS 10262) [illegible]

1. Determine the mean target strength (f_t) from the specified characteristic compressive strength at 28 days f_{ck} and the level of quality control.

$$f_t = f_{ck} + 1.65S$$

S = standard deviation.

2. Obtain the water cement ratio for the desired mean ~~strength~~ target using the empirical relationship b/w compressive strength and water cement ratio so chosen is checked against the limiting w/c ratio.

3. Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.

4. Select the water content for the required workability and maximum size of aggregates from table.

5. Determine the % of fine aggregates in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.

6. Adjust the value of water content and % of sand as provided in the table for any difference in workability water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

7. Calculate the cement content from the water - cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability and greater of the two values is adopted.

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8. From the quantities of ... already determined in ... of concrete and the % of sand already determined in step 6 and step 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relation,

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p} \frac{f_a}{S_{fa}} \right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p} \cdot \frac{C_a}{S_{ca}} \right] \times \frac{1}{1000}$$

V = absolute volume of concrete = gross volume (m3) − volume of entrapped air

Sc = sp. gravity of cement

W = mass of water per cubic metre of concrete, kg.

C = mass of cement per cubic metre of concrete, kg

p = ratio of fine aggregates to total aggregates by absolute volume.

Ca = total masses of fine and coarse aggregates

Sfa, Sca = sp. gravities of saturated surface dry fine and coarse aggregates.

9. Determine the concrete mix proportions for the first trial mix.

10. Prepare the concrete using the calculated proportions and cast three cubes of 150mm size and test them wet after 28 days moist curing and check for the strength.

11. Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

PROBLEMS

Q). CONCRETE MIX DESIGN - M50 GRADE CONCRETE

Grade Designation = M50

Type of cement = OPC-43 Grade

Brand of cement = Ultratech

Admixture = Silica

Fine aggregate = zone-II

SP. Gravity

cement = 3.15

fine aggregate = 2.61

C.A (20mm) = 2.65

C.A (10mm) = 2.66

Min. cement = 400 kg/m3

Max. water/cement Ratio = 0.45.

MIX CALCULATION:

1) Target Mean Strength:-

$f_t = f_{ck} + 1.65S$

$f_t = 50 + (1.65 \times 5)$

$f_t = 58.25$ MPa.

2) W/C ratio:-

(IS 10262-2009)

Assume W/C = 0.35

3) Calculation of water:-

Approximate water content for 20mm max. size of aggregate = 180 kg/m3 (table No.5, IS 10262)

As plasticizers is proposed we can reduce water content by 20%

100 - 20 = 80% = 0.8

water content = 180 × 0.8 = 144 kg/m3

4) Calculation of cement content:-

W/C ratio = 0.35

Water content / M^3 of concrete = 144 kg

Cement content = $\frac{144}{0.35}$ = 411.4 kg/m^3

Cement content = 412 kg/m^3 (As per controlled min.
cement content 400 kg/m^3)

Hence OK.

5) Calculation for C.A & F.A:-

Volume of concrete = 1 M^3

Volume of cement = $\frac{412}{(3.15 \times 1000)}$ = 0.1308 m^3

Volume of water = $\frac{144}{1 \times 1000}$ = 0.1440 m^3

Volume of admixture = $\frac{4.944}{(1.145 \times 1000)}$ = 0.0043 m^3

Total wt of materials except C.A = 0.1308 + 0.1440 + 0.0043
= 0.2791

Volume of CA & FA = 1 − 0.2791 = 0.7209 m^3

Volume of FA = 0.7209 × 0.33 = 0.2379 m^3 (Assume
33% by volume of total aggregate)

Volume of CA = 0.7209 − 0.2379 = 0.4830 M^3.

Weight of FA = 0.2379 × 2.61 × 1000 = 1282.365 kg/m^3
= 620.91 kg/m^3

Say weight of CA = 1284 kg/m^3.

Considering 20mm : 10mm = 0.55 : 0.45

20mm = 700 kg
10mm = 578 kg.

Hence mix details / m3

Increasing cement content, admixture by 2.5% for this operation.

Cement = 413 x 1.025 = 423 kg.

Water = 144 x 1.025 = 147.8 kg

F.A = 621 kg

C.A 20mm = 700 kg.

C.A 10mm = 578 kg.

Admixture = 1.2% by weight of cement = 5.064 kg.

Water : cement : F.A : C.A = 0.35 : 1 : 1.472 : 5.043.

Observations from concrete mix design —

A. Mix was cohesive & homogeneous
B. Slump = 120mm

C. No. of cube casted = 9 nos.

7 days avg compressive strength = 52.07 MPa
28 days avg compressive strength = 62.52 MPa.

UNIT - V

SPECIAL CONCRETE

LIGHT WEIGHT CONCRETE:

→ one of the disadvantages of conventional concrete is the high self weight of concrete.

→ Density of normal concrete is in the order of 2200 to 2600 kg/m3. This heavy self weight will make it to some extent an uneconomical structural material.

→ Attempts have been made in the past to reduce the self weight of concrete to increase the efficiency of concrete as a structural material.

→ The light weight concrete as we call is a concrete whose density varies from 300 to 1850 kg/m3.

→ There are many advantages of having low density. It helps in reduction of dead load, increases the progress of building, and lowers haulage and handling costs.

→ The weight of a building on the foundation is an important factor in design, particularly in the case of weak soil and tall structures.

→ In framed structures, the beams and columns have to carry load of floors and walls. This are made up of light-weight concrete it will result in considerable economy.

→ Another most important characteristic of light weight concrete is the relatively low thermal conductivity, a property which improves with decreasing density.

→ In extreme climatic conditions and also in case of buildings where air conditioning is to be installed, the use of light weight concrete with low thermal conductivity will be of considerable advantage from the point of view of thermal comforts and lower power consumption.

→ The adoption of light weight concrete gives an outlet for industrial wastes such as clinker, flyash, slag etc.

-> Basically there is only one method for making concrete lighter i.e by the inclusion of air in concrete.

i) By replacing the usual mineral aggregates by cellular porous (or) light weight aggregate.

ii) By introducing gas (or) air bubbles in mortar. This is known as aerated concrete.

iii) By omitting sand fraction from the aggregate. This is called no-fines concrete.

-> A particular type of light-weight concrete called structural light weight concrete is one which is comparatively lighter than conventional concrete but at the same time strong enough to be used for structural purpose.

LIGHT WEIGHT AGGREGATE CONCRETE:

-> Very often light-weight concrete is made by the use of light weight aggregates. We have seen that different light-weight aggregates have different densities.

-> Naturally when this aggregate used, concrete of different densities are obtained. By using expanded perlite (or) vermiculite, a concrete of density as low as 300 kg/m³ can be produced, and by the use of expanded slag, sintered fly ash, bloated clay etc. a concrete of density 1900 kg/m³ can be obtained.

-> The strength of the light weight concrete may also vary from about 0.3 N/mm² to 40 N/mm². A cement content of 200 kg/m³ to about 500 kg/m³ may be used.

-> Strength of light weight concrete depends on the density of concrete. Less porous aggregates which is more heavier in weight produces stronger concrete particularly with higher cement content.

-> The grading of aggregate, the water/cement ratio, the degree of compaction also effect the strength of concrete.

→ Most of the light-weight aggregate with the exception of bloated clay and sintered fly ash are angular in shape and rough in texture they produce harsh mix.

→ The strength of aggregate will also be influenced by the type of fine aggregates. For increasing the strength, for improving the workability and for reducing the water requirement, sometimes natural sand is used instead of crushed sand made out of light-weight aggregate.

→ Most of the light weight aggregates have a high and rapid absorption quality. This is one of the important difficulties in applying the normal mix design procedure to the light weight concrete.

→ Light weight concrete being comparatively porous when used for reinforced concrete, reinforcement may become prone to corrosion. Either the reinforcement must be coated with anticorrosive compound (or) the concrete must be plastered at the surface by normal mortar to inhibit the penetration of air and moisture inside.

Design :

→ Mix design methods applying to normal weight concrete are generally difficult to use with light-weight aggregate concrete. The lack of accurate value of absorption, specific gravity, and free moisture content in the aggregate make it difficult to apply the water/cement ratio accurately for mix proportioning.

→ Light weight concrete mix design is usually established by trial mixes. The proportion of fine to coarse aggregate and the cement and water requirement are estimated based on the previous experience with particular aggregate.

→ Sometimes the aggregate is saturated before mixing so that it (aggregate) does not suck up the water used for mixing.

→ The quality of concrete does not get altered on account of absorption by aggregate. It has been seen that the strength of the resulting concrete is about 5% to 10% less than when only aggregate is used for the same content and workability.

Mixing procedure:

→ Mixing procedure for light weight concretes may vary with different types of aggregates. The general practice for structural light weight concrete is to mix the aggregate and about 2/3 of the mixing water for a period upto one minute prior to the addition of cement and the balance mixing water.

→ Mixing is done continuously as required for homogeneity. Usually 2 or more minutes are required to get uniform mixing. In case of some insulating concrete the aggregate is added at the end of mixing to minimise degradation.

Aerated concrete / cellular concrete:

→ Aerated concrete is made by introducing air (or) gas into a slurry composed of portland cement (or) lime and finely crushed siliceous filler so that when the mix sets and hardens, a uniformly cellular structure is formed. Though it is called aerated concrete it is not a really not a concrete in the correct sense of the word. It is mixture of water, cement and finely crushed sand.

→ Aerated concrete is also referred as gas concrete, foam concrete, cellular concrete.

→ There are several ways in which aerated concrete can be manufactured.

(a) By the formation of gas by chemical reaction within the mass during liquid (or) plastic state.

(b) By mixing preformed stable foam with the slurry.

(c) By using finely powdered metal.

→ Powdered zinc may also be added in place of aluminium powder. Hydrogen peroxide and bleaching powder have also been used instead of metal powder. But this practice is not widely followed at present.

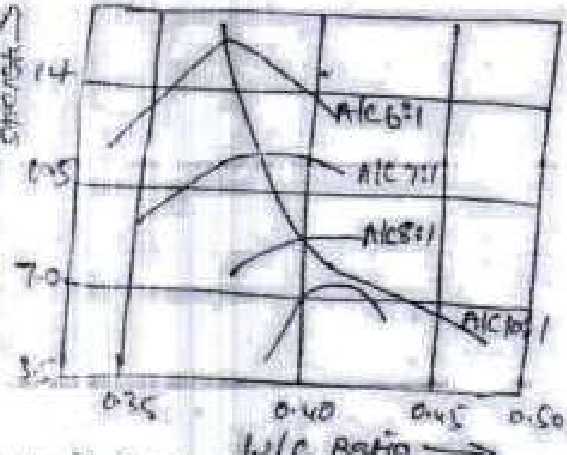
(b)
→ In the stable foam is mixed with cement and crushed sand slurry thus causing the cellular structure when this gets set and hardened.
→ However this method cannot be employed for decreasing the density of the concrete beyond a certain point and as such the use of air entrainment is not often practised for making aerated concrete.

(a)
→ Gasification method is most widely adopted methods using aluminium powder (or) such other similar material. This method is adopted in the large scale manufacture of aerated concrete in the factory where in the whole process is mechanised and the product is subjected to high pressure steam curing i.e. the products are autoclaved.

NO FINES CONCRETE :
→ No fines concrete as the term implies is a kind of concrete from which the fine aggregate fraction has been omitted. This concrete made up of only coarse aggregate, cement and water.
→ Very often only single sized coarse aggregate of size passing through 20mm retained on 10mm is used.
→ No fines concrete is becoming popular because of some of the advantages it posses over the conventional concrete.
→ This single sized aggregates make a good no fines concrete, which in addition to having large voids and hence light in weight also offers an architecturally attractive look.

Mix Proportion:

- → No fines concrete is generally made with the aggregate/cement ratio from 6:1 to 10:1.
- → Aggregates are used normally of size passing through 20mm and retained on 10mm. Unlike the conventional concrete, in which strength is primarily controlled by the water/cement ratio, the strength of fines concrete is dependent on the water/cement ratio, aggregate cement ratio and unit weight of concrete.
- → The w/c ratio for satisfactory consistency will vary b/w a narrow range of 0.38 and 0.52.
- → If too low w/c ratio is adopted, the paste will be so dry that aggregates does not get properly stored with paste which result in insufficient.



- → On the other hand if the w/c ratio is too high, the paste flows to the bottom of the concrete, particularly when vibrated and fills up the voids b/w the aggregates at the bottom and makes that portion dense.
- → No standard method is available, like slump test (or) compacting factor test for measuring the consistency of no-fines concrete.
- → No fines concrete when conventional aggregates are used, may show a density of about 1600 to 1900 kg/m³, but when no-fines concrete is made by using light weight aggregate, the density may come to about 360 kg/m³.
- → The bond strength of no fines concrete is very low and therefore reinforcement is not used in conjunction with no fines concrete. However if reinforcement is required to be used in no fines concrete, it is advisable to spread the RC with cement paste to improve the bond and also to protect it from rusting.

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HIGH DENSITY CONCRETE:

-> Density of normal concrete is in the order of about 2400 kg/m³

-> The density of light weight concrete will be less than about density 1900 kg/m³.

-> To call the concrete as high density concrete, it must have unit weight ranging from about 3360 kg/m³ — 3840 kg/m³, which is about 50% higher than the unit weight of conventional concrete.

-> The advent of the nuclear energy industry presents a considerable demand on the concrete technologists.

-> Large scale production of penetrating radiation and radioactive materials are as a result of the use of nuclear reactors, particle accelerator, industrial radiography, and X-ray, γ-ray therapy, require the need of shielding material for the protection of operating personnel against the biological hazards such radiation.

-> Concrete both high density and normal density are effective and economic construction material for permanent shielding purposes.

Types of radiation and hazards:

-> There are two general classes of radiation.

1) Electromagnetic waves

2) Nuclear particles

-> Electro magnetic waves the high energy, high frequency waves known as X- and γ-rays are only types which require shields for the protection of personnel. These are similar to light rays but of higher energy greater penetrating power.

-> Nuclear particles consist of nuclei of atoms (or) fragments thereof. They include neutrons, protons, alfa and beta particles of these all neutrons posess an electric charge.

FIBRE REINFORCED CONCRETE:

→ Fibre reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. continuous meshes, woven fabrics and long wires or rods are not considered to be discrete.

→ Fibre is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat.

→ The fibre is often described by a convenient parameter called 'aspect ratio' i.e ratio of its length to its diameter.

- The ratio ranges from 30 to 150.

TYPES OF F.R.C

→ Although every type of the fibre has been tried out in cement and concrete, not all of them can be effectively and economically used. Each type of fibre has its characteristic properties and limitations.

→ Some of the fibres could be used are ~~steel fibres~~

1) steel fibres
2) polypropylene fibres
3) nylons fibres
4) asbestos fibre
5) coir fibre
6) Glass fibre
7) Carbon fibre

1) Steel fibre:

→ It is one of the most commonly used fibre. Generally round fibres are used.

→ They diameter may vary from 0.25 to 0.75 mm. The steel fibre is likely to get rusted and lose some of its strengths. But investigations have shown that the rusting of fibres takes place only at the surface.

a) Polypropylene & nylon fibres:-

-> This fibres are found to be suitable to increase the impact strength. They posses very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to the flexural strength.

b) Asbestos fibres:-

-> Asbestos is a mineral fibre and has proved to be most successful of all fibres as it can be mixed with portland cement.

-> Tensile strength of asbestos varies b/w 560 to 980 N/mm². The composite product called asbestos cement has considerably higher flexural strength than the portland cement paste.

-> For un important fibre concrete, organic fibres like coir, jute, canesplits are also used.

c) Glass fibre:

-> It is a recent introduction in making fibre concrete. It has very high tensile strength 1020 – 4080 N/mm².

-> Glass fibres which is originally used in conjunction with cement was found to be affected by alkaline condition of cement.

-> Therefore alkali-resistant glass fibre by trade name "CEM-FIL" has been developed and used. The alkali resistant fibre reinforced concrete shows considerable improvements in durability to the conventional E-glass fibre.

d) Carbon fibre:

-> Carbon fibre posses very high tensile strength 2110 to 2815 N/mm² and young's modulus. It has been reported that cement composite made with carbon fibre as reinforcement will have very high modulus of elasticity and flexural strength.

-> The use of carbon fibres for structures like cladding, panels, and shells will have promising future.

FACTORS AFFECTING PROPERTIES OF F.R.C.

-> F.R.C reinforced concrete is the composite material containing fibres in the cement matrix in an orderly manner (or) randomly distributed manner.

-> Its properties would obviously depend upon the efficient transfer of stress between matrix and the fibres, which is largely dependent on the type of fibre, fibre geometry, fibre content, orientation and distribution of the fibres, mixing and compaction techniques of concrete, and size and shape of the aggregate.

1) Relative Fibre matrix stiffness:-

-> The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer. Low modulus of fibres such as nylons and polypropylene are therefore unlikely to give strength improvement, but they help in the absorption of large energy and therefore impart greater degree of toughness and resistance to impact.

-> High modulus fibres such as steel, glass and carbon impart strength and stiffness to the composite.

-> A good bond is essential for improving tensile strength of the composite.

-> The interfacial bond could be improved by larger area of contact improving the frictional properties and degree of gripping and by treating the steel fibres with sodium hydroxide (or) acetone.

2) Volume of fibres:-

-> The strength of the composite largely depends on the quantity of fibres used in it. Use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.

3) Aspect ratio of fibres :-

-> Another important factor which influences the properties and behaviour of the composite is the aspect ratio of the fibre. It has been reported that upto aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75 relative strength and toughness is reduced.

4) Orientation of fibres:

-> One of the differences b/w conventional reinforcement and fibre reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibres are randomly oriented.

-> To see the effect of randomness, mortar specimens reinforced with 0.5% volume of fibres were tested.

5) Workability and compaction of concrete :-

-> Incorporation of steel fibre decreases the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete.

-> The fibre volume which this situation is reached depends on the length and diameter of the fibre.

-> Another consequence of poor workability is non-uniform distribution of the fibres. Generally the workability and compaction standard of the mix is improved through increased w/c ratio.

6) Size of coarse aggregate :-

-> Several investigators recommended that the max. size of the coarse aggregate should be restricted to 10mm, to avoid appreciable reduction in strength of the composite.

7) Mixing:-

-> Mixing of fibre reinforced concrete needs careful conditions to avoid balling of fibres, segregation and in general the difficulty of mixing the materials uniformly.

-> Increase in the aspect ratio, volume % and size and quantity of coarse aggregate intensify the difficulties and balling tendencies.

-> A steel fibre content in excess of 2% by volume and an aspect ratio of more than 100 are difficult to mix.

-> The typical proportions for fibre reinforced concrete is

Cement content : 325 - 550 kg/m³

W/C ratio : 0.4 to 0.6

% of sand to total aggregate : 50 to 100%

Max. Aggregate size : 10mm.

Air content : 6 - 9 %

Fibre content : 0.5 - 2.5%

: steel - 1 % 78 kg/m³

Glass - 1% 25 kg/m³

Nylon - 1 % 11 kg/m³

Applications:

-> Fibre reinforced concrete is increasingly used on account of the advantages of increased static and dynamic tensile strength, energy absorbing characteristics and better fatigue strength.

-> The uniform dispersion of fibres throughout the concrete provides isotropic properties not common to conventionally reinforced concrete.

-> F.R.C has been used on overlays of air field, road pavements, industrial floorings, bridge decks, canal lining, explosive resistant structures, refractory linings etc.

-> F.R.C concrete can also be used for the fabrication of precast like pipes, boats, beams, stair case steps, wall panels, roof panels, manhole covers etc.

POLYMER CONCRETE :-

-> continous research by concrete technologists to understand improve and develop the properties of concrete has resulted in a new type of concrete known as "polymer concrete".

-> The porosity is due to air voids, water voids (or) due to the inherent porosity of gel structure itself on account of the porosity, the strength of concrete is naturally reduced. It is conceived by many research workers that reduction of porosity results in increase of strength of concrete.

-> Therefore process like vibration, pressure application spinning etc. have been practiced mainly to reduce porosity. All these methods have been found to be helpful to a great extent, but none of these methods could really help to reduce the water voids and the inherent porosity of gel which is estimated to be about 28%.

-> The development of concrete - polymer composite material is directed at producing a new material by combining the ancient technology of cement concrete with the modern technology of polymer chemistry.

TYPES OF POLYMER CONCRETE :

① Polymer impregnated concrete :- is one of the widely used polymer composite. It is nothing but a pre cast conventional concrete, cured and dried in oven, (or) by dielectric heating from which the air in the open cell is removed by vaccum. Then a low viscosity monometer is diffused through the open cell and polymerised by using radiation, application of heat (or) by chemical initiation.

-> Mainly the following types of monomer are used.

a) Methylmethacrylate
b) styrene
c) Acrylonitrile
d) t-butyl styrene.
e) other thermo plastic monometers.

-> The amount of monometer that can be loaded into a concrete specimen is limited by the amount of water and air that has occupied the total void space.

-> It is necessary to know the concentration of water and air void in the system to determine the rate of monometer penetration. However the main research effort has been towards obtaining a maximum monomer loading in concrete by the removal of water and air from the concrete by vacuum (or) thermal drying, the latter being more practicable for water removal because of its rapidity.

2) Polymer cement concrete (PCC)

-> Polymer cement concrete is made by mixing cement, aggregates, water and monometers. Such plastic mixture is cast in moulds, cured, dried and polymerised. The monometer that are used in PCC are.

a) Polyster-styrene
b) Epoxy-styrene
c) Furans
d) Vinylidene chloride.

-> However the results in obtained by the production of PCC in this way have been disappointing and have shown relatively modest improvement of strength and durability. In many cases, materials poorer than ordinary concrete are obtained.

-> This behaviour is explained by the fact that organic materials are incompatible with aqueous system and sometimes interfere with the alkaline cement hydration process.

3) Polymer concrete :-

-> Polymer concrete is an aggregate bound with a polymer binder instead of portland cement as in conventional concrete.

-> The main technique in producing PC is to minimise void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates.

-> This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume.

→ The graded aggregates are prepacked and vibrated in a mould. Monomer is then diffused up through the aggregates and polymerisation is initiated by radiation (or) chemical means.
→ An important reason for the development of this material is the advantage it offers over conventional concrete where the alkaline portland cement on curing, forms internal voids water can be entrapped in these voids which on freezing can readily crack the concrete.
→ Polymer concretes tend to be brittle and it is reported that dispersion of fibre reinforcement would improve the toughness and tensile strength of the material.
→ The use of fibrous polyester concrete (FPC) in the compression strength of reinforced concrete beams provides a high strength, ductile concrete at reasonable cost.

4) Partially impregnated and surface coated concrete:
→ Partial impregnation may be sufficient in situations where the major emphasis is surface resistance against chemical and mechanical attack in addition to strength increase.
→ Even with only partial impregnation, significant increases in the strength of original concrete has been obtained.
→ The depth of monomer penetration is dependent upon following.
1) Pore structure of hardened and dried concrete.
2) The duration of soaking.
3) Viscosity of the monomer.

Application of polymer impregnated concrete:

1) Prefabricated structural elements.
2) Prestressed concrete
3) Marine works
4) Desalination plants
5) Nuclear power plants
6) Sewage works - pipe & internal work.
7) Ferrocement products
10) Water proofing structures
11) Industrial applications.

SELF COMPACTING CONCRETE:

-> Modern application of self compacting concrete (SCC) is focussed on high performance, better and more reliable and uniform quality.

-> Self compacting concrete has been described as "the most revolutionary development in concrete construction for several decades"

-> Originally developed in Japan to offset a growing shortage of skilled labour, it has proved to be beneficial from the following points.

- 1) Faster construction
  2) Reduction in site manpower
  3) Better surface finish
  4) Easier placing
  5) Improved durability
  6) Greater freedom in design
  7) Thinner concrete sections
  8) Reduced noise level
  9) Safer working environment

Material for SCC

Cement: ordinary Portland cement, 43 or 53 grades can be used.

4. Aggregates.

→ The maximum size of aggregate is generally limited to 20mm. Aggregate of size 10to12mm is desirable for structures having congested reinforcement. possible size of aggregate higher than 20mm could also be used.

Mixing water:

→ water quality must be established on the same line as that for using reinforced concrete or prestressed concrete.

Chemical admixtures:

→ super plasticizers are an essential component of scc to provide necessary workability. the new generation super plasticisers termed poly-carboxylated ethers (pce) is particularly useful for scc.

Mineral admixtures:

a) Fly ash
b) GGBFS
c) silica fume
d) stone powder
e) fibres.

TYPES OF SSC

→ There are three types of SSC

i) powder type:

→ This is proportioned to give the required self compactability by reducing the water - powder ratio and provide adequate segregation resistance.

→ powdered type scc made by increasing powder content

ii) viscosity ~~[illegible]~~ modifying admixtures:

→ by the use of viscosity ~~[illegible]~~ SSC by the use of viscosity modifying admixtures to provide segregation

→ ~~Increasing powder content and using VMA.~~

iii) Combined type :-

-> reduce the water powder ratio.
-> It is made by increasing powder content and using VMA.

MIX DESIGN:

1) Determine the desired air content.
2) Determine the coarse aggregate volume.
3) Determine the sand content
4) Design the paste composition.
5) Determine the optimum water/powder ratio & super plasticizer dosage in mortar.

TESTS ON CONCRETE:

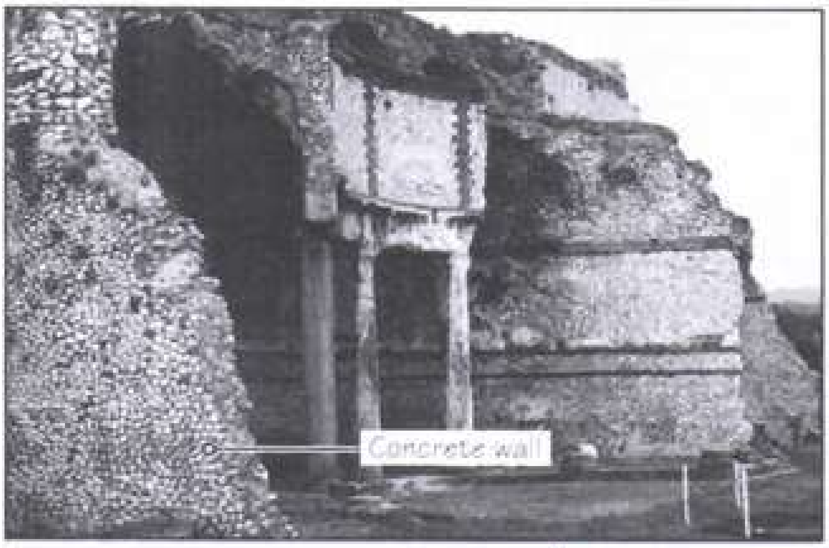
-> The concrete composition is now determined and the super-plasticizer dosage is finally selected on the basis of tests on concrete

Guidelines for mix composition:

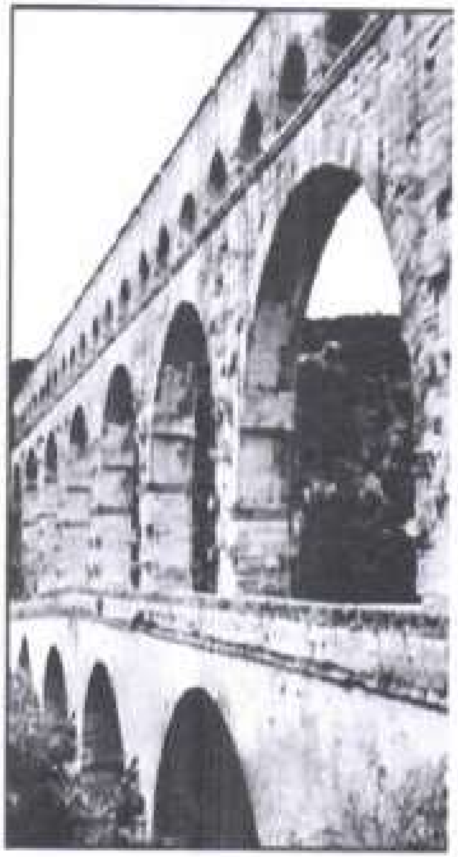
Coarse aggregate <50%
Water/powder ratio = 0.8 to 1.0
Total powder content = 400-600 kg/m3.
Sand content = < 40% of the mortar.
Sand < 50% of paste volume.
Sand > 50% weight of total aggregate.
Free water < 200 litres
Paste = 40% of the volume of the mix.

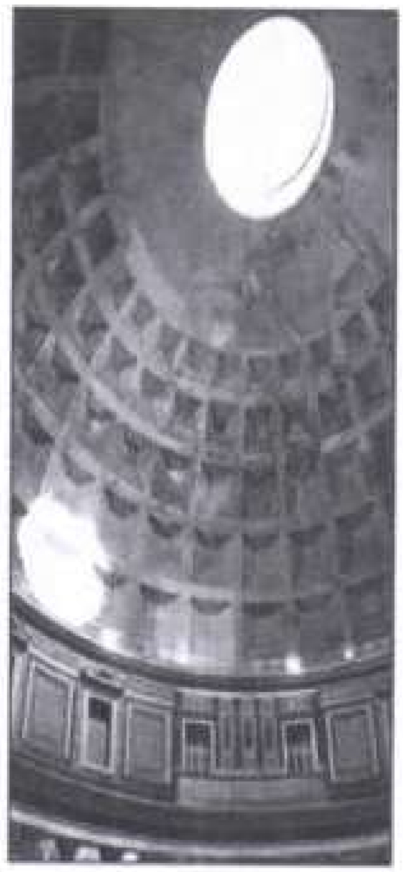
8. OHD/LCD SHEETS /CDS/DVDS/PPT (SOFT/HARD COPIES)

Concrete has deep roots in history:
Wall at Palestrina, Italy, 1st Century BC



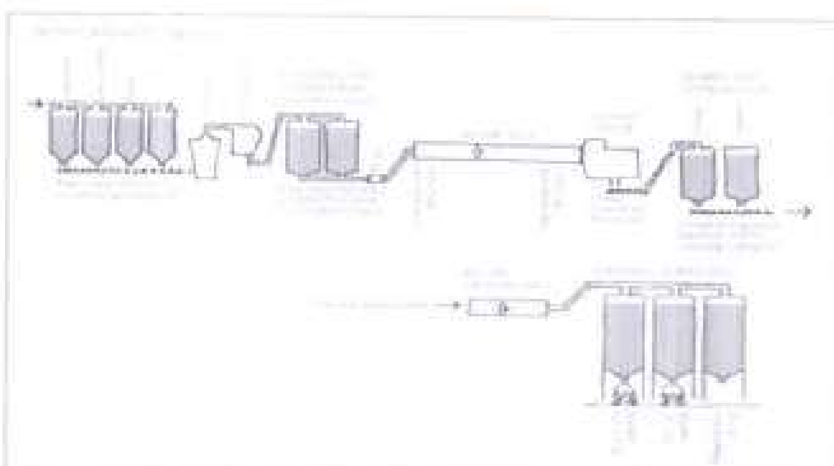
Roman Aqueduct & Pantheon





CONCRETE

Portland Cement Manufacturing Process



PHYSICAL PROPERTIES OF CEMENT

FIELD TEST

LABORATORY TEST

SETTING TIME TEST

FINENESS TEST

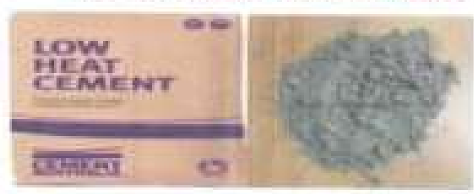
STRENGTH TEST

TYPES OF CEMENT

ORDINARY PORTLAND CEMENT

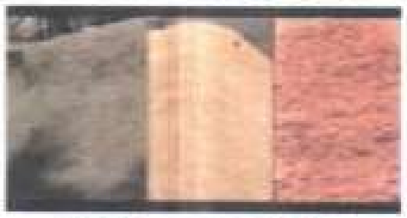
RAPID HARDENING CEMENT

QUICK SETTING CEMENT

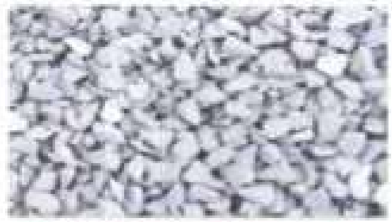


LOW HEAT CEMENT

AGGREGATE CLASSIFICATION:SIZE



FINE AGGREGATE

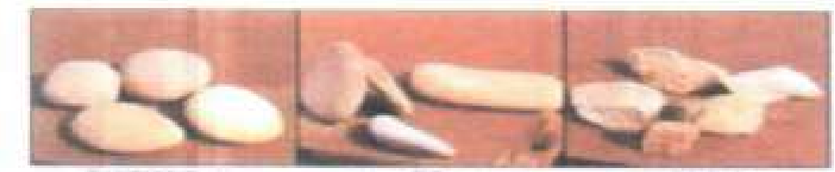


COARSE AGGREGATE

NORMAL AGGREGATE

LIGHT WEIGHT AGGREGATE

AGGREGATE CLASSIFICATION:SHAPE



PROPERTIES OF AGGREGATE

Specific gravity test

Bulk density test

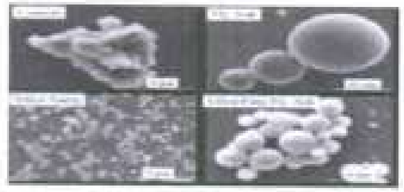
PROPERTIES OF AGGREGATE

IMPACT TEST

CRUSHING TEST

ADMIXTURES

CHEMICAL ADMIXTURES



MINERAL ADMIXTURES

FRESH CONCRETE

MANUFACTURING PROCESS OF CONCRETE

BATCHING OF CONCRETE

WEIGH BATCHING

VOLUME BATCHING

MIXING OF CONCRETE

HAND MIXING

MACHINE MIXING

TRANSPORTING

TRUCK

WHEEL BARROW

CHUTE

PLACING OF CONCRETE

CONVEYOR BELT

PUMPING OF CONCRETE

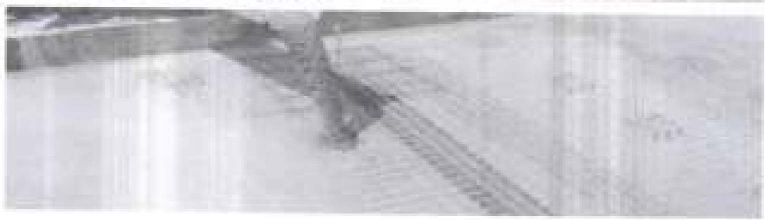
CURING

WATER

MEMBRANE

ELECTRICAL

WORKABILITY



FACTORS AFFECTING WORKABILITY

- water content
- mix proportion
- size of aggregate
- shape of aggregate
- texture of aggregate
- grading of aggregate
- use of admixtures

MEASUREMENT OF WORKABILITY

SLUMP TEST

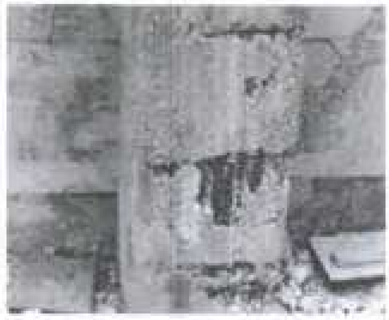
COMPACTION FACTOR TEST

FLOW TEST

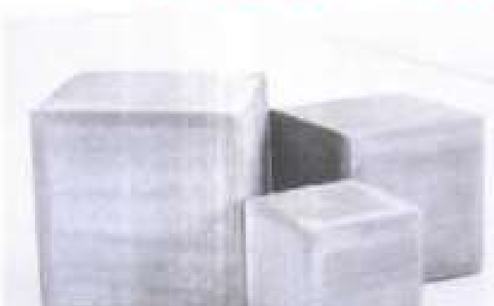
VEE-BEE CONSISTOMETER

BLEEDING OF CONCRETE

SEGGREGATION OF CONCRETE

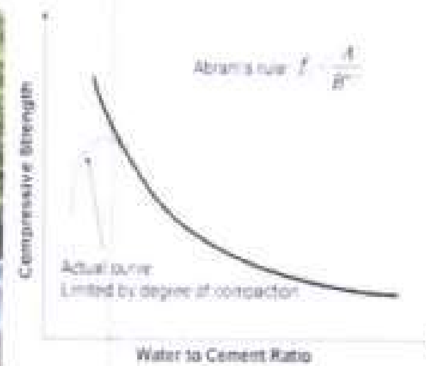


HARDENED CONCRETE

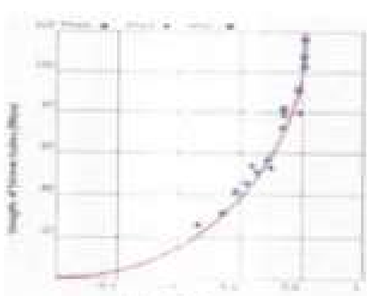


ABRAM'S LAW

WATER/CEMENT RATIO



GEL/SPACE RATIO



CALCULATION OF GEL/SPACE RATIO:

FULL HYDRATION:

GEL/SPACE RATIO = $\frac{0.657C}{0.319C\alpha + w_o}$

PARTIAL HYDRATION:

GEL/SPACE RATIO = $\frac{0.657C\alpha}{0.319C\alpha + w_o}$

MATURITY CONCEPT

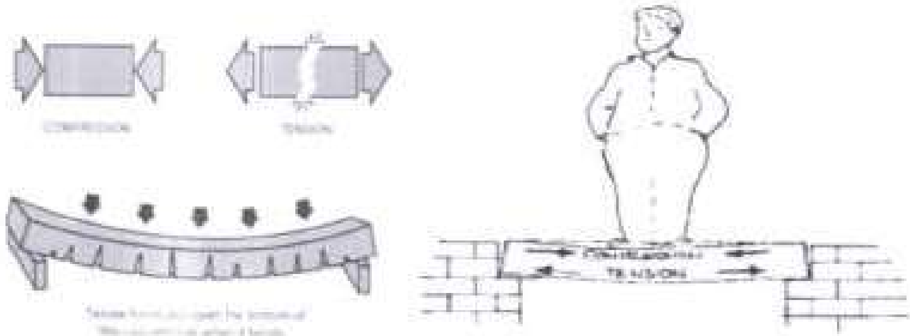
sensor for monitoring the temperature of concrete from fresh to hardened stage.

NATURE OF CONCRETE

FRACTURE OF CONCRETE CUBE

FAILURE OF CONCRETE CUBE

STRENGTH IN TENSION AND COMPRESSION



TESTING OF HARDENED CONCRETE

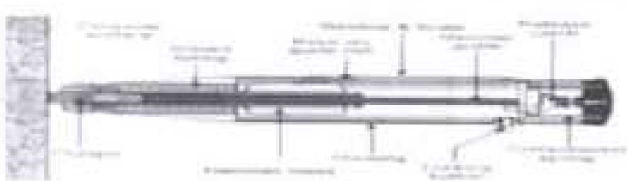
COMPRESSIVE STRENGTH OF CONCRETE

TENSILE STRENGTH OF CONCRETE

FLEXURAL TEST

SPLIT TENSILE TEST

NDT METHODS

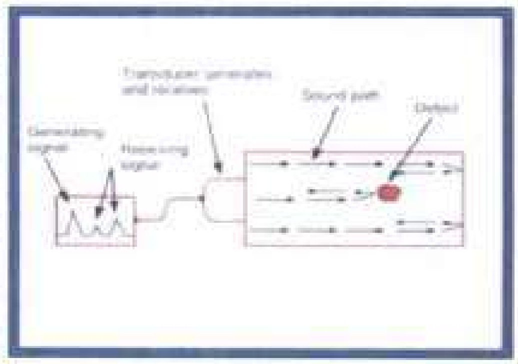


REBOUND HAMMER TEST

ULTRA SONIC PULSE VELOCITY

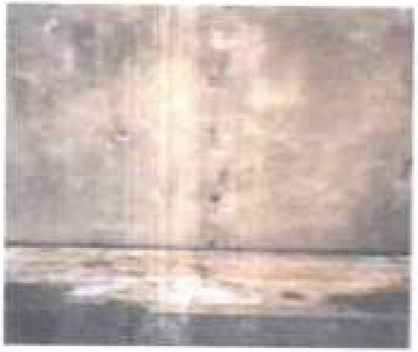
PULLOUT TEST

CTS Electrical Resistivity Testing Using Proceq Resi



ELECTRICAL RESISSTIVITY METHOD

SHRINKAGE



DRYING SHRINKAGE

PLASTIC SHRINKAGE

MIX DESIGN

FACTORS IN THE CHOICE OF MIX DESIGN

Compressive strength of concrete

Workability of concrete

Durability of concrete

Nominal size of aggregate

Fineness modulus

Quality control

MIX DESIGN PROCEDURE

TARGET MEAN STRENGTH:

$fck' = fck - 1.65s$

WATER/CEMENT RATIO:

Exposure	P.C.C			R.C.C		
	Minimum Cement Content Kg/m^3	Max Free Water - Cement Ratio	Minimum Grade of Concrete	Minimum Cement Content Kg/m^3	Max Free Water - Cement Ratio	Minimum Grade of Concrete
Mild	[illegible]	0.6	-	300	0.55	M20
Moderate	240	0.6	M15	300	0.5	M25
Severe	250	0.5	M20	320	0.45	M30
Very severe	260	0.45	M20	340	0.45	M35
Extreme	280	0.4	M25	360	0.4	M40

CALCULATION OF WATER

Table 2 Maximum Water Content per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate

(*Clauses* 4.2, A-5 *and* B-5)

Sl No.	Nominal Maximum Size of Aggregate mm	Maximum Water Content [1] kg
(1)	(2)	(3)
i)	10	208
ii)	20	186
iii)	40	165

CEMENT CONTENT:

take from above step

COARSE AND FINE AGGREGATES:

Maximum Size of Aggregate (mm)	Volume of Coarse Aggregate per Unit Volume of Total Aggregate			
	Zone IV	Zone III	Zone II	Zone I
10	0.50	0.48	0.46	0.44
20	0.66	0.64	0.62	0.60
40	0.75	0.73	0.71	0.69

SPECIAL CONCRETE




LIGHT WEIGHT AGGREGATE CONCRETE

LIGHT WEIGHT CONCRETE

Cellular concrete

NO FINES CONCRETE (OR) PERVIOUS CONCRETE

Self compacting concrete

High density concrete

Fibre reinforced concrete

Polymer concrete

9. University Previous Question papers

Code No: 115EP **R13**

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B. Tech III Year I Semester Examinations, November - 2015
CONCRETE TECHNOLOGY
(Common to CE, CEE)

Time: 3 hours **Max. Marks: 75**

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B consists of 5 Units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART - A (25 Marks)

1.a) List out different grades of cement. [2]
b) Explain about bulking of sand. [3]
c) Define workability. [2]
d) Explain about bleeding. [3]
e) Explain rheology of creep. [2]
f) Brief out different types of shrinkage. [3]
g) What is the difference between pumpable and normal concrete? [2]
h) Explain statistical quality control of concrete. [3]
i) What is aspect ratio of fibers? [2]
j) Explain about light weight aggregates. [3]

PART-B (50 Marks)

2.a) Explain in detail about heat of hydration of cement.
b) Explain in detail about influence of compound composition on properties of cement. [5+5]

OR

3.a) Explain deleterious substance in aggregate and soundness of aggregate.
b) Explain about gap graded aggregate and BIS grading. [5+5]

4.a) Explain setting times of concrete.
b) Explain effect of time and temperature on workability of concrete. [5+5]

OR

5. Explain in detail about measurement of workability by different tests. [10]

6.a) Explain factors affecting strength of concrete.
b) Explain nature of creep and effects of creep on structural concrete. [5+5]

OR

7. Explain in detail about maturity concept of concrete with illustrative examples. [10]

8.a) Explain in detail about durability of concrete.
b) What are different variables in proportioning that influence mix design of pumpable concrete? [5+5]

OR

9. Design M 20 grade concrete assuming suitable data according to IS 10262-2009. [10]

10. Explain in detail about Self compacting concrete. [10]

OR

11. Explain in detail about Fiber reinforced concrete. [10]

~

Principal
Vaageswari College of Engineering
KARIMNAGAR

R13

Code No: 115EP

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD

B.Tech III Year I Semester Examinations, February/March - 2016

CONCRETE TECHNOLOGY

(Common to CE, CEE)

Time: 3 hours **Max. Marks: 75**

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A.
Part B consists of 5 Units. Answer any one full question from each unit.
Each question carries 10 marks and may have a, b, c as sub questions.

Part- A

(25 Marks)

1.a) What is the role of calcium [illegible] in the hydration [illegible] of cement? [2]
b) Explain about surface acting [illegible]. [3]
c) Write about the [illegible] type of [illegible]. [2]
d) Explain about LAITANCE. [3]
e) What are different types of [illegible]? [2]
f) What is the relation between creep and time? [3]
g) How bulking of sand is corrected [illegible]? [2]
h) What is entrapped air? How is it accounted [illegible] mix design? [3]
i) What is no fines concrete? [2]
j) Explain about cellular concrete? [3]

Part-B

(50 Marks)

2.a) Explain about set controlling [illegible].
b) What is alkali aggregate reaction? What factors promote alkali aggregate reaction and how it can be controlled? [5+5]

OR

3.a) Explain the method of determining the fineness of cement by [illegible] method?
b) Explain the shape tests on aggregate? [5+5]

4.a) Explain in detail about bleeding and segregation of concrete? How it can be controlled?
b) Explain slump test on fresh concrete and the recommended slump values for different work abilities? [5+5]

OR

5.a) Discuss about the quality of mixing water [illegible] per IS code provisions?
b) Explain the steps in manufacture of concrete in [illegible] order? [5+5]

6.a) Calculate the Gel/Space ratio and hence estimate the 28 day strength for one bag of cement with 0.55 W/C ratio at 75% hydration?
b) Explain the creep behavior of concrete with the help of creep curve? [5+5]

8.a) Explain Maturity of concrete.
b) Write short notes on Gel/ space ratio. [5+5]

OR

9.a) Write step wise procedure for mix design of concrete as per Indian Standards.
b) Define durability and its significance. [5+5]

10.a) Explain light weight aggregate concrete.
b) Write short notes on self compacting concrete. [5+5]

OR

11.a) Explain various types of polymer concrete.
b) Write short notes on no-fines concrete. [5+5]

---ooOoo---

R13

Code No: 115EP

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD

B. Tech III Year I Semester Examinations, November/December - 2016

CONCRETE TECHNOLOGY

(Common to CE, CEM)

Time: 3 hours **Max. Marks: 75**

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B consists of 5 Units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART - A

(25 Marks)

1.a) Give the chemical composition of cement. [2]
b) What is fineness modulus of aggregate? What does it indicate? [3]
c) Define initial setting time and final setting time of cement. [2]
d) What is the purpose of mixing water in concrete? [3]
e) Define water cement ratio. [2]
f) State necessity of curing for cement concrete. [3]
g) Give any two requirements of concrete mix design. [2]
h) Differentiate preliminary test and trial mixes. [3]
i) Give two applications of light weight concrete. [2]
j) Give the advantages of fibre reinforced concrete. [3]

PART - B

(50 Marks)

2. Explain different methods of determination of moisture content of aggregates. [10]

OR

3.a) What is heat of hydration? How does this affect the quality of concrete?
b) Explain different laboratory tests to be conducted on cement to decide its quality. [5+5]

4.a) What are the various tests to measure workability? Explain any one with neat sketch.
b) Explain segregation and bleeding in concrete. [5+5]

OR

5.a) List out the factors affecting workability and explain them.
b) Write short notes on Quality of mixing water. [5+5]

6. List out the non-destructive tests and explain any two non - destructive testing methods on hardened concrete. [10]

OR

7.a) Define creep and explain the relation between creep and time.
b) Explain shrinkage and types of shrinkage. [5+5]

R13

Code No: 115EP

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD

B. Tech III Year I Semester Examinations, March - 2017

CONCRETE TECHNOLOGY

(Common to CE, CEE)

Time: 3 hours **Max. Marks: 75**

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B consists of 5 Units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART - A

(25 Marks)

1.a) What is flash set of cement and how to avoid this? [2]
b) Explain the mechanism of deflocculating of cement by superplasticizer. [3]
c) Define workability in terms of energy. [2]
d) Define [illegible] responsible for it. [3]
e) State Abram's water cement ratio law. [2]
f) How does drying shrinkage affect concrete? [3]
g) State the merits and demerits of IS mix design method. [2]
h) What do you understand by target mean strength? [3]
i) Give the application of cellular concrete. [2]
j) What is 'no-fines' concrete? [3]

PART - B

(50 Marks)

2.a) Explain how the Bogue's compounds participate in the development of strength of cement.
b) Explain the effect of h/d ratio and size of aggregate on the strength properties of concrete. [5+5]

OR

3.a) What is Alkali aggregate reaction and how it can be controlled.
b) What are the chemical admixtures? Explain different types of admixtures. [5+5]

4.a) List the factors effecting the workability of concrete.
b) Explain the procedure for determining the setting times of concrete. [5+5]

OR

5.a) Discuss the applicability of the various workability tests to concretes of different levels of workability.
b) Define bleeding and segregation of concrete and Explain the methods to control them. [5+5]

Code No: 125EP

17AG1A0139

R15

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD

B. Tech III Year I Semester Examinations, November/December - 2017

CONCRETE TECHNOLOGY

(Common to CE, CT)

Time: 3 hours Max. Marks: 75

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B consists of 5 Units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b, c as sub questions.

PART - A

(25 Marks)

1.a) What does the grade of cement indicate? [2]
b) What are the [illegible] and [illegible] of [illegible] aggregate? [3]
c) For which type of [illegible] do you use Vee Bee test? What are the [illegible] [2]
d) What is the [illegible] test for [illegible] of water as per IS 456 code? [3]
e) Define the Abram's law. [2]
f) What are the different types of shrinkage of concrete? [3]
g) Define the term 'Durability' of concrete. [2]
h) Differentiate between [illegible] strength and [illegible] strength in concrete mix design. [3]
i) What is Cellular concrete? [2]
j) Differentiate between RCC and fibre reinforced concrete. [3]

PART - B

(50 Marks)

2.a) [illegible] of [illegible] compounds of ordinary Portland cement.
b) What is bulking of fine aggregate? [illegible] [5+5]

OR

3.a) [illegible] in detail [illegible] [illegible]
b) Determine the fineness modulus of following [illegible] [illegible] kg. [5+5]

S.No.	Sieve size	Weight retained in grams
1	40 mm	0
2	20 mm	250
3	10 mm	800
4	4.75 mm	[illegible]
5	2.36 mm	0

10. MID exam Descriptive Question Papers with Key

VAAGESWARI COLLEGE OF ENGINEERING

(Approved by AICTE, Affiliated to JNTUH)

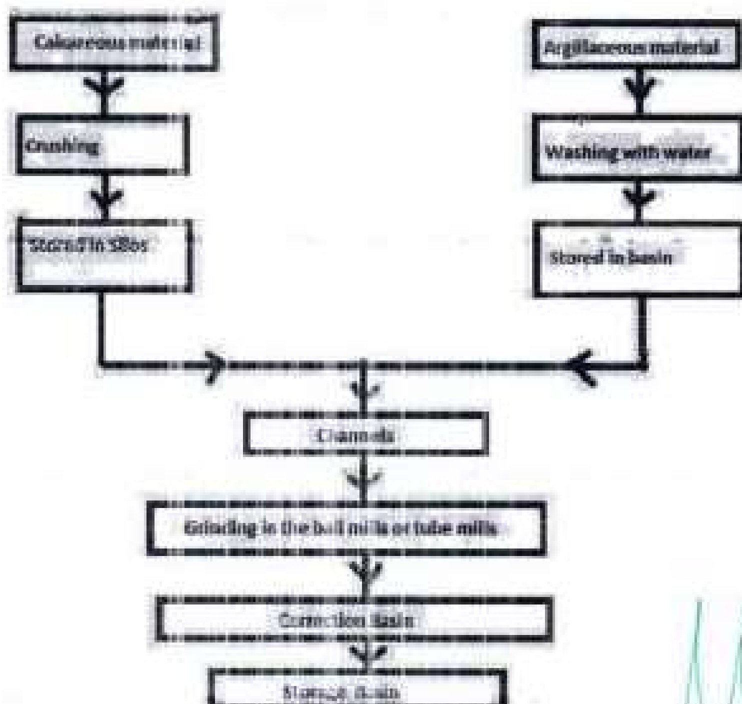
MID-I

Q.NO	Question	BLOOMS LEVEL	COURSE OUTCOME
1	**Give step by step method of manufacturing process of cement.**	Understand	CO1
2	**What is Admixtures and explain the classification of admixtures?**	understand	CO1
3	**a) Explain the mechanical properties of aggregates?** **b) Explain the classification of aggregates?**	understand	CO1
4	**Briefly explain manufacturing procedure of concrete.**	understand	CO2

KEY

1. Explain the manufacturing process of cement with flow chart

The basic ingredients of both the dry and wet processes are the same. By mass, lime and silica make up approximately 85% of Portland cement. The materials that are commonly used are limestone, shells, chalk, shale, clay, slate, silica sand, and iron ore.



2. What is Admixtures and explain the classification of admixtures?

A material other than water, aggregates, or cement that is used as an ingredient of concrete or mortar to control setting and early hardening, workability, or to provide additional cementing properties.

1. <u>**Chemical admixtures**</u>

Accelerators, Retarders, Water-reducing agents, Super plasticizers, Air entraining agents etc.

Water-reducing admixture / Plasticizers

- To achieve a higher strength by decreasing the water cement ratio at the same workability as an admixture free mix.
- To achieve the same workability by decreasing the cement content so as to reduce the heat of hydration in mass concrete.
- To increase the workability so as to ease placing in accessible locations
- Water reduction more than 5% but less than 12%.

Super Plasticizers:

These are more recent and more effective type of water reducing admixtures also known as *high range water reducer*.

Accelerator

An admixture which, when added to concrete, mortar, or grout, increases the rate of hydration of hydraulic cement, shortens the time of set in concrete, or increases the rate of hardening or strength development.

Air Entrained Admixtures:

An addition for hydraulic cement or an admixture for concrete or mortar which causes air, usually in small quantity, to be incorporated in the form of minute bubbles in the concrete or mortar during mixing, usually to increase its workability and frost resistance. Air-entraining admixtures are surfactants that change the surface tension of the water. Traditionally, they were based on fatty acid salts or vinsol resin but these have largely been replaced by synthetic surfactants or blends of surfactants to give improved stability and void characteristics to the entrained air. Air entrainment is used to produce a number of effects in both the plastic and the hardened concrete

2. <u>**Mineral admixtures**</u>

Fly-ash Blast-furnace slag, Silica fume and Rice husk Ash etc

Fly Ash:

The finely divided residue resulting from the combustion of ground or powdered coal. Fly ash is generally captured from the chimneys of coal-fired power plants; it has POZZOLANIC properties, and is sometimes blended with cement for this reason.

Fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Toxic constituents include arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium.

Silica Fume:

The terms condensed silica fume, microsilica, silica fume and volatilized silica are often used to describe the by-products extracted from the exhaust gases of silicon, ferrosilicon and other metal alloy furnaces. However, the terms microsilica and silica fume are used to describe those condensed silica fumes that are of high quality, for use in the cement and concrete industry.

Rice Husk Ash:

This is a bio waste from the husk left from the grains of rice. It is used as a pozzolanic material in cement to increase durability and strength. The silica is absorbed from the ground and gathered in the husk where it makes a structure and is filled with cellulose. When cellulose is burned, only silica is left which is grinded to fine powder which is used as pozzolana.

3.a). Explain the mechanical properties of aggregates?

Specific gravity

The ratio of weight of oven dried aggregates maintained for 24 hours at a temperature of 100 to 110^0C, to the weight of equal volume of water displaced by saturated dry surface aggregate is known as specific gravity of aggregates.

Specific gravities are primarily of two types.

- Apparent specific gravity
- Bulk specific gravity

Bulk density

It is defined as the weight of the aggregate required to fill a container of unit volume. It is generally expressed in kg/litre.

Bulk density of aggregates depends upon the following 3 factors.

- Degree of compaction
- Grading of aggregates
- Shape of aggregate particles

Porosity

The minute holes formed in rocks during solidification of the molten magma, due to air bubbles, are known as pores. Rocks containing pores are called porous rocks.

Adsorption and Moisture content

Water absorption may be defined as the difference between the weight of very dry aggregates and the weight of the saturated aggregates with surface dry conditions.

Depending upon the amount of moisture content in aggregates, it can exist in any of the 4 conditions.

- Very dry aggregate (having no moisture)
- Dry aggregate (contain some moisture in its pores)
- Saturated surface dry aggregate (pores completely filled with moisture but no moisture on surface)
- Moist or wet aggregates (pores are filled with moisture and also having moisture on surface)

3. b). Explain the classification of aggregates?

Aggregates are classified according to shape

- Rounded aggregates
- Irregular or partly rounded aggregates
- Angular aggregates
- Flaky aggregates

- Elongated aggregates
- Flaky and elongated aggregates

Aggregates are classified according to size

- Fine aggregate
- Coarse aggregate

Aggregates are classified according to source

- Igneous rocks
- Sedimentary rocks
- Metamorphic rocks

Aggregates are classified according to weight

- Normal weight aggregates
- Light weight aggregates
- Heavy weight aggregates

3. Briefly explain manufacturing procedureofconcrete.

Batching:
The measurement of materials making concrete is known as batching, these batching are two methods weigh batching and volume batching

Mixing:
Mixing of material is essential for the production of uniform concrete. The mixing should ensure that the mass becomes uniform in color and consistency .there are two methods adopted for mixing concrete hand mixing and machine mixing

Transporting:
The method adopted for transportation of concrete
Mortar pan, wheel barrow hand cart, crane bucket and rope way, truck mixer, belt conveyor, transit mixer, pump and pipeline, helicopter.

Placing of concrete:
Concrete is invariably laid as a foundation bed below the walls or columns before placing the concrete in the foundation all the loose earth must be removed from the bed.

Compaction:
Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. The method of compaction is hand compaction, vibration compaction, compaction by pressure and jolting, compaction by spinning.

Curing:
curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue more elaborately it can be described as the process of maintaining a satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service. Curing methods are water curing, membrane curing, and application of heat.

Finishing:

It's the last operation making concrete. Its increases does not apply to all concrete operations

11. Assignment topics with materials

UNIT-I

CEMENT

1. **Define mortar and its types**
2. **Explain about hydration of cement**
3. **What are the basic testing of cement**
4. **Determine the compressive strength of cement.**

TOPIC 1: Mortar and its types

The mortar is a paste like substance prepared by adding required amount of water to a dry mixture of sand or fine aggregate with some binding material like clay, lime or cement.

Limemortar:

If lime is used as a binding material, the resulting mortar is known as lime mortar.

Mudmortar:

When clay is used as a binding material, the resulting mortar is known as mud mortar

TOPIC 2:Hydration

The setting and hardening of concrete are the result of chemical and physical processes that take place between Portland cement and water, i.e. hydration. To understand the properties and behaviour of cement and concrete some knowledge of the chemistry of hydration is necessary.

A) Hydration reactions of pure cementcompounds

The chemical reactions describing the hydration of the cement are complex. One approach is to study the hydration of the individual compounds separately. This assumes that the hydration of each compound takes place independently of theothers.

I. Calciumsilicates

Hydration of the two calcium silicates gives similar chemical products, differing only in the amount of calcium hydroxide formed, the heat released, and reaction rate.

$2\ C_3S + 7\ H \rightarrow C_3S_2H_4 + 3\ CH\ 2\ C_2S + 5\ H \rightarrow C_3S_2H_4 + CH$

The principal hydration product is $C_3S_2H_4$, calcium silicate hydrate, or C-S-H (non- stoichiometric). This product is not a well-defined compound. The formula $C_3S_2H_4$is only an approximate description. It has amorphous structure making up of poorly organized layers and is called glue gel binder. C-S-H is believed to be the material governing concrete strength. Another product is CH - $Ca(OH)_2$, calcium hydroxide. This product is a hexagonal crystal often forming stacks of plates. CH can bring the pH value to over 12 and it is good for corrosion protection ofsteel.

II. Tri-calciumaluminate

Without gypsum, C_3A reacts very rapidly with water:

$C_3A + 6\ H \rightarrow C_3AH_6$

The reaction is so fast that it results in flash set, which is the immediate stiffening after mixing, making proper placing, compacting and finishing impossible.

With gypsum, the primary initial reaction of C_3A with water is

$C_3A + 3\ (C\ S\ H_2) + 26\ H \rightarrow C_6A\ S_3H_{32}$

The 6-calcium aluminate trisulfate-32-hydrate is usually called ettringite. The formation of ettringite slows down the hydration of C_3A by creating a diffusion barrier around C_3A. Flash set is thus avoided. Even with gypsum, the formation of ettringite occurs faster than the hydration of the calcium silicates.

It therefore contributes to the initial stiffening, setting and early strength development. In normal cement mixes,theettringite is not stable and will further react to form monosulphate ($C_4A\bar{S}H_{18}$)

B) Kinetics andReactivity's

The rate of hydration during the first few days is in the order of $C_3A > C_3S > C_4AF > C_2S$.

C) Calorimetric curve of Portlandcement

A typical calorimetric curve of Portland cement is shown in the following figure. The second heat peaks of both C_3S and C_3A can generally be distinguished, although their order of occurrence can be reversed.

D) Setting andHydration

Initial set of cement corresponds closely to the end of the induction period, 2-4 hours after mixing. Initial set indicates the beginning of forming of gel or beginning of solidification. It represents approximately the time at which fresh concrete can no longer be properly mixed, placed or compacted. The final set occurs 5-10 hours after mixing, within the acceleration period. It represents approximately the time after which strength develops at a significant rate.

In practice, initial and final set are determined in a rather arbitrary manner with the penetration test.

TOPIC 3: Basic test of cement

Fineness (= surface area / weight):

This test determines the average size ofcement grains. The typical value of fineness is 350 m^2 / kg.Fineness controls the rate and completeness of hydration. The finer a cement,the more rapidly it reacts, the higher the rate of heat evolution and the higher the early strength.

Normal consistency test:

This test is to determine the water required to achievea desired plasticity state (called normal consistency) of cement paste. It is obtained with the Vicat apparatus by measuring the penetration of a loaded needle.

Time of setting:

This test is to determine the time required for cement paste to harden. Initial set cannot be too early due to the requirement of mixing, conveying, placing and casting. Final set cannot be too late owing to the requirement of strength development. Time of setting is measured by Vicat apparatus. Initial setting time is defined as the time at which the needle penetrates 25 mm into cement paste. Final setting time is the time at which the needle does not sink visibly into the cement paste.

Soundness:

Unsoundness in cement paste refers to excessive volume change after setting. Unsoundness in cement is caused by the slow hydration of MgO or freelime.

Their reactions are $MgO + H_2O = Mg(OH)_2$ and $CaO + H_2O = Ca(OH)_2$. Another factor that can cause unsoundness is the delayed formation of ettringite after cement and concrete have hardened. The pressure from crystal growth will lead to cracking and damage. The soundness of the cement must be tested by accelerated methods. An example is the Le Chatelier test (BS 4550). This test is to measure the potential for volumetric change of cement paste. Another method is called Autoclave Expansion test (ASTM C151) which use an autoclave to increase the temperature to accelerate the process.

Strength:

The strength of cement is measured on mortar specimens made of cement and standard sand (silica). Compression test is carried out on a 2" cube with S/C ratio of 2.75:1 and w/cratio of 0.485 for Portland cements. The specimens are tested wet, using a loading rate at which the specimen will fail in 20 to 80 s. The direct tensile test is carried out on a specimen shaped like a dumbbell. The load is applied through specifically designed grips. Flexural strength is measured on a 40 x 40 x 160 mm prism beam test under a centre-point bending.

TOPIC 4: Compressive Strength of Cement

This test is carried out to determine the **compressive strength of cement**.

Test Procedure for compressive strength of cement:

(i) The mortar of cement and sand is prepared. The proportion is 1:3 which means that (X) gm of cement is mixed with 3(X) gm of sand.

(ii) The water is added to the mortar. The water cement ratio is kept as 0.4 which means that (X) gm of water is added to dry mortar.

(iii) The mortar is placed in moulds. The test specimens are in the form of cubes with side as 70.6 mm or 76 mm. The moulds are of metal and they are constructed in such a way that the specimens can be easily taken out without being damaged. For 70.6 mm and 76 mm cubes, the cement required is 185 gm and 235 gm respectively.

The mortar, after being placed in the moulds, is compacted in vibrating machine for 2 minutes.

(iv) Themoulds are placed in a damp cabin for 24 hours.

(vi) The specimens are removed from the moulds and they are submerged in clean water for curing.

(vii) The cubes are then tested in **compression testing machine** at the end of 3 days and 7 days. The testing of cubes is carried out on their three sides without packing. Thus three cubes are tested each time to find out the compressive strength at the end of 3 days and 7 days. The average value is then worked out. During the test, the load is to be applied uniformly at the rate of 350 kg/cm2 or 35 N/mm2.

(viii) The **compressive strength of cement** at the end of 3 days should not be less than 115 kg/cm2 or N/mm2 and that at the end of 7 days should not be less than 175 kg/cm2 or 17.50 N/mm2.

UNIT-II

AGGREGATES & ADMIXTURES

1. **Define aggregate and its classification**
2. **Explain the admixtures classification and functions**

TOPIC 1:Define aggregate and its classification

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone- like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete. The most popular use of aggregates is to form Portland cement concrete. Approximately three-fourths of the volume of Portland cement concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should have an important effect on the properties of both the fresh and hardened products. As another important application, aggregates are used in asphalt cement concrete in which they occupy 90% or more of the total volume. Once again, aggregates can largely influence the composite properties due to its large volume fraction.

Classification ofAggregate

Aggregates can be divided into several categories according to different criteria.

In accordance withsize:

Coarse aggregate: Aggregates predominately retained on the No. 4 (4.75 mm) sieve. For mass concrete, the maximum size can be as large as 150 mm.

Fine aggregate (sand): Aggregates passing No.4 (4.75 mm) sieve and predominately retained on the No. 200(75 μm) sieve.

In accordance withsources:

Natural aggregates: This kind of aggregate is taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Some examples in this category are sand, crushed limestone, and gravel.

Manufactured (synthetic) aggregates: This is a kind of man-made materials produced as a main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregate (e.g. expanded perlite), and heavy weight aggregates (e.g. iron ore or crushed steel).

In accordance with unitweight:

Light weight aggregate: The unit weight of aggregate is less than 1120kg/m^3. The corresponding concrete has a bulk density less than 1800kg/m^3. (cinder, blast-furnace slag, volcanic pumice).

Normal weight aggregate: The aggregate has unit weight of 1520-1680kg/m^3. The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m^3.

Heavy weight aggregate: The unit weight is greater than 2100 kg/m^3. The bulk density of the corresponding concrete is greater than 3200 kg/m^3. A typical example is magnesite limonite, a heavy iron ore. Heavy weight concrete is used in special structures such as radiation shields.

In accordance withorigin:

Igneous rock Aggregate:

- Hard, tough anddense.
- Massive structures: crystalline, glassy or both depending on the rate at which they are cooledduring formation.
- Acidic or basic: percentage of silicacontent.
- Light or darkcoloured.
- Chemically active: react withalkalis.

Sedimentary rock Aggregate:

- Igneous or metamorphic rocks subjected to weatheringagencies.
- Decompose, fragmentize, transport and deposit deep beneath ocean bed are cementedtogether.
- Range from soft-hard, porous-dense,light-heavy and can beflaky.
- Suitabilitydecidedby:degreeofconsolidation, typeofcementation,thicknessoflayerand contamination.

Metamorphic rock Aggregate:

- Rocks subjected to high temperature andpressure.
- Economic factor intoconsideration.
- Least overallexpense.

TOPIC 2: **Admixtures can be classified by function asfollows:**

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers
9. Alkali-silica reactivity inhibitors
10. Colouring admixtures
11. Miscellaneous admixtures such as workability, bonding, damp proofing, permeability reducing, grouting, gas forming, anti-washout, foaming, and pumping admixtures.

Concrete should be workable, finish able, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by resorting to admixtures (except air-entraining admixtures when needed).

The major reasons for using admixtures

1. To reduce the cost of concrete construction
2. To achieve certain properties in concrete more effectively than by other means
3. To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions
4. To overcome certain emergencies during concreting operations

UNIT-III

FRESH CONCRETE

1. Define workability and factors affecting workability
2. Explain about segregation and bleeding of concrete
3. Explain various methods of measuring workability

TOPIC 1: Workability

All the characteristics above describe many different aspects of concrete behavior. The term workability is used to represent all the qualities mentioned. Workability is often defined in terms of the amount of mechanical energy, or work, required to fully compact concrete without segregation. This is important since the final strength is a function of compaction.

The concept of viscosity is a measure of how a material behaves under stress. For a Newtonian fluid, the relationship may be written as:

$$\tau = \eta D$$

Where **τ** is the shear stress, **η** is the viscosity, and *D* is the rate of shear or velocity gradient. For a very dilute suspension of solids in liquids, this relationship holds true. However, for large volumes of suspended solids, like concrete, the Newtonian model does not work. Concrete has an initial shear strength that must be exceeded before it will flow. This type of behaviour is described by the Bingham model:

$$\tau - \tau_0 = \eta D$$

Where **τ0** is the yield shear stress, **η** is the plastic viscosity.

Factors AffectingWorkability

Water Content of the Mix:

This is the single most important factor governing workability of concrete. A group of particles requires a certain amount of water. Water is absorbed on the particle surface, in the volumes between particles, and provides "lubrication" to help the particles move past one another more easily. Therefore, finer particles, necessary for plastic behaviour, require more water. Some side- effects of increased water are loss of strength and possible segregation.

Influence of Aggregate Mix Proportions:

Increasing the proportion of aggregates relative to the cement will decrease the workability of the concrete. Also, any additional fines will require more cement in the mix. An "over sanded" mix will be permeable and less economical. A concrete deficient of fines will be difficult to finish and prone to segregation.

Aggregate Properties:

The ratio of coarse/fine aggregate is not the only factor affecting workability. The gradation and particle size of sands are important. Shape and texture of aggregate will also affect workability. Spherical shaped particles will not have the interaction problems associated with more angular particles. Also, spherical shapes have a low surface/volume ratio, therefore, less cement will be required to coat each particle and more will be available to contribute to the workability of the concrete. Aggregate which is porous will absorb more water leaving less to provide workability. It is important to distinguish between total water content, which includes absorbed water, and free water which is available for improving workability.

Time and Temperature:

In general, increasing temperature will cause an increase in the rate of hydration and evaporation. Both of these effects lead to a loss of workability.

Loss of Workability:

Workability will decrease with time due to several factors; continued slow hydration of C3S and C3A during dormant period, loss of water through evaporation and absorption, increased particle interaction due to the formation of hydration products on the particle surface. Loss of workability is measured as "slump loss" with-time.

Cement Characteristics:

Cement characteristics are less important than aggregate properties in determining workability. However, the increased fineness of rapid-hardening cements will result in rapid hydration and increased water requirements, both of which reduce workability.

Admixtures:

In general, air-entraining, water-reducing, and set-retarding admixtures will all improve workability. However, some chemical admixtures will react differently with cements and aggregates and may result in reduced workability.

TOPIC 2: Segregation and Bleeding

Segregation:

Segregation refers to a separation of the components of fresh concrete, resulting in a non-uniform mix. This can be seen as a separation of coarse aggregate from the mortar, caused from either the settling of heavy aggregate to the bottom or the separation of the aggregate from the mix due to improper placement.

Some factors that increase segregation are:

1. Larger maximum particle size (25mm) and proportion of the larger particles.
2. High specific gravity of coarse aggregate.
3. Decrease in the amount of fine particles.
4. Particle shape and texture.
5. Water/cement ratio.

Bleeding:

Bleeding is defined as the appearance of water on the surface of concrete after it has consolidated but before it is set. Since mixing water is the lightest component of the concrete, this is a special form of segregation. Bleeding is generally the result of aggregates settling into the mix and releasing their mixing water. Some bleeding is normal for good concrete.

However, if bleeding becomes too localized, channels will form resulting in "craters". The upper layers will become too rich in cement with a high w/c ratio causing a weak, porous structure. Salt may crystallize on the surface which will affect bonding with additional lifts of concrete. This formation should always be removed by brushing and washing the surface. Also, water pockets may form under large aggregates and reinforcing bars reducing the bond.

Bleeding may be reduced by:

- Increasing cement fineness.
- Increasing the rate of hydration.
- Using air-entraining admixtures.
- Reducing the water content.

TOPIC 3: Measurement of Workability

Workability, a term applied to many concrete properties, can be adequately measured by three characteristics:

1. Compatibility, the ease with which the concrete can be compacted and air void removed.
2. Mobility, ease with which concrete can flow into forms and around reinforcement.
3. Stability, ability for concrete to remain stable and homogeneous during handling and vibration without excessive segregation.

Different empirical measurements of workability have been developed over the years. None of these tests measure workability in terms of the fundamental properties of concrete. However, the following tests have been developed:

Slump Test:

The oldest, most widely used test for determining workability. The device is a hollow cone-shaped mould. The mould is filled in three layers of each volume. Each layer is rodded with a 16mm steel rod 25 times. The mould is then lifted away and the change in the height of the concrete is measured against the mould. The slump test is a measure of the resistance of concrete to flow under its own weight.

There are three classifications of slump; "true" slump, shear slump, and collapse slump. True slump is a general reduction in height of the mass without any breaking up. Shear slump indicates a lack of cohesion, tends to occur in harsh mixes. This type of result implies the concrete is not suitable for placement. Collapse slump generally indicates a very wet mix. With different aggregates or mix properties, the same slump can be measured for very different concretes.

Compaction Test:

Concrete strength is proportional to its relative density. A test to determine the compaction factor was developed in 1947. It involves dropping a volume of concrete from one hopper to another and measuring the volume of concrete in the final hopper to that of a fully compacted volume. This test is difficult to run in the field and is not practical for large aggregates (over 1in.).

Flow Test:

Measures a concretes ability to flow under vibration and provides information on its tendency to segregate. There are a number of tests available but none are recognized by ASTM. However, the flow table test described for mortar flows is occasionally used.

Re-moulding Test:

Developed to measure the work required to cause concrete not only to flow but also to conform to a new shape.

Vebee Test:

A standard slump cone is cast, the mould removed, and a transparent disk placed on top of the cone. The sample is then vibrated till the disk is completely covered with mortar. The time required for this is called the Vebee time.

Thaulow Drop Table - Similar to the Vebee test except a cylinder of concrete is remoulded on a drop table. The number of drops to achieve this remoulding is counted.

Penetration Test:

A measure of the penetration of some indenter into concrete. Only the Kelly ball penetration test is included in the ASTM Standards. The Kelly ball penetration test measures the penetration of a 30 lb. hemisphere into fresh concrete. This test can be performed on concrete in a buggy, open truck, or in form if they are not too narrow. It can be compared to the slump test for a measure of concrete consistency.

TOPIC 4: Setting of Concrete

Setting is defined as the onset of rigidity in fresh concrete. Hardening is the development of useable and measurable strength; setting precedes hardening. Both are gradual changes controlled by hydration. Fresh concrete will lose measurable slump before initial set and measurable strength will be achieved after final set.

Setting is controlled by the hydration of C_3S. The period of good workability is during the dormant period, (stage 2). Initial set corresponds to the beginning of stage 3, a period of rapid hydration. Final set is the midpoint of this acceleration phase. A rapid increase in temperature is associated with stage 3 hydration, with a maximum rate at final set.

If large amounts of ettringite rapidly form from C_3A hydration, the setting times will be reduced. Cements with high percentages of C_3A, such as expansive or set-regulated cements, are entirely controlled by ettringite formation.

Abnormal Setting Behavior

False Set: Early stiffening of concrete, fluidity may be restored by remixing. Basically, it is a result of hydration of dehydrated gypsum, which forms rigid crysals. Because there are few of these crystals and they are weak, the matrix can be destroyed by remixing. Accelerated hydration of C3A will cause rapid development of ettringite and false-set.

Flash Set: Stiffening of concrete due to the rapid development of large quantities of C3A hydration products which cannot be returned to a fluid state with mixing. This is generally no longer a problem since the introduction of gypsum to control C3A hydration. However, some admixtures will increase C3A hydration and flash set may be a problem.

UNIT-IV

HARDENED CONCRETE

1. **Explain about the strength of hardened concrete**
2. **Explain Dimensional stability--Shrinkage and creep**
3. **What are the factors affecting in creep explain briefly.**

TOPIC 1: Strength of hardened concrete

Strength is defined as the ability of a material to resist stress without failure. The failure of concrete is due to cracking. Under direct tension, concrete failure is due to the propagation of a single major crack. In compression, failure involves the propagation of a large number of cracks, leading to a mode of disintegration commonly referred to as 'crushing'.

The strength is the property generally specified in construction design and quality control, for the following reasons:

(1) It is relatively easy to measure, and

(2) Other properties are related to the strength and can be deduced from strength data.
The 28-day compressive strength of concrete determined by a standard uni-axial compression testis accepted universally as a general index of concrete strength.

TOPIC 2:Dimensional stability--Shrinkage and creep

Dimensional stability of a construction material refers to its dimensional change over a long period of time. If the change is so small that it will not cause any structural problems, the material is dimensionally stable. For concrete, drying shrinkage and creep are two phenomena that compromise its dimensional stability.

Shrinkage and creep are often discussed together because they are both governed by the deformation of hydrated cement paste within concrete. The aggregate in concrete does not shrink or creep, and they serve to restrain the deformation.

Drying shrinkage

After concrete has been cured and begins to dry, the excessive water that has not reacted with the cement will begin to migrate from the interior of the concrete mass to the surface. As the moisture evaporates, the concrete volume shrinks. The loss of moisture from the concrete varies with distance from the surface. The shortening per unit length associated with the reduction in volume due to moisture loss is termed the shrinkage. Shrinkage is sensitive to the relative humidity. For higher relative humidity, there is less evaporation and hence reduced shrinkage. When concrete is exposed to 100% relative humidity or submerged in water, it will actually swell slightly.

Shrinkage can create stress inside concrete. Because concrete adjacent to the surface of a member dries more rapidly than the interior, shrinkage strains are initially larger near the surface than in the interior. As a result of the differential shrinkage, a set of internal self-balancing forces, i.e. compression in the interior and tension on the outside, is set up.

In additional to the self-balancing stresses set up by differential shrinkage, the overall shrinkage creates stresses if members are restrained in the direction along which shrinkage occurs. If the tensile stress induced by restrained shrinkage exceeds the tensile strength of concrete, cracking will take place in the restrained structural element. If shrinkage cracks are not properly controlled, they permit the passage of water, expose steel reinforcements to the atmosphere, reduce shear strength of the member and are bad for appearance of the structure. Shrinkage cracking is often controlled with the incorporation of sufficient reinforcing steel, or the provision of joints to allow movement. After drying shrinkage occurs, if the concrete member is allowed to absorb water, only part of the shrinkage is reversible. This is because water is lost from the capillary pores, the gel pores (i.e., the pore within the C-S-H), as well as the space between the C-S-H layers. The water lost from the capillary and gel pores can be easily replenished. However, once water is lost from the interlayer space, the bond between the layers becomes stronger as they get closer to one another. On wetting, it is more difficult for water to re-enter. As a result, part of the shrinkage is irreversible.

The magnitude of the ultimate shrinkage is primarily a function of initial water content of the concrete and the relative humidity of the surrounding environment. For the same w/c ratio, with increasing aggregate content, shrinkage is reduced. For concrete with fixed aggregate/cement ratio, as the w/c ratio increases, the cement becomes more porous and can hold more water. Its ultimate shrinkage is hence also higher. If a stiffer aggregate is used, shrinkage is reduced.

The shrinkage strain, ε , is time dependent. Approximately 90% of the ultimate shrinkage occurs during the first year.

Both the rate at which shrinkage occurs and the magnitude of the total shrinkage increase as the ratio of surface to volume increases. This is because the larger the surface area, the more rapidly moisture can evaporate.

Based on a number of local investigations in Hong Kong, the value of shrinkage strain (after one year) for plain concrete members appears to lie between 0.0004 and 0.0007 (although value as high as 0.0009 has been reported). For reinforced concrete members, the shrinkage strain values are reduced, as reinforcement is helpful in reducing shrinkage.

Creep

Creep is defined as the time-dependent deformation under a constant load. Water movement under stress is a major mechanism leading to creeping of concrete. As a result, factors affecting shrinkage also affect creep in a similar way. Besides moisture movement, there is evidence that creep may also be due to time-dependent formation and propagation of microcracks, as well as microstructural adjustment under high stresses (where stress concentration exists). These mechanisms, together with water loss from the gel interlayer, lead to irreversible creep. Creeping develops rapidly at the beginning and gradually decreases with time. Approximately 75% of ultimate creep occurs during the first year. The ultimate creep strain (after 20 years) can be 3-6 times the elastic strain.

Creep can influence reinforced concrete in the following aspects.

i). Due to the delayed effects of creep, the long-term deflection of a beam can be 2-3 times larger than the initial deflection.

ii). Creeping results in the reduction of stress in pre-stressed concrete which can lead to increased cracking and deflection under service load.

iii). In a R.C column supporting a constant load, creep can cause the initial stress in the steel to double or triple with time because steel is non-creeping and thus take over the force reduced in concrete due to creep.

Creep is significantly influenced by the stress level. For concrete stress less than 50% of its strength, creep is linear with stress. In this case, the burger's body, which is a combination of Maxwell and Kelvin models, is a reasonable representation of creep behaviour. For stress more than 50% of the strength, the creep is a nonlinear function of stress, and linear viscoelastic models are no longer applicable. For stress level higher than 75-80% of strength, creep rupture can occur. It is therefore very important to keep in mind that in the design of concrete column, 0.8 f is taken to be the strength limit.

TOPIC 3: Factors Affecting Creep Of Concrete

a) w/c ratio: The higher the w/c ratio, the higher is the creep.

b) Aggregate stiffness (elastic modulus): The stiffer the aggregate, the smaller the creep.

c) Aggregate fraction: higher aggregate fraction leads to reduced creep.

d) Theoretical thickness: The theoretical thickness is defined as the ratio of section area to the semi- perimeter in contact with the atmosphere. Higher the theoretical thickness, smaller the creep and shrinkage.

e) Temperature: with increasing temperature, both the rate of creep and the ultimate creep increase. This is due to the increase in diffusion rate with temperature, as well as the removal of more water at a higher temperature.

f) Humidity: with higher humidity in the air, there is less exchange of moisture between the concrete and the surrounding environment. The amount of creep is hence reduced.

g) Age of concrete at loading: The creep strain at a given time after the application of loading is lower if loading is applied to concrete at a higher age. For example, if the same loading is applied to 14 day and 56 day concrete (of the same mix), and creep strain is measured at 28 and 70 days respectively (i.e., 14 days after load application), the 56 day concrete is found to creep less. This is because the hydration reaction has progressed to a greater extent in the 56 day concrete. With less capillary pores to hold water, creep is reduced.

UNIT-V

MIX DESIGN & SPECIAL CONCRETE

1. **Explain the test procedure for concrete mix design**
2. **Define special concrete and its types**
3. **Explain about polymer concrete**
4. **Define self-compacting concrete and its types**

TOPIC 1: Procedure for Concrete Mix Design –IS456:2000

1. Determine the mean target strength ft from the specified characteristic compressive strength at 28-day $f_{ck}$and the level of quality control. $f_t = f_{ck} + 1.65S$

Where, S is the standard deviation obtained from the Table of approximate contents given after the design mix.

2. Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.

3. Estimate the amount of entrapped air for maximum nominal size of the aggregate fromthe table.

4. Select the water content, for the required workability and maximum size of aggregates(for aggregates in saturated surface dry condition) from table.

5. Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.

6. Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

7. Calculate the cement content form the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability, and greater of the two values is adopted.

8. From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relations:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] \times \frac{1}{1000}$$

Where, V = absolute volume of concrete = gross volume ($1 m^3$) minus the volume of entrapped air

S_c = specific gravity of cement

W = Mass of water per cubic metre of concrete, kg C = mass of cement per cubic metre of concrete, kg
p = ratio of fine aggregate to total aggregate by absolute volume

fa, Ca = total masses of fine and coarse aggregates, per cubic metre of concrete, respectively, kg, and

S_{fa}, S_{ca} = specific gravities of saturated surface dry fine and coarse aggregates, respectively

9. Determine the concrete mix proportions for the first trial mix.
10. Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28-days moist curing and check for thestrength.
11. Prepare trial mixes with suitable adjustments till the final mix proportions arrived.

TOPIC 2: SPECIAL CONCRETE

Special types of concrete are those with out-of-the-ordinary properties or those produced by unusual techniques. Concrete is by definition a composite material consisting essentially of a binding medium and aggregate particles, and it can take many forms.

These concretes do have advantages as well as disadvantages.

Types of special concrete

1. High Volume Fly Ash Concrete.
2. Silica fumes concrete.
3. GGBS, Slag based concrete.
4. Ternary blend concrete.
5. Light weight concrete.
6. Polymer concrete.

7. Self-Compacting Concrete.
8. Coloured Concrete.
9. Fibre-reinforced Concrete.
10. Pervious Concrete.
11. Water-proof Concrete.
12. Temperature Controlled Concrete

TOPIC 3: Polymer concrete

Polymer concrete is part of group of concretes that use polymers to supplement or replace cement as a binder. The types include polymer-impregnated concrete, polymer concrete, and polymer-Portland-cement concrete.

- In polymer concrete, thermosetting resins are used as the principal polymer component due to their high thermal stability and resistance to a wide variety of chemicals.
- Polymer concrete is also composed of aggregates that include silica, quartz, granite, limestone, and other high quality material.
- Polymer concrete may be used for new construction or repairing of old concrete.
- The low permeability and corrosive resistance of polymer concrete allows it to be used in swimming pools, sewer structure applications, drainage channels, electrolytic cells for base metal recovery, and other structures that contain liquids or corrosive chemicals.
- It is especially suited to the construction and rehabilitation of manholes due to their ability to withstand toxic and corrosive sewer gases and bacteria commonly found in sewer systems.
- It can also be used as a replacement for asphalt pavement, for higher durability and higher strength.
- Polymer concrete has historically not been widely adopted due to the high costs and difficulty associated with traditional manufacturing techniques.

TOPIC 4: Self compacting concrete

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement.

The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Very close to the Kolhapur there is project of steel industry, sand used for the formation of mould when the moulds are opened the waste sand is dumped for the filling the low lying areas while doing this the agriculture areas is converted into barren area. Because there is no space for the waste other than the land filling. similar case is in case of aluminium industry where red mud is concluded to be waste, which contains lot amount of bauxite and that is why red mud is also dump in the nearby areas here it is causing big threat for the society and it is disturbing the eco system of the environment. So it is the need to use this particular otherwise waste material for the constructive in such fashion in the case of concrete so that concrete which became cost effective as well as eco-friendly.

Types

Powder type of self-compacting concrete: This is proportioned to give the required self-compactability by reducing the water-powder ratio and provide adequate segregation resistance.

Viscosity agent type self-compacting concrete: This type is proportioned to provide self-compaction by the use of viscosity modifying admixture to provide segregation resistance.

Combination type self-compacting concrete: This type is proportioned so as to obtain self-compactability mainly by reducing the water powder ratio.

13. **Unit wise-Question bank**

UNIT-I
CEMENT

Two marks question with answers

1. **What is the chemical composition of cement?**

Composition of Portland cement consists essentially of compounds of lime (calcium oxide, CaO) mixed with silica (silicon dioxide, SiO_2) and alumina (aluminum oxide, Al_2O_3). The lime is obtained from a calcareous (lime-containing) raw material, and the other oxides are derived from an argillaceous (clayey) material.

2. **What is grade of cement? List any three grades of cement with their strengths.**

- 721 hr not less than 23 MPa for 43 grade, 27 MPa for 53 grade
- 1682 hrs not less than 33MPa for 43 grade, 37MPa for 53 grade
- 6724 hrs not less than 43MPa for 43 grade, 53 MPa for 53 grade

3. **Explain bogue's compounds of cement?**

Thorn bohm's description of the minerals in cement was found to be similar to Bogue's compound. Hence, Bough's Compounds C3S, C2S, C3A, C4AF are sometimes called in literature as Alite, Belite, Celite, and Felite.

4. **Define hydration of cement?**

The water causes the hardening of concrete through a process called hydration. Hydration is a chemical reaction in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products.

5. **Write brief about Portland cement?**

Concrete is made by Portland cement, water and aggregates. Portland cement is hydraulic cement that hardens in water to form a water-resistant compound. The hydration products act as binder to hold the aggregates together to form concrete. The name Portland cement comes from the fact that the colour and quality of the resulting concrete are similar to Portland stone, a kind of limestone found in England.

Three marks question with answers

1. **List various types of cement.**

- Rapid Hardening Cement
- Quick setting cement
- Low Heat Cement
- Sulphates resisting cement
- Blast Furnace Slag Cement
- High Alumina Cement
- White Cement
- Coloured cement
- Pozzolanic Cement
- Air Entraining Cement
- Hydrographic cement

2. **What is the purpose of plasticizer in concrete?**

Plasticizers or water reducers, and superplasticizer or high range water reducers, are chemical admixtures that can be added to concrete mixtures to improve workability. Unless the mix is "starved" of water, the strength of concrete is inversely proportional to the amount of water added or water-cement (w/c) ratio.

3. **Explain about Normal consistency test?**

This test is to determine the water required to achieve a desired plasticity state (called normal consistency) of cement paste. It is obtained with the Vicat apparatus by measuring the penetration of a loaded needle.

4. **Explain about Soundness of cement?**

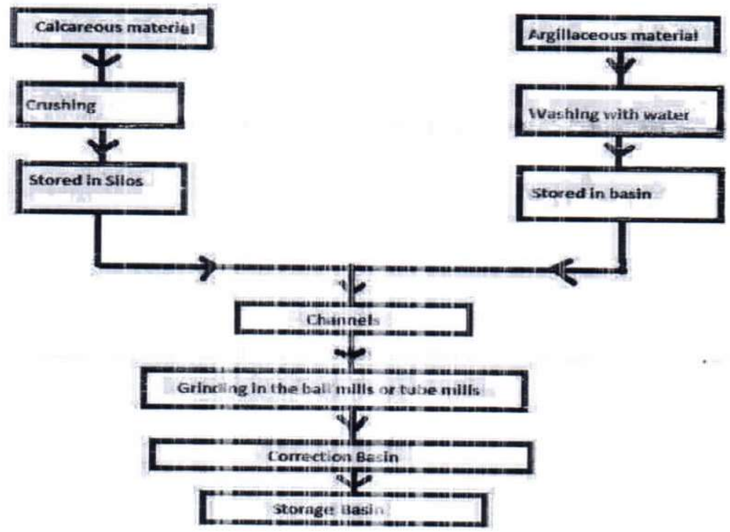
Unsoundness in cement paste refers to excessive volume change after setting and cement is caused by the slow hydration of MgO or free lime. Their reactions are $MgO + H_2O = Mg(OH)_2$ and $CaO + H_2O = Ca(OH)_2$. Another factor that can cause unsoundness is the delayed formation of cement and concrete have hardened. The pressure from crystal growth will lead to cracking and damage. The soundness of the cement must be tested by accelerated methods. Le Chatelier test this test is to measure the potential for volumetric change of cement paste. Another method is Autoclave Expansion test which use an autoclave to increase the temperature to accelerate the process.

Five marks question with answers

1. **Explain the manufacturing process of cement?**

Manufacturing Portland cement:

The basic ingredients of both the dry and wet processes are the same. By mass, lime and silica make up approximately 85% of Portland cement. The materials that are commonly used are limestone, shells, chalk, shale, clay, slate, silica sand, and iron ore.



2. **What is hydrated cement? Explain the heat of hydration**

A compound produced by combining a substance chemically with water. Many minerals and crystalline substances are hydrates. To combine a compound with water, especially to form a hydrate.to supply water to a person in order to restore or maintain a balance of fluids.

Heat of Hydration

The heat of hydration is the heat generated when water and portland cement react. Heat of hydration is most influenced by the proportion of C_3S and C_3A in the cement, but is also influenced by water-cement ratio, fineness and curing temperature. As each one of these factors is increased, heat of hydration increases. In large mass concrete structures such as gravity dams, hydration heat is produced significantly faster than it can be dissipated (especially in the center of large concrete masses), which can create high temperatures in the center of these large concrete masses that, in turn, may cause undesirable stresses as the concrete cools to ambient temperature. Conversely, the heat of hydration can help maintain

3. Explain the testing method of Compressive Strength of Cement

This test is carried out to determine the **compressive strength of cement.**

Test Procedure for compressive strength of cement:

(i) The mortar of cement and sand is prepared. The proportion is 1:3 which means that (X) gm of cement is mixed with 3(X) gm of sand.

(ii) The water is added to the mortar. The water cement ratio is kept as 0.4 which means that (X) gm of water is added to dry mortar.

(iii) The mortar is placed in moulds. The test specimens are in the form of cubes with side as 70.6 mm or 76 mm. The moulds are of metal and they are constructed in such a way that the specimens can be easily taken out without being damaged. For 70.6 mm and 76 mm cubes, the cement required is 185 gm and 235 gm respectively.

The mortar, after being placed in the moulds, is compacted in vibrating machine for 2 minutes.

(iv) Themoulds are placed in a damp cabin for 24 hours.

(vi) The specimens are removed from the moulds and they are submerged in clean water for curing.

(vii) The cubes are then tested in **compression testing machine** at the end of 3 days and 7 days. The testing of cubes is carried out on their three sides without packing. Thus three cubes are tested each time to find out the compressive strength at the end of 3 days and 7 days. The average value is then worked out. During the test, the load is to be applied uniformly at the rate of 350 kg/cm2 or 35 N/mm2.

(viii) The **compressive strength of cement** at the end of 3 days should not be less than 115 kg/cm2 or 11.50 N/mm2 and that at the end of 7 days should no be less than 175 kg/cm2 or N/mm2.

Objective question with answers

1. For quality control of Portland cement, the test essentially done is [ ]
   A. Setting time B. Soundness C. tensile strength D. All the above
2. Lower the normal consistency value, [ ]
   A. Lower will be the strength of concrete B. Medium will be the strength of concrete
   C. Higher will be the strength of concrete D. None of the above
3. The mixture of different ingredients of cement, is burnt at [ ]
   A.1000°C B.1200°C C.1400°C D.1900°C
4. The size of vic at needle, used to conduct setting of cement is [ ]
   A. 10mmDia B.1mm^2 C.3mm2 D. 10 mm Dia

5. To obtain cement dry powder, lime stones and shales or their slurry, is burnt in a rotary kiln at a temperature between [ ]
A. 1100° and 1200°C B. 1200° and 1300°C
C. 1300° and 1400°C D. 1400° and 1500°C

6. Vicat's apparatus is used for [ ]
A. Fineness test B.consistency test C. setting time test D. B and C

7. Fine aggregates are the aggregates having the size less than: [ ]
A. 5mm B.4.75mm C. 3.50mm D. 2mm

8. For the improvement of workability of concrete, the shape of aggregate recommended is
A. Angular B.Round C.Flaky D.Irregular

9. In an ordinary Portland cement, the composition oflimeis [ ]
A. 50% B.63% C.21% D.33%

10. Inconcretecubetest,thestandardsizeofcubeis [ ]
A. 15 cm x 15 cm x15cm B. 10 cm x 10 cm x 10cm
C. 20 cm x20cmx 20cm D. None

KEY

Q.NO	1	2	3	4	5	6	7	8	9	10
ANS	D	A	C	B	D	D	B	B	B	A

Fill in the blanks question with answers

1. Approximate percentage range of CaO in OPC is=
2. Approximate percentage range of Al_2O_3 in OPCis =
3. Approximate percentage of SIO_2in OPC is=
4. _ number of grades available in OPC
5. Which compound is liberates higher Vheat=
6. Which compound is liberate slower heat=
7. In M20 concrete M refers to=
8. At an early age greater strength contribute compound is=
9. The role of gypsum in cement is=
10. Least strength contributes compounds is=

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KEY

Q.NO	ANSWERS
1	60-67%
2	3-8_%
3	17-25%
4	3
5	C_3A
6	C4AF
7	mix proportion
8	C_2S
9	control the "setting of cement"
10	C4AF

UNIT-II

AGGREGATE AND ADMIXTURES

Two marks question with answers

1. **How does alkali aggregate reaction affect concrete?**

➢ The alkali–silica reaction (ASR), more commonly known as "concrete cancer", is a swelling reaction that occurs over time in concrete between the highly alkaline cement paste and the reactive non-crystalline (amorphous) silica found in many common aggregates, given sufficient moisture.

2. **What is the common classification of aggregates?**

Aggregates are classified into 2 types according to size

- Fine aggregate
- Coarse aggregate

Aggregates are classified according to shape

- Rounded aggregates
- Irregular or partly rounded aggregates
- Angular aggregates
- Flaky aggregates
- Elongated aggregates
- Flaky and elongated aggregates

3. List out the types of admixtures?

a) Accelerating admixtures

b) Retarding admixtures

c) Water-reducing admixtures

d) Air-entraining admixtures

e) Super plasticizing admixtures

f) Air-entraining admixtures

g) Accelerating admixtures

h) Water reducing and set controlling admixtures

i) Admixtures for flowing concrete

j) Miscellaneous admixtures

4. Define admixtures?

A material other than water, aggregates, or cement that is used as an ingredient of concrete or mortar to control setting and early hardening, workability, or to provide additional cementing properties

5. Explain Alkali Aggregate Reaction

Alkali–aggregate reaction is a term mainly referring to a reaction which occurs over time in concrete between the highly alkaline cement paste and non-crystalline silicon dioxide, which is found in many common aggregates. This reaction can cause expansion of the altered aggregate, leading to spalling and loss of strength of the concrete. The alkali–aggregate reaction is a general, but relatively vague, expression which can lead to confusion. More precise definitions include the following:

1. Alkali–silica reaction (ASR, the most common reaction of this type);
2. Alkali–silicate reaction, and;
3. Alkali–carbonate reaction

Five marks question with answers

1. Explain the soundness of aggregate?

Soundness of Aggregate

The soundness test determines an aggregate's resistance to disintegration by weathering and, in particular, freeze-thaw cycles. Aggregates that are durable (resistant to weathering) are less likely to degrade in the field and cause premature HMA pavement distress and potentially, failure.

The soundness test repeatedly submerges an aggregate sample in a sodium sulphate or magnesium sulphate solution. This process causes salt crystals to form in the aggregate's water permeable pores. The formation of these crystals creates internal forces that apply pressure on aggregate pores and tend to break the aggregate. After a specified number of submerging and drying repetitions, the aggregate is sieved to determine the percent loss of material.

2. What is Admixtures and explain the classification of admixtures?

A material other than water, aggregates, or cement that is used as an ingredient of concrete or mortar to control setting and early hardening, workability, or to provide additional cementing properties.

Chemical admixtures: Accelerators, Retarders, Water-reducing agents, Super plasticizers, Air entraining agents etc.

Water-reducing admixture / Plasticizers

- To achieve a higher strength by decreasing the water cement ratio at the same workability as an admixture free mix.
- To achieve the same workability by decreasing the cement content so as to reduce the heat of hydration in mass concrete.
- To increase the workability so as to ease placing in accessible locations
- Water reduction more than 5% but less than 12%.

Super Plasticizers:

These are more recent and more effective type of water reducing admixtures also known as *high range water reducer.*

Accelerator

An admixture which, when added to concrete, mortar, or grout, increases the rate of hydration of hydraulic cement, shortens the time of set in concrete, or increases the rate of hardening or strength development.

Air Entrained Admixtures:

An addition for hydraulic cement or an admixture for concrete or mortar which causes air, usually in small quantity, to be incorporated in the form of minute bubbles in the concrete or mortar during mixing, usually to increase its workability **and** frost resistance. Air-entraining admixtures are **surfactants** that change the surface tension of the water. Traditionally, they were based on fatty acid salts or vinsol resin but these have largely been replaced by synthetic surfactants or blends of surfactants to give improved stability and void characteristics to the entrained air. Air entrainment is used to produce a number of effects in both the plastic and the hardened concrete

Mineral admixtures

Fly-ash Blast-furnace slag, Silica fume and Rice husk Ash etc

Fly Ash:

The finely divided residue resulting from the combustion of ground or powdered coal. Fly ash is generally captured from the chimneys of coal-fired power plants; it has POZZOLANIC properties, and is sometimes blended with cement for this reason.

Fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Toxic constituents include arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium.

Silica Fume:

The terms condensed silica fume, microsilica, silica fume and volatilized silica are often used to describe the by-products extracted from the exhaust gases of silicon, ferrosilicon and other metal alloy furnaces. However, the terms micro silica and silica fume are used to describe those condensed silica fumes that are of high quality, for use in the cement and concrete industry.

Rice Husk Ash:

This is a bio waste from the husk left from the grains of rice. It is used as a pozzolanic material in cement to increase durability and strength. The silica is absorbed from the ground and gathered in the husk where it makes a structure and is filled with cellulose. When cellulose is burned, only silica is left which is grinded to fine powder which is used as pozzolana.

3. **How does alkali aggregate reaction affect concrete? Also explain thermal properties of aggregates?**

Alkali–aggregate reaction is a term mainly referring to a reaction which occurs over time in concrete between the highly alkaline cement paste and non-crystalline silicon dioxide, which is found in many common aggregates. This reaction can cause expansion of the altered aggregate, leading to spalling and loss of strength of the concrete.

The alkali–aggregate reaction is a general, but relatively vague, expression which can lead to confusion. More precise definitions include the following:

1. Alkali–silica reaction (ASR, the most common reaction of this type);
2. Alkali–silicate reaction, and;
3. Alkali–carbonate reaction.

Thermal properties:

Rock and aggregates posses' three thermal properties which are coefficient of expansion, specific heat and thermal conductivity

The thermal conductivity varies with the density of concrete, with heavier aggregates resulting in higher thermal conductivity. The conductivity of concretes known generally to decrease with increased temperature, through the loss of pore water and the dehydration of cement paste.

4. **What is Bulk Density of Aggregates**

Bulk density of aggregates is the mass of aggregates required to fill the container of a unit volume after aggregates are batched based on volume It depends on the packing of aggregate i.e. either loosely packed aggregates or well dense compacted aggregates. In case, if the specific gravity of material is known, then it depends on the shape and size of particles. It is because, if all the particles are of same size than packing can be done up to a very limited extent. If the addition of smaller particles is possible within the voids of larger particles than these smaller particles enhance the bulk density of the packed material. Shape of the particles also influence very widely, because closeness particles depends on the shape of aggregates.

Loose Bulk Density

Loose bulk density can be determined by filling the container with dried aggregates until it overflows from the container. Now level the top surface of container by rolling a rod on it. After that, weight the aggregate mass that is inside the container and divide it by the volume of container. This will give you the bulk density of the loose aggregates.

Compacted Bulk Density

Compacted bulk density can be determined by filling the container in three layers and tamped each layer with a 16mm diameter rounded nosed rod. After filling in three layersnow leveled the top surface and evaluate compacted bulk density by using the same expression as for loose bulk density.

5. **Explain the classification of aggregates?**

Aggregates are classified according to shape

1.Rounded aggregates

2.Irregular or partly rounded aggregates

3.Angular aggregates

4.Flaky aggregates

5.Elongated aggregates

6.Flaky and elongated aggregates

Aggregates are classified according to size

1.Fine aggregate

2.Coarse aggregate

Aggregates are classified according to source

1. Igneous rocks
2. Sedimentary rocks
3. Metamorphic rocks

Aggregates are classified according to weight

1. Normal weight aggregates
2. Light weight aggregates
3. Heavy weight aggregates

Objectives question with answers

1. The rock which is notcalcareous,is: [ ]
   A.limestone B.Macl C.Chalk D.Laterite
2. The resistance of an aggregate to compressive forces isknownas [ ]
   A.Crushingstrength B. Impact value C. Shear resistance D.None of the above
3. For the improvement of workability of concrete, the shape of aggregate recommendedis
   A.Angular B.Round C.Flaky D.Irregular
4. Determination of Moisture Content of aggregateby [ ]
   A.Dryingmethod B. Displacementmethod
   C. CalciumCarbidemethod D. All of theabove.
5. Factors which promote alkali aggregate reactionare [ ]
   A. Reactive typeofaggregate B. High alkalicontent
   C. AvailabilityofMoisture D. All theabove
6. In concrete the fine aggregates is usedto [ ]
   A. Fill up the voidsincement B. Fill up the voids in coarseaggregate
   C. Fill up the voidsinsand D. All theabove
7. In Shape Test, the dimension of thickness gauge is calculatedas [ ]
   A. 2.4timestheaverageofthesizeofretainedandpassingSieve
   B. 1.2timestheaverageofthesizeofretainedandpassingSieve
   C. 0.6timestheaverageofthesizeofretainedandpassingSieve
   D. 1.8timestheaverageofthesizeofretainedandpassingSieve
8. In concrete the material used as a fineaggregateis [ ]
   A. Cement B.Sand C.jelly D.Gypsum

9. The commonly used material in the manufacture of cementis[]

A.sandstone B.Slate C.limestone D.graphite.

KEY

Q.NO	1	2	3	4	5	6	7	8	9	10
ANS	B	C	B	D	D	D		B	C	

Fill in the blanks question with answers

1. Thesizeofthecoarseaggregateismorethan=
2. Thesizeofthefineaggregateislessthan=
3. The minimum 28 days' compressive strength of 43 grade cementis=
4. The easiness of handling concrete is knownas=
5. Device which is used to find out normal consistency of cementis=

KEY

Q.NO	ANSWERS
1	4.75mm
2	4.75mm
3	43Mpa
4	workability
5	vicats apparatus
6	
7	

UNIT-III

FRESH CONCRETE

Two marks question with answers

1. Definebleeding.

Bleeding is one form of segregation, where water comes out to the surface of the concrete, being lowest specific gravity among all the ingredients of concrete. Bleeding can be easily identified in the field by the appearance of a thin layer of water in the top surface of freshly mixed concrete.

2. DefineSegregation.

Segregation in concrete is commonly thought as separation of some size groups of aggregates from cement mortar in isolated locations with corresponding deficiencies of these materials in other locations. Segregation results in proportions of the laid concrete being in variation to those as designed Segregation could result from internal factors such as concrete that is not proportioned properly and not mixed adequately, or too workable a mix. It also could result from external factors such as too much vibration, improper transportation, placement, or adverse weather conditions. The corresponding increase in proportion of cement paste in upper areas would tend to make them susceptible to increased shrinkage and formation of cracks. These cracks could be 10 µm to 500 µm wide, formed perpendicular to the surface, and be in the form of map patterns."

1. **Define workability.**

According to Granville "it is that property of the concrete which determines the amount of useful internal work necessary to produce full compaction."

Powers defined it as "that property of plastic concrete mixture which determines the ease with which it can be placed and the degree to which it resists segregation"

ACI (American Concrete Institute) defines it as 'that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished'.

ASTM (American Society for Testing and Materials) defines it as "that property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity".

4. List the different factors affecting workability.

- Cement content of concrete.
- Water content of concrete.
- Mix proportions of concrete.
- Size of aggregates.
- Shape of aggregates.
- Grading of aggregates.
- Surface texture of aggregates.
- Use of admixtures in concrete.

5. Define Compacting Factor of workable concrete?

The ratio of the weight of partially compacted concrete to the weight of the concrete when fully compacted in the same mould. The Compacting Factor Apparatus is used to determine the compaction factor of concrete with low, medium and high workability.

Three marks question with answers

1. What is the slump test for?

The slump test is a means of assessing the consistency of fresh concrete. It is used, indirectly, as a means of checking that the correct amount of water has been added to the mix.

2. What is mixing of concrete and its methods?

Through mixing of concrete is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency. There are two methods adopted for mixing concrete hand mixing and machine mixing

3. Define compaction and its methods?

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In process of mixing, transporting, and placing of concrete air is likely to get entrapped in the concrete.

Methods of compaction:

- Hand compaction
- Compaction by vibrators
- Compaction by pressure and jolting
- Compaction by spinning

4. Flow Table Test

The flow table test or flow test, also known as the slump-flow test, is a method to determine consistency of fresh concrete. Flow table test is also used to identify transportable moisture limit of solid bulk cargoes. It is used primarily for assessing concrete that is too fluid (workable) to be measured using the slump test, because the concrete will not retain its shape when the cone is removed.

Application when fresh concrete is delivered to a site by a truck mixer, its consistency needs to be checked before it is poured into formwork.

If consistency is not at the desired level, concrete will not have the required strength and other qualities once it has set. If concrete is too pasty, cavities may form within it. Rebar may become corroded, and concrete will crack. Cavities also reduce the concrete strength.

5. What is meant by proportioning of concrete?

The process of relative proportions of cement, sand, coarse aggregate and water, so as to obtain a concrete of desired quality is known as the proportioning of concrete.

The proportions of coarse aggregate, cement and water should be such that the resulting concrete has the following properties:

- When concrete is fresh, it should have enough workability so that it can be placed in the formwork economically.
- The concrete must possess maximum density or in the other words, it should be strongest and most water-tight.
- The cost of materials and labour required to form concrete should be minimum.

Five marks question with answers

1. Explain in detail the slump test procedure and working principles

Concrete slump test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete slump test is

carried out from batch to batch to check the uniform quality of concrete during construction.
The slump test is the most simple workability test for concrete, involves low cost and provides immediate results

Factors which influence the concrete slump test:

1. Material properties like chemistry, fineness, particle size distribution, moisture content and temperature of cementitious materials. Size, texture, combined grading, cleanliness and moisture content of the aggregates,
2. Chemical admixtures dosage, type, combination, interaction, sequence of addition and its effectiveness,
3. Air content of concrete,
4. Concrete batching, mixing and transporting methods and equipment,
5. Temperature of the concrete,
6. Sampling of concrete, slump-testing technique and the condition of test equipment,
7. The amount of free water in the concrete, and
8. Time since mixing of concrete at the time of testing.

PROCEDURE FOR CONCRETE SLUMP TEST:

1. Clean the internal surface of the mould and apply oil.
2. Place the mould on a smooth horizontal non- porous base plate.
3. Fill the mould with the prepared concrete mix in 4 approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mould. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mould and the base plate.
7. Raise the mould from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mould and that of height point of the specimen being tested.

2. Explain brieflyFactors affecting workability

Workable concrete shows very less internal friction between particles and overcomes the frictional resistance with just the amount of compacting efforts provided. Workability of the concrete depends on a number of interrelating factors. Water content, aggregate properties, use of admixtures, fineness of cement are the factors affecting workability.

1. **Water content:**

The increase in water content increases the fluidity of the concrete thus providing greater lubrication. This helps to increase the workability of the concrete. Increasing the water content should be the last resort to improve the workability in the concrete as this will seriously affect the strength of the concrete. Even if more amount of water is to be added, more cement also should be added so that the water/ cement ratio remains the same and hence the strength of the concrete remains unaffected.

2. **Size of aggregates:**

The surface area of bigger aggregates is less and hence less amount of water is required for lubricating the surface to reduce the friction. Thus the concrete having large sized aggregate is more workable (of course, within certain limits).

3. **Mix proportions:**

Aggregate/ cement ratio is the measure of how lean or rich the concrete is. If aggregate/ cement ratio is higher, the concrete becomes leaner. In lean concrete less paste is available for the lubrication of the aggregate, while in rich concrete with low a/c ratio, more paste is available which makes the mix more cohesive and hence provides better workability.

4. **Shape of aggregates:**

Rounded aggregates have considerably less surface area and less voids in comparison to angular or flaky aggregates which provide better possibility of overcoming the frictional resistance. Further, angular and flaky aggregates make concrete very harsh.

5. **Surface texture of aggregates:**

The aggregates having smooth or glossy texture have less surface area compared to rough textured aggregates. This provides better workability as less amount of water is required for lubricating effect. But, taking into account the poor interlocking action provided by the glossy textured aggregate, its use is generally discouraged in high strength concrete.

6. **Grading of aggregates:**

Well graded aggregate is the one with least amount of voids in a given volume. If the grading of aggregate is good, the voids will be less and hence higher the workability.

7. **Use of admixtures:**

Use of admixtures in concrete is the major factor that affects the workability. The use of plasticizers and super-plasticizers amply increase the workability of the concrete. Air entraining agents produce air bubbles which act as rollers between particles and provide better mobility thus improving the workability.

8. **Time and temperature:**

Fresh concrete gets stiffened as the time flows. This is because some of the water used to mix the concrete gets evaporated and some gets absorbed by the aggregates. Thus the workability of concrete reduces with time. This loss of workability with time is known *as slump loss.* The effect of temperature on workability of concrete is noteworthy. As the temperature increases, the workability of the mix reduces.

3. Explain the Measurements of workability/Workability Tests

Slump test

- It is the most common method for measuring the workability of freshly mixed concrete. It can be performed both in lab and at site. Uniformity of the concrete regarding workability and quality aspects can be assessed from batch to batch by observing the nature in which the concrete slumps. It is not very suitable for very wet or very dry concrete.
- A steel mould in the form of frustum of cone is used in slump test which has the top diameter of 100 mm, bottom diameter of 200 mm and the height is 300 mm. According to Indian standard specification, the maximum size of the aggregate in concrete that can be used to perform slump test is restricted to 38 mm.
- The mould is cleaned and freed from any surface moistures and then the concrete is placed in three layers. Each layer is tamped 25 times with a standard tamping rod (16 mm dia, 0.6 meter length). Immediately after filling, the cone is slowly lifted and the concrete is allowed to subside. The decrease in the height of the center of the slumped concrete is called slump and is measured to the nearest 5mm.
- If the concrete subsides evenly all round, the slump measured is true slump. If one half of the cone slides down an inclined plane, a shear slump is said to have taken place and the test has to be repeated. Too wet mix shows collapsible nature of slump.

Compacting factor test

- This test is generally carried out in laboratory but can be used in site also. It is particularly useful for concrete mixes of very low workability (or very dry concrete) as they are insensitive to slump test.
- This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height.

Container	Top diameter (mm)	Bottom diameter (mm)	Height (mm)
Upper hopper	254	127	279

Lower hopper	229	127	229
Cylinder	152	152	305
Distance between bottom of upper hopper and top of lower hopper = 203 mm			
Distance between bottom of lower hopper and top of cylinder = 203 mm			

➢ The concrete is placed in the upper hopper gently so that no effort is applied to produce compaction. The bottom door is opened so that the concrete falls on the lower hopper. Again the bottom door of the lower hopper is opened and the concrete falls on the cylinder. After removing the excess concrete by the help of blades, the weight of the cylinder (known volume) is taken to nearest 10 grams. This weight is known as "weight of partially compacted concrete". The cylinder is emptied and then filled with the same sample rammed heavily so as to obtain full compaction. The cylinder is weighed to nearest 10 grams. This weight is known as "weight of fully compacted concrete".

➢ Compacting factor = (weight of partially compacted concrete) / (weight of fully compacted concrete)

Vee-Bee test

➢ Vee-Bee test is a good laboratory test suitable for stiff concrete mixes having low and very low workability. It consists of a vibrating table, a metal pot, a sheet of metal cone and a standard iron rod.

➢ In this test, Slump test as mentioned above is performed by placing the slump cone inside the sheet metal cylindrical pot. Then the vibration is started and the time on a stop watch is noted. The time taken by the concrete to take cylindrical shape after the conical shape disappears is noted. This time recorded is known as Vee-Bee Degree or Vee-Bee seconds.

Flow Test

➢ This is a laboratory test. It gives an indication of the quality of the concrete with respect to consistency, cohesiveness and the proneness to segregation. The spread of the flow of the concrete is measured and this is related to workability. This test is best suitable for flowing concrete made by the use of superplasticizing admixtures.

Kelly Ball Test

➢ This is a simple field test consisting of the determination of the indentation made by 15 cm diameter metal hemisphere weighing 13.6 kg when freely placed on fresh concrete. It is quite faster and provides precise measurement of workability than slump test. But it requires large amount of concrete to be

4. Briefly explain manufacturing procedureofconcrete.

Batching:

The measurement of materials making concrete is known as batching, these batching are two methods weigh batching and volume batching

Mixing:

Mixing of material is essential for the production of uniform concrete. The mixing should ensure that the mass becomes uniform in color and consistency .there are two methods adopted for mixing concrete hand mixing and machine mixing

Transporting:

The method adopted for transportation of concrete

Mortar pan, wheel barrow hand cart, crane bucket and rope way, truck mixer, belt conveyor, transit mixer, pump and pipeline, helicopter.

Placing of concrete:

Concrete is invariably laid as a foundation bed below the walls or columns before placing the concrete in the foundation all the loose earth must be removed from the bed.

Compaction:

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. the method of compaction is hand compaction, vibration compaction, compaction by pressure and jolting, compaction by spinning.

Curing:

curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue more elaborately it can be described as the process of maintaining a satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service. Curing methods are water curing, membrane curing, and application of heat.

Finishing:

It's the last operation making concrete. Its increases does not apply to all concrete operations

5. Explain briefly quality of mixing water inconcrete

Concrete is a chemically combined mass which is manufactured from binding materials and inert materials with water.

Function of Water in Concrete:

To wet the surface of aggregates to develop adhesion because the cement pastes adheres quickly and satisfactory to the wet surface of the aggregates than to a dry surface. To prepare a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position and

Water is also needed for the hydration of the cementing materials to set and harden during the period of curing.

The quantity of water in the mix plays a vital role on the strength of the concrete. Some water which have adverse effect on hardened concrete. Sometimes may not be harmless or even beneficial during mixing. So clear distinction should be made between the effect on hardened concrete and the quality of mixing water.

The effect on concreting for different types of contamination or impurities are described below:

Suspended Solids:

Mixing water which high content of suspended solids should be allowed to stand in a setting basing before use as it is undesirable to introduce large quantities of clay and slit into the concrete.

Acidity and Alkalinity:

Natural water that is slightly acidic are harmless, but presence of humic or other organic acids may result adverse affect over the hardening of concrete. Water which are highly alkaline should also be tested.

Algae:

The presence of algae in mixing water causes air entrainments with a consequent loss of strength. The green or brown slime forming algae should be regarded with suspicion and such water should be tested carefully.

Sea Water:

Sea water contains a total salinity of about 3.5%(78% of the dissolved solids being NaCl and 15% $MgCl_2$ and $MgSO_4$), which produces a slightly higher early strength but a lower long-term strength. The loss of strength is usually limited to 15% and can therefore be tolerated. Sea water reduces the initial setting time of cement but do not effect final setting time.

Chloride:

Water containing large amount of chlorides tends to cause persistent dampness and surface efflorescence. The presence of chlorides in concrete containing embedded steel can lead to its corrosion.

Moisture Content of Aggregate:

Aggregate usually contains some surface moisture. Coarse aggregate rarely contains more than 1% of surface moisture but fine aggregate can contain in excess of 10%. This water can represent a substantial proportion of the total mixing water indicating a significant importance in the quality of the water that contributes surface moisture in aggregate

6. Explain the Effect of time and temperature on workability

When fresh concrete is laid at the site then proper curing of concrete is required, because structures are exposed to the environment and in these conditions if there is no such an arrangement against the environment, then there are many factors that affect the workability of concrete and temperature is One of them. Temperature, almost in every aspect has negative effects on the properties of concrete and same is the case with the workability of fresh concrete.

When temperature increases, then in the same proportion workability of fresh concrete decreases. The reason that stands behind is " when temperature increases then evaporation rate also increases due to that hydration rate decreases and hence, concrete will gain strength earlier ". Due to fast hydration of concrete, a hardening comes in concrete and that decreases the workability of fresh concrete. Therefore, In return manipulation of concrete becomes very difficult.

It indicates that the temperature has a negative effect on the workability of concrete as well as strength up to some extent. Temperature decreases the setting time by increasing hydration rate and that increase the early age strength of the concrete.

This is an advantage that less time will be required before removing of form works on site, but this decrease the use of proper placement of concrete in the initial stages. And if concrete is not properly laid, then strength distribution will not remain the same throughout the cross-section

7. Explain briefly the setting time of concrete?

Generally Initial setting is the time elapsed between the moment water is added to the cement to the time at which paste starts losing its plasticity. Final setting time of cement is the time elapsed between the moment the water is added to the cement to the time at which paste has completely lost its plasticity and attained sufficient firmness to resist certain definite pressure.

Cement + water = paste

Paste + fine aggregate = mortar,

Mortar + coarse aggregate = concrete

Time is required for mixing, transporting, placing, compacting and finishing. During this time the above mentioned cement paste/mortar/concrete must be in plastic condition which is termed as Initial setting time of cement. Here 30 min are given while handling these mixing operations, here fineness of cement and suitable constituents are maintained in such a way that concrete is remained in plastic condition for handling procedures.

Initial setting time:

1. Cement is mixed with 0.85 times the water required for standard consistency.
2. As per vicat's test "the time elapsed since the addition of water to the cement up to the time at which the needle cannot penetrate 5 to 7 mm from the bottom of the vicat'smould.

Final setting time:

1. Determined by Vicat's apparatus using vicat's needle with annular collar of 5cm diameter.
2. As per vicat's test "the time elapsed since the addition of water to the cement up to the time at which the needle with annular collar can only make a mark on the hard cement surface.

8. What is segregation and how can it be prevented?

Segregation of concrete is separation of ingredients of concrete from each other. In good concrete all concrete aggregates are evenly coated with sand and cement paste and forms a homogeneous mass.

During handling, transporting and placing, due to jerks and vibrations the paste of cement and sands gets separated from coarse aggregate. If concrete segregates during transit it should be remixed properly before depositing. However a concrete where initial setting time is over, should not be used.

Prevention of Segregation of Concrete:

Wherever depth of concreting is more than 1.5 meters it should be placed through temporary inclined chutes. The angle of inclination may be kept between 1:3 and 1:2 so that concrete from top of chutes travels smoothly to bottom, use of small quantity of free water from top at intervals helps in lubricating the path of flow of concrete to bottom smoothly. The delivery end of chute should be as close as possible to the point of deposit.

Segregation in deep foundations and rafts of thickness more than 1 meter, there is every possibility of presence of segregated concrete near bottom or in center if proper supervision is not there. Such segregation can be detected by advanced method of testing like ultrasonic testing. In case of doubt random ultrasonic testing should be conducted and if it is present, designer's opinion should be taken. This type of segregation can be rectified by pressure grounding with special chemical compounds.

After any defect rectified by pressure grouting core test has to be performed to ensure that the strength of concrete has reached to the desired level

9. What is meant by curing of concrete?

Curing of concrete is defined as the process of maintaining the moisture and temperature conditions of concrete for hydration reaction to normally so that concrete develops hardened properties over time. The main components which need to be taken care are moisture, heat and time during curing process.

Why curing of concrete is required?

Curing of concrete is required for the following reasons:

- To prevent the concrete to dry out prematurely due to solar radiation and wind. This prevents plastic shrinkage of concrete.
- It helps to maintain the concrete temperature by allowing the hydration process. Hydration process requires water to carry on and releases heat.
- Curing helps the concrete to harden and bond with internal materials and reinforcement. This helps to prevent damage to bond between concrete and reinforcement due to vibration and impact.
- This helps development of impermeable, crack free and durable concrete.

Objective question with answers

1. In rich mixes; use of _size aggregate givesbetterresults. [ ]
   A. Larger B.Medium C.Smaller D.None

2. For given water content, workability decreases if the concrete aggregates contain an excess of
   A. Thin particles B. elongated particles Flakyparticles D. all theabove
   B.
3. For ensuring quality of concrete use [ ]
   A. Single sized aggregates B. two sized aggregate
   C. graded aggregates D. coarseaggregates

4. The standard sand now a days used in India, is obtained from [ ]
   A. Jaipur B.Jullundur C.Hyderabad D.Ennore

5. The maximum amount of dust which may be permitted in aggregates is [ ]
   A. 5%of the total aggregates for low workability with a coarse grading
   B. 10% of the total aggregates for low workability with a fine grading
   C. 20% of the total aggregates for a mix having high workability with finegrading
   D. all the above.

6. The bulk density of aggregates does not depend upon: [ ]
   A. size and shape of aggregates B. specific gravity ofaggregates

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C. gradingofaggregates D. size and shape of the container

7. An aggregate is said to be flaky if its least dimension is less than [ ]
   A. 1/5th ofmeandimension B. 2/5th of meandimension
   C. 3/5th ofmeandimension D. 4/5th of meandimension

8. To ensure constant moisture content inaggregates [ ]
   A. height of each aggregate pile should not exceed 1.50m
   B. aggregatepileshouldbeleftfor24hoursbeforeaggregatesareused
   C. conical heaps of aggregates should be avoided to prevent moisturevariation
   D. all theabove

9. For the construction of cement concrete floor, the maximum permissible size of fine aggregate is [ ]
   A.4.75mm B.6.23mm C.8.12mm D. 10.50mm

10. The process of proper and accurate measurement of concrete ingredients for uniformity of proportion, is known [ ]
    A. grading B.Curing C.Mixing D.Batching

KEY

Q.NO	1	2	3	4	5	6	7	8	9	10
ANS	C	D	C	D	D	D	C	D	D	D

Fill in the blanks question with answers

1. In rich mixes; use of size aggregate gives better results.

2. Slump test is done for=

3. Concrete mainly consists of=

4. Workability of concrete is measured by =

5. The property of separation of cement paste from concrete material is known as=

6. Commonly employed test for measurement of cement workability is=

7. The process of proper and accurate measurement of concrete ingredients foruniformity of proportion is known=

8. In order to make concrete durable, the water cement ratio should be=

9. While compacting the concrete by a mechanical vibrator, the slump should not exceed=

10. Compacting factor formula =

Q.NO	ANSWERS
1	small
2	concrete
3	cement, aggregates and admixtures
4	slump test
5	segregation
6	vee-bee test
7	batching
8	Moderate
9	5CM
10	partially compacted concrete/fully compacted concrete

Two marks question with answers

UNIT-IV HARDENED CONCRETE

1. Define Water/cement ratio?

The water–cement ratio is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Workability can be resolved with the use of plasticizers or super-plasticizers.

2. What is meant by gel-space ratio?

Strengths of cement pastes with different mixture properties and maturities depend in a very similar over linear fashion on the gel–space ratio, which is the ratio of the volume of hydration products over the volume of both hydration products and capillary pores.

3. Why is the modulus of elasticity important?

It is dependent upon temperature and pressure however. The Young's Modulus (or Elastic Modulus) is in essence the stiffness of a material. In other words, it is how easily it is bended or stretched. When a material reached a certain stress, the material will begin to deform.

4. Define Shrinkage cracking?

When concrete is subjected to compressive loading it deforms instantaneously. This immediate deformation is called instantaneous strain. ... This time-dependent strain is termed as creep. Drying shrinkage (often, simply shrinkage) is the reduction in volume of hardened concrete due to loss of moisture by evaporation.

Drying shrinkage is defined as the contracting of a hardened concrete mixture due to the loss of capillary water. This shrinkage causes an increase in tensile stress, which may lead to cracking, internal warping, and external deflection, before the concrete is subjected to any kind of loading.

5. Define Tension cracking?

The stress intensity factors at the tension crack tip are computed with three tensile loading conditions Instead, researchers believe that the angular outline was produced by giant tension cracks in the moon's crust as it cooled around an upwelling plume of hot material from the deep interior.

<u>Three marks question with answers</u>

1. **Define Concrete creep**

Concrete creep is defined as deformation of structure under sustained load. Basically as long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending.

2. **What is plastic shrinkage?**

They are usually parallel to each other on the order of 1 to 3 feet apart, relatively shallow, and generally do not intersect the perimeter of the slab. Plastic shrinkage cracking is more likely to occur when high evaporation rates cause the concrete surface to dry out before it has set.

3. **What is Poisson's ratio?**

Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative.

4. **What is the modulus of elasticity?**

Young's modulus(E) describes tensile elasticity, or the tendency of an object to deform along an axis when opposing forces are applied along that axis; it is defined as the ratio of tensile stress to tensile strain. It is often referred to simply as the elastic modulus.

5. What is tensile modulus?

Tensile Modulus is defined as the "ratio of stress (force per unit area) along an axis to strain (ratio of deformation over initial length) along that axis" It can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material

Five marks question with answers

1. Explain nondestructive tests. What are the codal provisions for NDT?

Nondestructive testing of concrete can be defined as the test method used to examine the properties of concrete used in the actual structure. These test methods can also be said as in-situ tests or in-place tests. Traditionally these tests are said to be as the non-destructive test although some minor damage to the structure may be involved. An important feature of non-destructive test is that the place where test is done can be used for re-testing. The use of non-destructive tests has increased the safety level of construction and also helps in improving the scheduling of construction. All this increases the speed of construction besides keeping the economy of construction in considerable limits.

These tests can be categorized in two parts:

- Tests used to determine the strength of concrete
- Tests used to determine the other characteristics of concrete like voids, cracks etc

The most common tests which are usually conducted are:

Rebound Hammer Test

It is one of the oldest nondestructive tests. This test is widely used because of its economical procedure

Penetration Resistance Test

In this test resistance to the penetration of steel rod in the concrete is used as the strength value

Ultrasonic Pulse Velocity Test

This test has automatic program apparatus. Apparatus is just placed on specimen. The waves pass through the specimen. Time taken by waves to reach from one end of specimen to other is considered to be the strength of specimen. Less the time taken, weaker will be the specimen and vice versa

Pull out Test

This test measure the strength of specimen by means of special tension jacks that are usually used to be inserted in test specimen

2.Explain briefly factors affecting concrete strength

Concrete strength is affected by many factors, such as quality of raw materials, water/cement ratio, coarse/fine aggregate ratio, and age of concrete, compaction of concrete, temperature, relative humidity and curing of concrete.

Quality of Raw Materials:

Cement, aggregate and water

Water / Cement Ratio:

The higher the water/cement ratio, the greater the initial spacing between the cement grains and the greater the volume of residual voids not filled by hydration products.

Coarse / fine aggregate ratio:

Following points should be noted for coarse/fine aggregate ratio:

- If the proportion of fines is increased in relation to the coarse aggregate, the overall aggregate surface area will increase.
- If the surface area of the aggregate has increased, the water demand will also increase.
- Assuming the water demand has increased, the water cement ratio will increase.
- Since the water cement ratio has increased, the compressive strength will decrease.

Age of concrete:

The degree of hydration is synonymous with the age of concrete provided the concrete has not been allowed to dry out or the temperature is too low.

Compaction of concrete:

Any entrapped air resulting from inadequate compaction of the plastic concrete will lead to a reduction in strength. If there was 10% trapped air in the concrete, the strength will fall down in the range of 30 to 40%.

Temperature

The rate of hydration reaction is temperature dependent. If the temperature increases the reaction also increases. This means that the concrete kept at higher temperature will gain strength more quickly than a similar concrete kept at a lower temperature.

Relative humidity:

If the concrete is allowed to dry out, the hydration reaction will stop. The hydration reaction cannot proceed without moisture. The three curves shows the strength development of similar concretes exposed to different conditions

Curing:

It should be clear from what has been said above that the detrimental effects of storage of concrete in a dry environment can be reduced if the concrete is adequately cured to prevent excessive moisture loss.

3. Explain neat procedure for Compressive strength of concrete?

Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not.

Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, and quality control during production of concrete etc.

Procedure: Compressive Strength Test of Concrete Cubes

For cube test two types of specimens either cubes of 15cm X 15cm X 15cm or 10cm X 10cm x 10cm depending upon the size of aggregate are used. For most of the works cubical moulds of size 15cm x 15cm x 15cm are commonly used.

This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of this specimen should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen.

These specimens are tested by compression testing machine after 7 days curing or 28 days curing. Load should be applied gradually at the rate of 140 kg/cm2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

4. What is tensile strength of concrete? Explain its types in detail?

Flexural strength of concrete:

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 6 x 6 inch (150 x 150-mm) concrete beams with a span length at least three times the depth. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).
Flexural Strength of Concrete Flexural MR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. The MR determined by third-point loading is lower than the MR determined by center-point loading, sometimes by as much as 15%.

Split tensile strength of concrete:

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete.

The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

5.Explain in detail the creep of concrete and its factors?

Creep is the time-dependent flow of concrete caused by its being subjected to stress. This deformation, which occurs rapidly at first and then decreases with time, can be several times larger than the strains due to elastic shortening.Using more scientific approach; When load is applied to concrete at time to, a deformation occurs immediately which can be expressed as the elastic strain, ε (to). If this applied load is left on concrete producing a constant stress, the instantaneous elastic strain ε (to) begins to increase.
The rate of increase is fast during the first 3 months, after which it begins to slow down.

Factors effecting creep

Creep has been found to depend on

-the mix proportions (w/c ratio,aggregate type)

-humidity,temperature

-curing conditions,

-maturity of the concrete when first loaded

The deformation due to creep causes a shortening of the pre-stressing strands, which leads to a loss in stress in the strand.

Effects of Creep:

Creep of plain concrete does not by itself affect strength, although under very high stresses creep hastens the approach of the limiting strain at which failure takes place.

The influence of creep on the ultimate strength of a simply supported, reinforced concrete beam subjected to a sustained load is insignificant, but deflection increases considerably and may in many cases be a critical consideration in design.

Another instance of the adverse effects of creep is its influence on the stability of the structure through increase in deformation and consequent transfer of load to other components.

Thus, even when creep does not affect the ultimate strength of the component in which it takes place, its effect may be extremely serious as far as the performance of the structure as a whole is concerned.

The loss of prestress due to creep is well known and accounted for the failure of all early attempts at prestressing. Only with the introduction of high tensile steel did prestressing become a successful operation.

The effects of creep may thus be harmful. On the whole, however, creep unlike shrinkage is beneficial in relieving stress concentrations and has contributed to the success of concrete as a structural material.

6. Explain in detail the shrinkage of concrete and its types?

Concrete is subjected to changes in volume either autogenus or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete.

We have discussed elsewhere the effect of volume change due to thermal properties of aggregate and concrete, due to alkali/aggregate reaction, due to sulphate action etc. Presently we shall discuss the volume change on account of inherent properties of concrete **"shrinkage".**

One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage. It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude.

Now the question is how to reduce the shrinkage and shrinkage cracks in concrete structures. The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.

Types of Shrinkage in Concrete

To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage

(b) Drying Shrinkage

(c) Autogeneous Shrinkage

(d) Carbonation Shrinkage

7. Define modulus of elasticity and dynamic modulus of elasticity?

Modulus Elasticity

Defining modulus of elasticity of concrete is difficult; Because concrete is not a linearly elastic material Since the slope of σ-ε curve of concrete is not constant. We must first describe modulus of elasticity (Ec). In general; Modulus of elasticity defined for concrete is the instantaneous Ec. This is not influenced by the time effect (mean Ec is function of many variables) Instantaneous Ec can be defined in 3 ways.

– Initial Modulus of Elasticity, E

– Secant modulus

– Tangent modulus

Dynamic Modulus of Elasticity

Dynamic modulus is the ratio of stress to strain under vibratory conditions (calculated from data obtained from either free or forced vibration tests, in shear, compression, or elongation). It is a property of visco elastic materials

8. What is curing? What are the different methods of curing?

Curing can be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process of maintaining satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service.

If curing is neglected in the early period of hydration, the quality of concrete will experience a sort of irreparable loss. An efficient curing in the early period of hydration can be compared to a good and wholesome feeding given to a new born baby.

Methods of Curing Concrete

Concrete curing methods may be divided broadly into four categories:

1. Water curing
2. Membrane curing
3. Application of heat
4. Miscellaneous

1. Water curing

This is by far the best method of curing as it satisfies all the requirements of curing, namely, promotion of hydration, elimination of shrinkage and absorption of the heat of hydration. It is pointed out that even if the membrane method is adopted, it is desirable that a certain extent of water curing is done before the concrete is covered with membranes. Water curing can be done in the following ways:

- Immersion
- Ponding
- Spraying or Fogging
- Wet Covering

2. Membrane curing

Sometimes, concrete works are carried out in places where there is acute shortage of water. The lavish application of water for water curing is not possible for reasons of economy. Curing does not mean only application of water; it means also creation of conditions for promotion of uninterrupted and progressive hydration. It is also pointed out that the quantity of water, normally mixed for making concrete is more than sufficient to hydrate the cement, provided this water is not allowed to go out from the body of concrete. For this reason, concrete could be covered with membrane which will effectively seal off the evaporation of water from concrete.

3. Application of heat

The development of strength of concrete is a function of not only time but also that of temperature. When concrete is subjected to higher temperature it accelerates the hydration process resulting in faster development of strength. Concrete cannot be subjected to dry heat to accelerate the hydration process as the presence of moisture is also an essential requisite. Therefore, subjecting the concrete to higher temperature and maintaining the required wetness can be achieved by subjecting the concrete to steam curing. A faster attainment of strength will contribute to many other advantages mentioned below. The exposure of concrete to higher temperature is done in the following manner:

- Steam curing at ordinary pressure
- Steam curing at high pressure
- Curing by Infra-red radiation
- Electrical curing.

4. Miscellaneous methods

Calcium chloride is used either as a surface coating or as an admixture. It has been used satisfactorily as a curing medium. Both these methods are based on the fact that calcium chloride being a salt shows affinity for moisture. The salt not only absorbs moisture from atmosphere but also retains it at the surface. This moisture held at the surface prevents the mixing water from evaporation and thereby keeps the concrete wet for a long time to promote hydration. Formwork prevents escaping of moisture from the concrete, particularly, in the case of beams and columns.

Keeping the form work intact and sealing the joint with wax or any other sealing compound prevents the evaporation of moisture from the concrete. This procedure of promoting hydration can be considered as one of the miscellaneous methods of curing.

9. Explain the procedure for Ultra Sonic Pulse Velocity(UPV)

UPV Procedure

i) Preparing for use: Before switching on the 'V' meter, the transducers should be connected to the sockets marked "TRAN" and " REC". The 'V' meter may be operated with either:

a) the internal battery,

b) an external battery or

c) the A.C line.

ii) Set reference: A reference bar is provided to check the instrument zero. The pulse time for the bar is engraved on it. Apply a smear of grease to the transducer faces before placing it on the opposite ends of the bar. Adjust the 'SET REF' control until the reference bar transit time is obtained on the instrument read-out.

iii) Range selection: For maximum accuracy, it is recommended that the 0.1 microsecond range be selected for path length upto 400mm.

iv) Pulse velocity: Having determined the most suitable test points on the material to be tested, make careful measurement of the path length 'L'. Apply couplant to the surfaces of the transducers and press it hard onto the surface of the material. Do not move the transducers while a reading is being taken, as this can generate noise signals and errors in measurements. Continue holding the transducers onto the surface of the material until a consistent reading appears on the display, which is the time in microsecond for the ultrasonic pulse to travel the distance 'L'. The mean value of the display readings should be taken when the units digit hunts between two values

Pulse velocity= (Path length/Travel time)

v) Separation of transducer leads: It is advisable to prevent the two transducer leads from coming into close contact with each other when the transit time measurements are being taken. If this is not done, the receiver lead might pick-up unwanted signals from the transmitter lead and this would result in an incorrect display of the transit time

10. Explain the procedure for rebound hammer test?

Procedure for rebound hammer.

i) Before commencement of a test, the rebound hammer should be tested against the test anvil, to get reliable results, for which the manufacturer of the rebound hammer indicates the range of readings on the anvil suitable for different types of rebound hammer.

ii) Apply light pressure on the plunger – it will release it from the locked position and allow it to extend to the ready position for the test.

iii) Press the plunger against the surface of the concrete, keeping the instrument perpendicular to the test surface. Apply a gradual increase in pressure until the hammer impacts. (Do not touch the button while depressing the plunger. Press the button after impact, in case it is not convenient to note the rebound reading in that position.)

iv)Take the average of about 15 readings.

Interpretation of Results

The rebound reading on the indicator scale has been calibrated by the manufacturer of the rebound hammer for horizontal impact, that is, on a vertical surface, to indicate the compressive strength. When used in any other position, appropriate correction as given by the manufacturer is to be taken into account.

Objective question with answers

1. In ultrasonic test for hardened concrete good quality ofconcreteisindicatedifthepulsevelocityis
   A. below3km/s B. above 3.5km/s
   C. Above4.5km/s D. None of theabove

2. Specified compressive strength of concrete is obtainedfrom cube tests at the end of
   A. 3days B.7days C.14days D. 28days

3. Shrinkage in concrete can be reduced by using
   A. low watercementratio B. less cement in theconcrete
   C. properconcretemix D.None

4. The ratio between stress in steel to that of stress in concrete in expressedas
   A. Poisson'sratio B. Modularratio C. Densityratio D.None

5. Select the Non – destructive test amongthefollowing
   A. Compressiontest B. Flexuretest C. Reboundhammerstest D. All theabove

6. According to IS 456-2000, the modulus of elasticity of concrete Ec, can be taken
   A. $E_c = 570\sqrt{fck}$ B. 5700fck C.$5700\sqrt{fck}$ D.$5000\sqrt{fck}$

7. Compressive strength of M 150 grade concrete is
A.100 Kg/cm^2 B.150 Kg/cm^2 C.200Kg/cm^2 D. 300Kg/cm^2

8. The process of mixing, transporting, placing and compacting concrete using OPC should not take more than

A. 30 min B.40 min C. 50 min D. 90 min

9. Strength of concrete with passage of time

A. Increases B. Decreases C. Equal D. None

Q.NO	1	2	3	4	5	6	7	8	9	10
ANS	C	D	A	B	C	D	B	A	A	A

Fill in the Blanks question with answers

1. Modulus of rupture of concrete is a measure of=
2. Increase in the moisture content in concrete =
3. The factor of safety for concrete _than steel
4. Select the Non – destructive test=
5. Modulus of rupture of concrete is a measure of=
6. The formula for determining the cement content is given by=
7. Maturity of concrete is the product of=
8. As per IS: 456-2000, the high strength concrete should have thecharacteristic Strengthof=
9. The ratio between stress in steel to that of stress in concrete in expressed as=
10. Concrete gains strength due to=

KEY

Q.NO	ANSWER
1	Tensile strength
2	Reducesthestrength
3	Greater
4	rebound hammer test
5	flexural strength
6	water/cement ratio
7	time x temperature
8	>M 40
9	modular ratio
10	hydration of cement

UNIT-V

MIX DESIGN & SPECIAL CONCRETE

Two marks question with answers

1. **Define concrete mix design?**

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. One of the ultimate aims of studying the various properties of the materials of concrete, plastic concrete and hardened concrete is to enable a concrete technologist to design a concrete mix for a particular strength and durability.

2. **What are the factors influencing the selection of materials?**

A wide range of construction materials is available. The proper selection of materials to be used in a particular construction project depends on the following factors

- Strength
- Availability
- Durability
- Workability
- Ease of Transportation
- Cost
- Aesthetics
- Resistance to Fire
- Ease of Cleaning

3. **What are the Requirements of concrete mix design as per BIS?**

The requirements which form the basis of selection and proportioning of mix ingredients are

a) The minimum compressive strength required from structural consideration

b) The adequate workability necessary for full compaction with the compacting equipment available.

c) Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions

d) Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

4. What are the types of concrete mixes? Explain

1. Nominal Mixes: In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

2. Standard mixes: The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

5. What are the Factors affecting the choice of mix proportions?

- Compressive strength of concrete
- Workability of concrete
- Durability of concrete
- Maximum nominal size of aggregate
- Grading and type of aggregate
- Quality Control at site

6. Define Aerated Concrete

Autoclaved aerated concrete (AAC), also known as autoclaved cellular concrete (ACC), autoclaved lightweight concrete (ALC), autoclaved concrete, cellular concrete, porous concrete, Aircrete, Hebel Block, and Ytong is a lightweight, precast, foam concrete building material invented in the mid-1920s that simultaneously provides structure, insulation, and fire- and mold-resistance. AAC products include blocks, wall panels, floor and roof panels, cladding (facade) panels and lintel

7. What is the general use of Shotcrete?

Shotcrete is concrete (or sometimes mortar) conveyed through a hose and pneumatically projected at high velocity onto a surface, as a construction technique. It is reinforced by conventional steel rods, steel mesh, and/or fibers.

8. What is meant by No fine concrete?

No-Fines Concrete is a method of producing light concrete by omitting the fines from conventional concrete. No-fines concrete as the term implies, is a kind of concrete from which the fine aggregate fraction has been omitted. This concrete is made up of only coarse aggregate, cement and water.

9. What do you mean by Fibre Reinforced Concrete?

Fiber reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers.

Three marks question with answers

1. What is M20 Mix concrete?

If the ratio for M20 concrete is 1:1.5:3 then 1 part cement, 1.5 part sand and 3 part aggregate (crushed stone) in volume is batched for mixing. Ordinary concrete up to M20 grade can be designed by nominal mix concrete procedure.

2. Define Standard mixes.

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

3. What are designed mixes?

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

4. What is an acceptance criterion of concrete?

It is often observed that construction engineer neglects acceptance criteria of the concrete from flexural strength point of view under the argument that flexural strength of the concrete is of no/least importance as in the strength design the tensile strength of the concrete is neglected.

5. What is self-compacting concrete?

Self-consolidating concrete, also known as self-compacting concrete (SCC), is a highly flowable, non-segregating concrete that spreads into place, fills formwork, and encapsulates even the most congested reinforcement, all without any mechanical vibration.

6. What is the Aspect ratio of the fiber?

- A fiber's aspect ratio is defined as its length divided by its diameter.
- Long, thin fibers (fiber B) often provide superior properties, but are also often more expensive to produce and may be more difficult to disperse uniformly in the composite.
- Small aspect ratio fibers(fiber A) typically provide better compressive properties but these composites are typically less resistant to damage propogation.

7. What is SIFCON?

Slurry infiltrated fibre concrete (SIFCON) is one of the recently developed construction material. SIFCON could be considered as a special type of fibre concrete with high fibre content. The matrix consists of cement slurry or flowing cement mortar.

8. What are the types of polymer concrete?

- Polymer impregnated concrete (PIC).
- Polymer cement concrete (PCC).
- Polymer concrete (PC).

9. What is meant by high performance of concrete?

High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer.

Five marks question with answers

1. **Describe ACI method of mix design in detail.**

ACI method of concrete mix design is based on the estimated weight of the concrete per unit volume. This method takes into consideration the requirements for consistency, workability, strength and durability.

Following are the steps of ACI Method of Concrete Mix Design:

(a) Depending on the degree of workability and placing condition determine the slump value.

(b) Depending on the economical availability and dimensions of the structure determine the maximum size of aggregate.

(c) For the given slump and maximum size of coarse aggregate determine the amount of mixing water

(d) Determine the minimum water-cement ratio either from strength considerations or from durability considerations.

(e) Determine the amount of cement per unit volume of concrete from steps (c) and (d). This cement content should not be less than the cement content required based on durability criteria.

(f) Determine the amount of coarse aggregate required for a unit volume of concrete. This value is multiplied by the dry rodded unit weight of the aggregate to get the required dry weight.

(g) Determine the amount of fine aggregate. If the weight of concrete per unit volume is assumed, the required weight of fine aggregate is obtained by the difference between the weight of fresh concrete and the total weight of all other ingredients.

2. **Describe Indian standard method of mix design in detail**

1. Determine the mean target strength ft from the specified characteristic compressive strength at 28-day fck and the level of quality control.

$f_t = f_{ck} + 1.65\ S$

where S is the standard deviation obtained from the Table of approximate contents given after the design mix.

2. Obtain the water cement ratio for the desired mean target using the empirical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.

3. Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.

4. Select the water content, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from table.

5. Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.

6. Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

7. Calculate the cement content form the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability, and greater of the two values is adopted.

8. From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relations:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] \times \frac{1}{1000}$$

9. Determine the concrete mix proportions for the first trial mix.

10. Prepare the concrete using the calculated proportions and cast three cubes of 150

11. Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

3. Explain in detail about the statistical quality control and acceptance criteria of concrete.

Concrete cube strength is a random variable and the test results are influenced by many different factors related to variations in the materials, batching, sampling, concrete testing, equipment and personnel.

Being a random variable, the results of a concrete cube test taken from a particular grade of concrete will, for practical purposes, take the form of a normal distribution when plotted graphically. **This type of distribution is sometimes called a "bell" curve because of its shape.** Like many aspects of concrete technology this is not strictly true – low strength and very high strength concrete test results give skewed distribution curves to the left and right respectively, but for practical purposes a symmetrical distribution is assumed.

The normal distribution curve is characterised by two values: the mean or average value, and the standard deviation which quantifies the spread of the curve either side of the mean value. The requirement that the average strength exceeds the specified (characteristic) strength by 1.64 times the standard deviation implies that slightly fewer than 5% of results will fall below the specified strength.
The only factor under the concrete suppliers control is the standard deviation, the specified strength and the "1.64" being fixed.

The value 1.64 x SD is called the margin. The higher the SD, the higher the margin and the higher the average binder content of the concrete. In other words, **the higher the SD, the more expensive the concrete in terms of binder cost.**

For example, improving control from poor (SD = 7 MPa) to good (SD = 5 MPa) reduces the margin by 1.64 *(7-5) MPa = 3.4 MPa. **A reduction in average strength by 3.4 MPa is equivalent to saving 20 kg of bind**erper cubic metre of concrete.

At current prices this is a saving of roughly R25 / m^3. Of course one has to balance this against the cost of the additional quality control necessary to reduce the SD and there is an optimum point where it becomes uneconomical to reduce the SD any further. For sophisticated concrete suppliers this point would be an SD somewhere in the region of 2.5 to 3 MPa.

4.Define Nominal Mixes and Standard mixes. What are designed Mixes?

Nominal Mixes:

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

Standard mixes:

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

Design mixes:

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

5. Explain detail the factors in the choice of mix design

Concrete mix design:

It is defined as the appropriate selection and proportioning of constituents to produce a concrete with pre-defined characteristics in the fresh and hardened states. In general, concrete mixes are designed in order to achieve a defined workability, strength and durability.

The various factors affecting the choice of concrete mix design are:

Compressive strength of concrete:

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

Workability of concrete:

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

Durability of concrete:

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

Maximum nominal size of aggregate

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate. IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

Grading and type of aggregate

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive. The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

Quality Control at site:

The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control

5. Write a brief note on self-compacting concrete?

SCC is defined as "a concrete that is able to flow under its own weight and completely fill the formwork, while maintaining homogeneity even in the presence of congested reinforcement, and then consolidate without the need for vibrating compaction"

The noise associated with the compaction of conventional concrete can be significant. SCC affords quiet casting, and the environmental loadings from noise are therefore reduced. It also eliminates the issue of blood circulatory problems caused by the vibration of concrete.

SCC affords the designer greater flexibility in designing complex shapes. It is independent of the quality of mechanical vibration and therefore provides homogeneity leading to improved durability and potential for reuse.

Self compacting concrete (SCC) can be classified as an advanced construction material. The SCC as the name suggests, does not require to be vibrated to achieve full compaction. This offers following benefits and advantages over conventional concrete.

- Improved quality of concrete and reduction of onsite repairs.
- Faster construction times.
- Lower overall costs.
- Facilitation of introduction of automation into concrete construction.
- Improvement of health and safety is also achieved through elimination of handling of vibrators.
- Substantial reduction of environmental noise loading on and around a site.

6. Explain the properties of polymer Impregnated Concrete.

Polymer impregnated concrete consists of polymers or epoxies which are used to impart certain special properties to concrete. Various applications of polymers in concrete and their properties is discussed. The polymers are used in the concrete due to the following reasons:

- Polymers improve the strength and durability of hardened concrete
- The chemical resistance and the impermeability of hardened concrete is increased
- The flow properties of fresh concrete can be modified based on the required specifications
- The bond characteristics between old and new concrete can be improved

Some of the polymers that are used popularly are:

1. Urethanes: Urethanes are produced by the reaction of isocyanates with the polyols
2. Acrylics: These are esters of acrylic and methacrylic acids
3. Vinyl
4. Epoxies: These are type of synthetic fibers
5. SBR or Styrene Butadiene Resins: These are synthetic rubbers in the solution

6. Applications of Different Polymers in Concrete

The different ways in which the polymer is introduced into the concrete (hardened concrete) will vary widely based on the commercial objective. The polymers can be employed in concrete in different ways. They are:

- Polymer Impregnated Concrete (PIC)
- Polymer-Modified Concrete (PMC)
- Polymer Concrete (PC)
- Polymer as Protective Coating
- Polymer as Bonding Agent
- Other Applications

7. Explain briefly about the types of fiber reinforced concrete

Different Types of Fiber Reinforced Concrete

Following are the different type of fibers generally used in the construction industries.

- Steel Fiber Reinforced Concrete
- Polypropylene Fiber Reinforced (PFR) cement mortar & concrete
- GFRC Glass Fiber Reinforced Concrete
- Asbestos Fibers
- Carbon Fibers
- Organic Fibers

Steel Fiber Reinforced Concrete:

A no of steel fiber types are available as reinforcement. Round steel fiber the commonly used type are produced by cutting round wire in to short length. The typical diameter lies in the range of 0.25 to 0.75mm. Steel fibers having a rectangular c/s are produced by silting the sheets about 0.25mm thick. Fiber made from mild steel drawn wire. Conforming to IS:280-1976 with the diameter of wire varying from 0.3 to 0.5mm have been practically used in India. Round steel fibers are produced by cutting or chopping the wire, flat sheet fibers having a typical c/s ranging from 0.15 to 0.41mm in thickness and 0.25 to 0.90mm in width are produced by silting flat sheets. Deformed fiber, which are loosely bounded with water-soluble glue in the form of a bundle are also available. Since individual fibers tend to cluster together, their uniform distribution in the matrix is often difficult. This may be avoided by adding fibers bundles, which separate during the mixing process.

Polypropylene Fiber Reinforced (PFR) concrete:

Polypropylene is one of the cheapest & abundantly available polymers polypropylene fibers are resistant to most chemical & it would be cementitious matrix which would deteriorate first under aggressive chemical attack. Its melting point is high (about 165 degrees centigrade). So that a working temp. As (100 degree centigrade) may be sustained for short periods without detriment to fiber properties.

Polypropylene fibers being hydrophobic can be easily mixed as they do not need lengthy contact during mixing and only need to be evenly distressed in the mix.

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Polypropylene short fibers in small volume fractions between 0.5 to 15 commercially used in concrete.

8. **Glass Fiber Reinforced Concrete:**

Glass fiber is made up from 200-400 individual filaments which are lightly bonded to make up a stand. These stands can be chopped into various lengths, or combined to make cloth mat or tape. Using the conventional mixing techniques for normal concrete it is not possible to mix more than about 2% (by volume) of fibers of a length of 25mm.

The major appliance of glass fiber has been in reinforcing the cement or mortar matrices used in the production of thin-sheet products. The commonly used verities of glass fibers are e-glass used. In the reinforced of plastics & AR glass E-glass has inadequate resistance to alkalis present in Portland cement where AR-glass has improved alkali resistant characteristics. Sometimes polymers are also added in the mixes to improve some physical properties such as moisture movement.

Asbestos Fibers:

The naturally available inexpensive mineral fiber, asbestos, has been successfully combined with Portland cement paste to form a widely used product called asbestos cement. Asbestos fibers here thermal mechanical & chemical resistance making them suitable for sheet product pipes, tiles and corrugated roofing elements. Asbestos cement board is approximately two or four times that of unreinforced matrix. However, due to relatively short length (10mm) the fiber have low impact strength.

Carbon Fibers:

Carbon fibers from the most recent & probability the most spectacular addition to the range of fiber available for commercial use. Carbon fiber comes under the very high modulus of elasticity and flexural strength. These are expansive. Their strength & stiffness characteristics have been found to be superior even to those of steel. But they are more vulnerable to damage than even glass fiber, and hence are generally treated with resign coating.

Organic Fibers:

Organic fiber such as polypropylene or natural fiber may be chemically more inert than either steel or glass fibers. They are also cheaper, especially if natural. A large volume of vegetable fiber may be used to obtain a multiple cracking composite. The problem of mixing and uniform dispersion may be solved by adding a super plasticize.

9. **Explain about polymer – modified concrete**

Polymer concretes are a type of concrete that use polymers to replace lime-type cements as a binder. In some cases the polymer is used in addition to portland cement to form Polymer Cement Concrete (PCC) or Polymer Modified Concrete (PMC)

Properties

The exact properties depend on the mixture, polymer, aggregate used etc. etc. but generally speaking with mixtures used:

- The binder is more expensive than cement
- Significantly greater tensile strength than unreinforced Portland concrete (since plastic is 'stickier' than cement and has reasonable tensile strength)[1]
- Similar or greater compressive strength to Portland concrete[1]
- Much faster curing
- Good adhesion to most surfaces, including to reinforcements
- Good long-term durability with respect to freeze and thaw cycles[1]
- Low permeability to water and aggressive solutions
- Good chemical resistance
- Good resistance against corrosion
- Lighter weight (slightly less dense than traditional concrete, depending on the resin content of the mix)
- May be vibrated to fill voids in forms
- Allows use of regular form-release agents (in some applications)
- Dielectric

- Product hard to manipulate with conventional tools such as drills and presses due to its density. Recommend getting pre-modified product from the manufacturer
- Small boxes are more costly when compared to its precast counterpart however pre cast concretes induction of stacking or steel covers quickly bridge the gap.

10. How can high-strength concrete be classified? Explain.

High strength concrete is defined purely on the basis of its compressive strength, defined the **high-performance concrete (HPC)** as concrete mixtures possessing high workability, high durability and high ultimate strength.

High strength of concrete is achieved by reducing porosity, in-homogeneity, and micro-cracks in the hydrated cement paste and the transition zone. Consequently, there is a reduction of the thickness of the interfacial transition zone in high-strength concrete. The densification of the interfacial transition zone allows for efficient load transfer between the cement mortar and the coarse aggregate, contributing to the strength of the concrete. For very high-strength concrete where the matrix is extremely dense, a weak aggregate may become the weak link in concrete strength.

Materials for High-Strength Concrete:

Cement

Cement composition and fineness play an important role in achieving high strength of concrete. It is also required that the cement is compatible with chemical admixtures to obtain the high-strength. Experience has shown that low-C3A cements generally produce concrete with improved rheology.

Aggregate

Selection of right aggregates plays an important role for the design of high-strength concrete mix. The low-water to cement ratio used in high-strength concrete makes the concrete denser and the aggregate may become the weak link in the development of the mechanical strength. Extreme care is necessary, therefore, in the selection of aggregate to be used in very high-strength concrete.

The particle size distribution of the fine aggregates plays an important role in the high strength concrete. The particle size distribution of fine aggregate that meets the ASTM specifications is adequate for high-strength concrete mixtures.

Guidelines for the selection of materials:

- For the higher target compressive strength of concrete, the maximum size of concrete selected should be small, so that the concrete can become more dense and compact and less void ratio.
- Up to 70 MPa compressive strength can be produced with a good coarse aggregate of a maximum size ranging from 20 to 28 mm.
- To produce 100 MPa compressive strength aggregate with a maximum size of 10 to 20 mm should be used.
- To date, concretes with compressive strengths of over 125 MPa have been produced, with 10 to 14 mm maximum size coarse aggregate.
- Using supplementary cementitious materials, such as blast-furnace slag, fly ash and natural pozzolans, not only reduces the production cost of concrete, but also addresses the slump loss problem.
- The optimum substitution level is often determined by the loss in 12- or 24-hour strength that is considered acceptable, given climatic conditions or the minimum strength required.
- While silica fume is usually not really necessary for compressive strengths under 70 MPa, most concrete mixtures contain it when higher strengths are specified.

11. Explain the polymer concrete and its advantages and types?

➢ Polymer concrete is an ordinary concrete produced with OPC (Ordinary portland cement) wet cured and inseminated with liquid or vaporous chemical compound (Methyl methacrylate monomer) and polymerized by gamma radiation or with chemical initiated implies, i.e by utilizing thermal catalytic method (Adding 3% Benzoyl peroxide) to the monomer as a catalyst. The impregnation is helped by drying the concrete at an extreme temperature by evacuations and absorbing the monomer under limited pressure.

Application of Polymer Concrete:

Polymer concrete is broadly utilizing in several circumstances as following

1. Nuclear power plants.
2. Kerb-stones.
3. Prefabricated structural element.
4. Precast slabs for bridge decks.
5. Roads.
6. Marine Works.
7. Pre-stressed concrete.
8. Irrigation works.
9. Sewage works.
10. Waterproofing of building.

Advantages of polymer concrete:

1. It has high impact resistance and high compressive strength.

2. Polymer concrete is highly resistant to freezing and thawing.

3. Highly resistant to chemical attack and abrasion.

4. Permeability is lower than other conventional concrete.

Objective question with answers

1. The compaction of concrete, improves [ ]

   A. Density B.Strength C. Durability D. all theabove.

2. Segregation is responsible for [ ]

   A. honey-combed concrete B. porous layers in concrete

   C. surface scaling in concrete D. sand streaks in concrete

3. Addition of pozzolanatocement [ ]

   A. decreasesworkability B. increasesstrength

   C. increases heatofhydration D. Increaseworkability

4. PermissiblecompressivestrengthofM150concretegradeis [ ]

A. 100kg/cm^2 B.150kg/cm^2

C.200kg/cm^2 D. 250kg/cm2

5. Pozzolana cement is used with confidence forconstructionof [ ]

A. Dams B.massivefoundations C. Abutments D. All the above

6. Efflorescence in cement is caused due to an excessof [ ]

A. Alumina B. iron oxide C.MagnesiumOxide D.alkalis

7. ThediameteroftheVicatplungeris10mmanditslengthvariesfrom [ ]

A. 20 mm to30mm B. 30 mm to40mm C. 40 mm to50mm D. 50 mm to 60mm

8. The ratio of various ingredients (cement, sand, aggregates) in concrete of grade M 20, is

A. 1:2:4 B. 1:3: 6 C. A&B D. None of theAbove

9. Tri-calciumaluminate [ ]

A. reacts fastwithwater B. generates less heat ofhydration

C. causes initial setting and early strength ofcement

D. does not contribute to develop ultimatestrength

10. Hightemperature

A. increases the strengthofconcrete B. decreases the strength ofconcrete

C. has no affecton the strengthofconcrete D. none ofthese.

KEY

Q.NO	1	2	3	4	5	6	7	8	9	10
ANS	D	A	A	C	D	C	C	D	C	C

Fill In the Blanks question with answers

1. Increase in the moisture contentinconcrete=

2. Modulus of rupture of concrete is a measureof=

3. The relation between modulus of rupture for and characteristic strength ofconcrete fck is givenby =

4. ModulusofelasticityofsteelasperIS:456—2000shallbetaken as =

5. The factor of safety for concrete _than steel

6. The characteristic strength of M50 concreteis=

7. Maturity of concrete is the productof =

8. The cylindrical strength of concrete istimes the strength ofthecube

9. The ratio of various ingredients in concrete of grade M 25=

10. The ratio of various ingredients in concrete of grade M 10 =

KEY

Q.NO	ANSWERS
1	Decreases strength
2	Flexural strength
3	$0.7\sqrt{fck}$
4	$2 X10^{6}N/cm^{2}$
5	LESS
6	50N/mm2
7	Time x Temp
8	1.25times
9	1:1:4
10	1:3:6

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14. COURSE ATTAINMENT

VAAGESWARI COLLEGE OF ENGINERING							
Department:		CIVIL ENGINEERING					
Course Outcome Attainment - Internal Assessments							
Name of the Faculty:				Academic Year:		2020-21	
Branch & Section:		CIVIL A&B		Exam:		Mid-1	
Course:		CT		Semister:		I	
Sl.No	Roll Number	Question No.				Objective	Assignment
		1	2	3	4		
Maximum Marks		5	5	5	5	10	5
1	17WJ1A0167			2	1	8	5
2	18S41A0101			2		7	5
3	18S41A0103	5			4	6	5
4	18S41A0104	4.5			2.5	8	5
5	18S41A0105	5			3	6	5
6	18S41A0106	4.5			1.5	7	5
7	18S41A0107	4				8	5
8	18S41A0108	3		2		8	5
9	18S41A0109	4			4	8	5
10	18S41A0110	5			4	8	5
11	18S41A0111	5			5	8	5
12	18S41A0113	5			4	6	5
13	18S41A0114			3		7	5
14	18S41A0115	4.5			1.5	7	5
15	18S41A0116	5			5	7	5
16	18S41A0117	3			5	8	5
17	18S41A0118	3				8	5
18	18S41A0120	AB	AB	AB	AB	AB	5
19	18S41A0121	5			1	7	5
20	18S41A0122	4.5			5	6.5	5
21	18S41A0123	5			4	7	5
22	18S41A0124	5	5			8	5
23	18S41A0125			1		8	5
24	18S41A0126				3	7	5
25	18S41A0127		3	2		7	5
26	18S41A0129	5	5			7	5
27	18S41A0132	5	5			7	5
28	18S41A0133	3.5			1.5	7	5
29	18S41A0135	5			3	7	5
30	18S41A0136	4.5		1.5		7	5
31	18S41A0137	4.5	2.5			7	5

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32	18S41A0138		3	4		7	5
33	18S41A0140		2	5		7	5
34	18S41A0141	4		5		7	5
35	19S45A0101		3	4		8	5
36	19S45A0102	4	5			8	5
37	19S45A0103	5	5			8	5
38	19S45A0104	5	3			7	5
39	19S45A0105	4		2		7	5
40	19S45A0106	AB	AB	AB	AB	AB	5
41	19S45A0107	2.5	3.5			7	5
42	19S45A0108	4	3			7	5
43	19S45A0109	5	3			8	5
44	19S45A0110	5	5			8	5
45	19S45A0111	4.5	4.5			7	5
46	19S45A0112	AB	AB	AB	AB	AB	5
47	19S45A0113		2.5	2.5		8	5
48	19S45A0114	5	3			8	5
49	19S45A0115	5	2			7	5
50	19S45A0116		4	2		7	5
51	19S45A0117	5	5			8	5
52	19S45A0118	3	2.5			7.5	5
53	19S45A0119	AB	AB	AB	AB	AB	5
54	19S45A0120	2.5	3.5			7	5
55	19S45A0121		2			6	5
56	19S45A0122		3		3	7	5
57	19S45A0123	AB	AB	AB	AB	AB	5
58	19S45A0124		3.5	2.5		6	5
59	19S45A0125		3		3	7	5
60	16S41A0112	AB	AB	AB	AB	AB	5
61	16S41A0182	AB	AB	AB	AB	AB	5
62	17S41A0116	AB	AB	AB	AB	AB	5
63	17S41A0117		1	2		5	5
64	17S41A0123				1	7	5
65	17S41A0125		2	1		6	5
66	17S41A0136	2				6	5
67	17S41A0163	2	1			6	5
68	17S41A0166	1		1		6	5
69	18S45A0109	2	3			7	5
70	18S45A0116	AB	AB	AB	AB	AB	5
71	18S41A0145	1				4	5
72	18S41A0147	2				6	5
73	18S41A0148	2.5	1.5			6	5
74	18S41A0150	AB	AB	AB	AB	AB	5

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75	18S41A0151	4	3			5	5
76	18S41A0153	1	1			7	5
77	18S41A0154	5		4		7	5
78	18S41A0155	4	4			6	5
79	18S41A0157			1		7	5
80	18S41A0158	5				5	5
81	18S41A0159	4	4			6	5
82	18S41A0160	5	4			8	5
83	18S41A0161	3	3			8	5
84	18S41A0162	5	3			7	5
85	18S41A0166	5		5		7	5
86	18S41A0170		2.5	2.5		7	5
87	18S41A0171	5	3			7	5
88	19S45A0126		1	1		7	5
89	19S45A0127	4	3			7	5
90	19S45A0128		3		2	7	5
91	19S45A0129			2	2	7	5
92	19S45A0130	1		3		7	5
93	19S45A0131		3		1	7	5
94	19S45A0132	4				7	5
95	19S45A0133		3		2	9	5
96	19S45A0134	4			3	8	5
97	19S45A0135	4	3			8	5
98	19S45A0136	4.5	3.5			7	5
99	19S45A0137	5		2.5		6.5	5
100	19S45A0138	5	4			7	5
101	19S45A0139	2.5	3.5			7	5
102	19S45A0140	5		5		9	5
103	19S45A0141		3	4		7	5
104	19S45A0142		3			8	5
105	19S45A0143		3		3	7	5
106	19S45A0144		1	2		6	5
107	19S45A0145		2		2	7	5
108	19S45A0146		3	3		7	5
109	19S45A0147		3		3	7	5
110	19S45A0148	AB	AB	AB	AB	AB	5
111	19S45A0149	5	5			9	5
112	19S45A0150	2	2			7	5
113	19S45A0151	5	4			7	5
114	19S45A0152		3	3		7	5
115	19S45A0153	AB	AB	AB	AB	AB	5
116	19S45A0154	5	5			7	5
117	19S45A0155		3	2		8	5

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118	19S45A0156	5	3			7	5
119	19S45A0157	AB	AB	AB	AB	AB	5
120	19S45A0158	2	3			8	5
121	19S45A0159		3		2	6	5
No. of students attempted		86	79	45	43	121	121
Max Marks Question wise		5	5	5	5	10	5
Threshold 55%		2.75	2.75	2.75	2.75	5.5	2.75
No. of Students above thresold		59	50	12	17	104	121
% of Students>Target Score		68.61	63.3	26.67	39.54	85.96	100
Attainment Level		3	3	1	1	3	3

Attainment Level 1: 40% students score more than threshold
Attainment Level 2: 50% students score more than threshold
Attainment Level 3: 60% students score more than threshold

Course Outcome Mapping with each Question						
CO's	**Question No**				**Objective**	**Assignment**
	1	**2**	**3**	**4**		
Course outcome - 1	y				y	y
Course outcome - 2		y	y		y	y
Course outcome - 3				y	y	y
Course outcome - 4					y	y
Course outcome - 5					y	y

Course Outcome Attainment based on Exam Questions in terms of percentage of total students when mapped to each question						
CO's	**Question No**				**Objective**	**Assignment**
	1	**2**	**3**	**4**		
Course outcome - 1	3				3	3
Course outcome - 2		3	1		3	3
Course outcome - 3				1	3	3
Course outcome - 4					3	3
Course outcome - 5					3	3

Course Outcome Attainment based on Exam Questions in terms of percentage of total students when mapped to each question				
CO's	Subjective	Objective	Assignment	Attainment Level
Course outcome - 1	3	3	3	3.00
Course outcome - 2	2	3	3	2.67
Course outcome - 3	1	3	3	2.33
Course outcome - 4		3	3	3.00
Course outcome - 5		3	3	3.00

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Department:		CIVIL ENGINEERING					
Course Outcome Attainment - Internal Assessments							
Name of the Faculty:				Academic Year:		2020-21	
Branch & Section:		CIVIL A&B		Exam:		Mid-2	
Course:		CT		Semister:		I	
Sl.No	Roll Number	Question No.				Objective	Assignment
		1	2	3	4		
Maximum Marks		5	5	5	5	10	5
1	18S41A0101				4	6	5
2	18S41A0103	5			3	8	5
3	18S41A0104	5			1	8	5
4	18S41A0105	1			2	8	5
5	18S41A0106	5				7	5
6	18S41A0107	5			3	8	5
7	18S41A0108	4			3	7	5
8	18S41A0109	5			3	8	5
9	18S41A0110	5			4	7	5
10	18S41A0111	5			5	9	5
11	18S41A0113	1	2			8	5
12	18S41A0114	0				8	5
13	18S41A0115	2	1			8	5
14	18S41A0116	5	4			9	5
15	18S41A0117	5			4	9	5
16	18S41A0118	5	1			7	5
17	18S41A0120	AB	AB	AB	AB	AB	5
18	18S41A0121				4	7	5
19	18S41A0122	5			5	9	5
20	18S41A0123	5			3	8	5
21	18S41A0124	5	3			9	5
22	18S41A0125	1				9	5
23	18S41A0126		5			8	5
24	18S41A0127	2			3	7	5

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25	18S41A0129		2		3	9	5
26	18S41A0132				3	8	5
27	18S41A0133	1				8	5
28	18S41A0135	5			3	7	5
29	18S41A0136	4				7	5
30	18S41A0137	5	5			6	5
31	18S41A0138	5				8	5
32	18S41A0140	5				8	5
33	18S41A0141	5			3	5	5
34	19S45A0101	5				7	5
35	19S45A0102	5			4	9	5
36	19S45A0103	5			4	9	5
37	19S45A0104	1			3	9	5
38	19S45A0105	5			4	8	5
39	19S45A0106				3	7	5
40	19S45A0107	5			3	8	5
41	19S45A0108	5			3	8	5
42	19S45A0109	5			4	9	5
43	19S45A0110	5			4	8	5
44	19S45A0111		4		4	7	5
45	19S45A0112	AB	AB	AB	AB	AB	5
46	19S45A0113	3			2	8	5
47	19S45A0114	5				9	5
48	19S45A0115	5			4	9	5
49	19S45A0116		3		2	8	5
50	19S45A0117	5	4			9	5
51	19S45A0118	AB	AB	AB	AB	AB	5
52	19S45A0119	1	1			7	5
53	19S45A0120	5			4	9	5
54	19S45A0121	5			4	9	5
55	19S45A0122	5			4	8	5
56	19S45A0123	5				8	5
57	19S45A0124	5				8	5
58	19S45A0125	5			3	8	5
59	17S41A0116	AB	AB	AB	AB	AB	5
60	17S41A0123	2				8	5
61	17S41A0136	1	1			8	5
62	17S41A0163	2	1			8	5
63	18S41A0145	5				7	5
64	18S41A0147	1			2	7	5
65	18S41A0148	4			2	7	5
66	18S41A0150	5	4			6	5
67	18S41A0151	5	1			7	5

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68	18S41A0153				2	8	5
69	18S41A0154	5		5		8	5
70	18S41A0155	5			4	9	5
71	18S41A0157	4				8	5
72	18S41A0158	5			4	8	5
73	18S41A0159		3		4	9	5
74	18S41A0160	5	2			8	5
75	18S41A0161	5			3	9	5
76	18S41A0162	5			3	7	5
77	18S41A0166	5			3	7	5
78	18S41A0170	5		4		7	5
79	18S41A0171	5			3	9	5
80	19S45A0126	5			3	8	5
81	19S45A0127	2	1			7	5
82	19S45A0128	5				8	5
83	19S45A0129	3				8	5
84	19S45A0130	5		2		9	5
85	19S45A0131	5				8	5
86	19S45A0132	3	1			7	5
87	19S45A0133	1			3	9	5
88	19S45A0134	4				9	5
89	19S45A0135	5		3		8	5
90	19S45A0136	5		3		8	5
91	19S45A0137	5			3	8	5
92	19S45A0138	5			3	8	5
93	19S45A0139	3			3	8	5
94	19S45A0140		2		4	8	5
95	19S45A0141	1			3	8	5
96	19S45A0142	2			3	8	5
97	19S45A0143	5			2	9	5
98	19S45A0144	1			2	7	5
99	19S45A0145	1			2	8	5
100	19S45A0146	5			3	8	5
101	19S45A0147	4			3	8	5
102	19S45A0148	4			1	7	5
103	19S45A0149	5			3	9	5
104	19S45A0150	1			1	8	5
105	19S45A0151	5		2		8	5
106	19S45A0152	5		3		8	5
107	19S45A0153	2			3	7	5
108	19S45A0154	5	4			7	5
109	19S45A0155	4			2	8	5
110	19S45A0156	5			3	9	5

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111	19S45A0157	3	3			9	5
112	19S45A0158	4			1	9	5
113	19S45A0159	1			2	9	5
114	20S48A0101	5	1			8	5
115	16S41AO112	AB	AB	AB	AB	AB	5
116	16S41A0182		1	1		8	5
117	17S41A0117	1				8	5
118	17S41A0125	1			2	8	5
119	17S41A0166	1		1		8	5
120	18S45A0109			3	3	8	5
121	18S45A0116	5			3	7	5
No. of students attempted		108	30	15	74	121	121
Max Marks Question wise		5	5	5	5	10	5
Threshold 55%		2.75	2.75	2.75	2.75	5.5	2.75
No. of Students above thresold		78	11	6	53	115	121
% of Students>Target Score		72.23	36.67	40	71.63	95.05	100
Attainment Level		3	1	1	3	3	3

Attainment Level 1: 40% students score more than threshold
Attainment Level 2: 50% students score more than threshold
Attainment Level 3: 60% students score more than threshold

Course Outcome Mapping with each Question						
CO's	Question No				Objective	Assignment
	1	2	3	4		
Course outcome - 1	y				y	y
Course outcome - 2		y	y		y	y
Course outcome - 3				y	y	y
Course outcome - 4					y	y
Course outcome - 5					y	y

Course Outcome Attainment based on Exam Questions in terms of percentage of total students when mapped to each question						
CO's	Question No				Objective	Assignment
	1	2	3	4		
Course outcome - 1	3				3	3
Course outcome - 2		1	1		3	3

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Course outcome - 3				3	3	3
Course outcome - 4					3	3
Course outcome - 5					3	3

Course Outcome Attainment based on Exam Questions in terms of percentage of total students when mapped to each question

CO's	Subjective	Objective	Assignment	Attainment Level
Course outcome - 1	3	3	3	3.00
Course outcome - 2	1	3	3	2.33
Course outcome - 3	3	3	3	3.00
Course outcome - 4		3	3	3.00
Course outcome - 5		3	3	3.00

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Department:	CIVIL ENGINEERING	
Course Outcome Attainment External Examination		
Name of the Faculty:		Academic Year:
Branch & Section:	CIVIL A&B	Exam:
Course:	CT	Semister:

S.NO.	HALLTICKET NO	TOTAL(Max. Score:75)
1	17WJ1A0167	
2	16S41A0112	-1
3	16S41A0182	6
4	17S41A0116	
5	17S41A0117	9
6	17S41A0123	11
7	17S41A0125	3
8	17S41A0136	26
9	17S41A0163	26
10	17S41A0166	0
11	18S41A0101	16
12	18S41A0103	32
13	18S41A0104	26
14	18S41A0105	26
15	18S41A0106	4
16	18S41A0107	11
17	18S41A0108	4
18	18S41A0109	40
19	18S41A0110	28

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20	18S41A0111	26
21	18S41A0113	17
22	18S41A0114	9
23	18S41A0115	30
24	18S41A0116	29
25	18S41A0117	31
26	18S41A0118	28
27	18S41A0120	
28	18S41A0121	11
29	18S41A0122	38
30	18S41A0123	26
31	18S41A0124	28
32	18S41A0125	15
33	18S41A0126	26
34	18S41A0127	28
35	18S41A0129	33
36	18S41A0132	26
37	18S41A0133	14
38	18S41A0135	26
39	18S41A0136	14
40	18S41A0137	27
41	18S41A0138	8
42	18S41A0140	8
43	18S41A0141	34
44	18S41A0145	3
45	18S41A0147	13
46	18S41A0148	13
47	18S41A0150	27
48	18S41A0151	28
49	18S41A0153	6
50	18S41A0154	33
51	18S41A0155	26
52	18S41A0157	11
53	18S41A0158	37
54	18S41A0159	41
55	18S41A0160	37
56	18S41A0161	36
57	18S41A0162	32
58	18S41A0166	44
59	18S41A0170	13
60	18S41A0171	26
61	18S45A0109	15
62	18S45A0116	30

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63	19S45A0101	4
64	19S45A0102	33
65	19S45A0103	48
66	19S45A0104	9
67	19S45A0105	39
68	19S45A0106	6
69	19S45A0107	26
70	19S45A0108	32
71	19S45A0109	32
72	19S45A0110	39
73	19S45A0111	26
74	19S45A0112	
75	19S45A0113	26
76	19S45A0114	40
77	19S45A0115	39
78	19S45A0116	26
79	19S45A0117	38
80	19S45A0118	-1
81	19S45A0119	30
82	19S45A0120	31
83	19S45A0121	26
84	19S45A0122	26
85	19S45A0123	6
86	19S45A0124	29
87	19S45A0125	35
88	19S45A0126	15
89	19S45A0127	28
90	19S45A0128	26
91	19S45A0129	26
92	19S45A0130	26
93	19S45A0131	26
94	19S45A0132	34
95	19S45A0133	26
96	19S45A0134	28
97	19S45A0135	26
98	19S45A0136	37
99	19S45A0137	26
100	19S45A0138	37
101	19S45A0139	29
102	19S45A0140	38
103	19S45A0141	26
104	19S45A0142	26
105	19S45A0143	35

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106	19S45A0144	26
107	19S45A0145	35
108	19S45A0146	28
109	19S45A0147	33
110	19S45A0148	32
111	19S45A0149	31
112	19S45A0150	5
113	19S45A0151	26
114	19S45A0152	34
115	19S45A0153	29
116	19S45A0154	28
117	19S45A0155	26
118	19S45A0156	33
119	19S45A0157	41
120	19S45A0158	26
121	19S45A0159	30
122	20S48A0101	16
No. of students who attempted the subject		116
Max. Marks		75
Thresold 40%		30
No. of students who scored more than the target score		40
Percentage of students who scored more than target score		34.48
Overall External Attainment level		**1**

Attainment Level 1: **40% students score more than threshold**
Attainment Level 2: **50% students score more than threshold**
Attainment Level 3: **60% students score more than threshold**

VAAGESWARI COLLEGE OF ENGINERING			
Department:	**CIVIL ENGINEERING**		
Overall Course Outcome Attainment			
Name of the Faculty:		Academic Year:	2020-21
Branch & Section:	CIVIL A&B	Exam:	
Course:	CT	Semister:	I

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Course Outcomes	1st Internal Exam	2nd Internal Exam	Internal Exam(Avg.)	University Exam
Course outcome - 1	2.67	3.00	2.84	3.00
Course outcome - 2	2.83	2.33	2.58	3.00
Course outcome - 3	3.00	3.00	3.00	3.00
Course outcome - 4	3.00	3.00	3.00	3.00
Course outcome - 5	3.00	3.00	3.00	3.00
Average			2.88	3.00

Final CO Attainment for the Subject	**2.970833333**

COURSE OUTCOMES AND PROGRAM OUTCOMES MAPPING														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
Course outcome - 1	2	3	3	-	2	-	-	-	-	1	-	-	-	-
Course outcome - 2	3	2	3	-	1	-	-	-	-	2	-	-	-	-
Course outcome - 3	2	2	3	-	2	-	-	-	-	1	-	-	1	1
Course outcome - 4	2	2	2	-	1	-	-	-	-	2	-	-	-	-
Course outcome - 5	2	2	3	-	2	-	-	-	-	2	-	-	-	-
Average Pos	2.2	2.2	2.8	-	1.6	-	-	-	-	1.6	-	-	1	1
PO ATTAINMENT	**2.18**	**2.18**	**2.77**	-	**1.58**	-	-	-	-	**1.58**	-	-	**0.99**	**0.99**

15. CO-PO MAPPING

Course Outcomes	Program Outcomes											
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3		3						3		
CO2	3			3						1		
CO3	1		3	3						3		
CO4	3	3	3							1		
CO5	3		3	1						1		

1: Slight (Low)   **2: Moderate (Medium)**   **3: Substantial (High)**

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