BHUBANANANDA ORISSA SCHOOL OF ENGINEERING, CUTTACK

DEPARTMENT OF CIVILENGINEERING

LECTURE NOTE ON: CONCRETETECHNOLOGY

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SECTION: B

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CONCRETE TECHNOLOGY

CHAPTER-1&2

1. CONCRETE AS CONSTRUCTION MATERIAL
2. CEMENT

- *CONCRETE:-*
  - Cement concrete is a major building material in the world which is widely using because of its marvelous structural properties. The ingredients of cement concrete are cement, fine aggregate, coarse aggregate and water respectively.
  - Due to the versatile property of concrete it is widely used in construction.

Cement

Aggregate

Sand

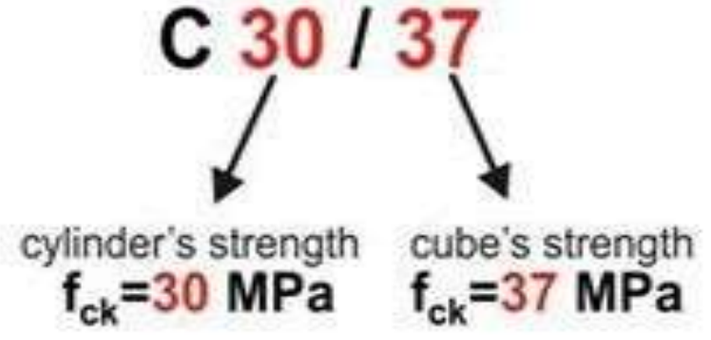
Water

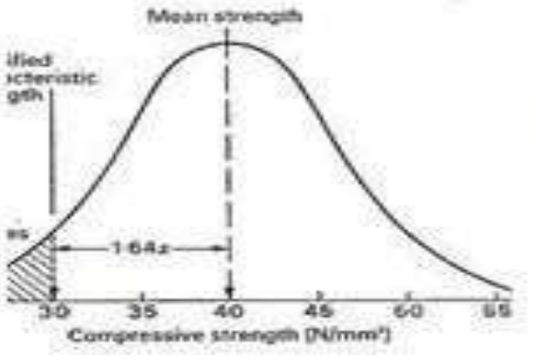
- ***Grade of Concrete:-***
  - Grade of concrete is defined as the minimum ***strength the concrete (compressive strength)*** must posses after 28 days of construction with proper quality control. Grade of concrete is denoted by prefixing M to the desired strength in MPa.
  - ***For example***, for a grade of concrete with 20 MPa strength, it will be denoted by M20, where M stands for Mix.

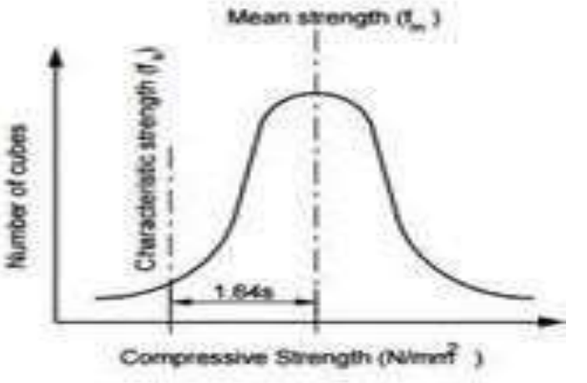
NORMAL GRADE OF CONCRETE	STANDARD GRADE OF CONCRETE	HIGH STRENGTH CONCRETE
M5- M20	M25- M45	M50- M70

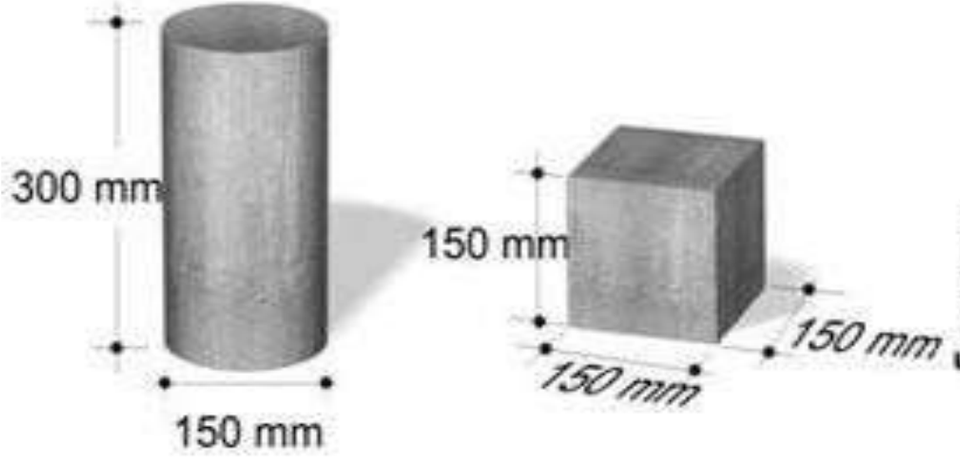
Characteristics Strength of Concrete:-

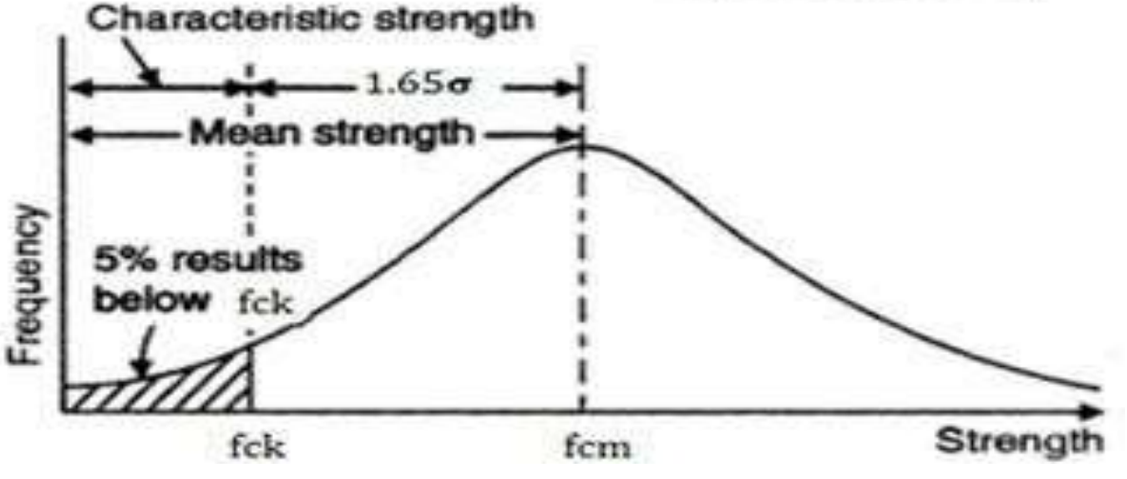
- The characteristic strength is defined as **the strength of the concrete below which not more than 5% of the test results are expected to fall**.











NORMAL GRADE OF CONCRETE	STANDARD GRADE OF CONCRETE	HIGH STRENGTH CONCRETE
M5- 1:5:10 COMP. STRENGTH 5MPA	M25 1:1:2 COMP. STRENGTH 25MPA	M50- M70
M10 - 1:3:6 COMP. STRENGTH 10MPA	M30 ONWARDS DESIGN MIX	
M15- 1:2:4 COMP. STRENGTH 15MPA		
M20- 1:1.5:3 COMP. STRENGTH 20MPA		

- Regular grades of concrete are M15, M20, M25 etc. For plain cement concrete works, generally M15 is used.
- For ***reinforced concrete construction minimum M20 grade of concrete*** **are used.**
- ***Design mix concrete*** are those for which mix proportions are obtained from various lab tests. Use of design mix concrete requires good quality control during material selection, mixing, transportation and placement of concrete.
  - This concrete offers mix proportions based on locally available material and offers economy in construction if large scale concrete construction is carried out.
  - Thus, large concrete construction projects uses design mix concrete.

ADVANTAGES OF CONCRETE

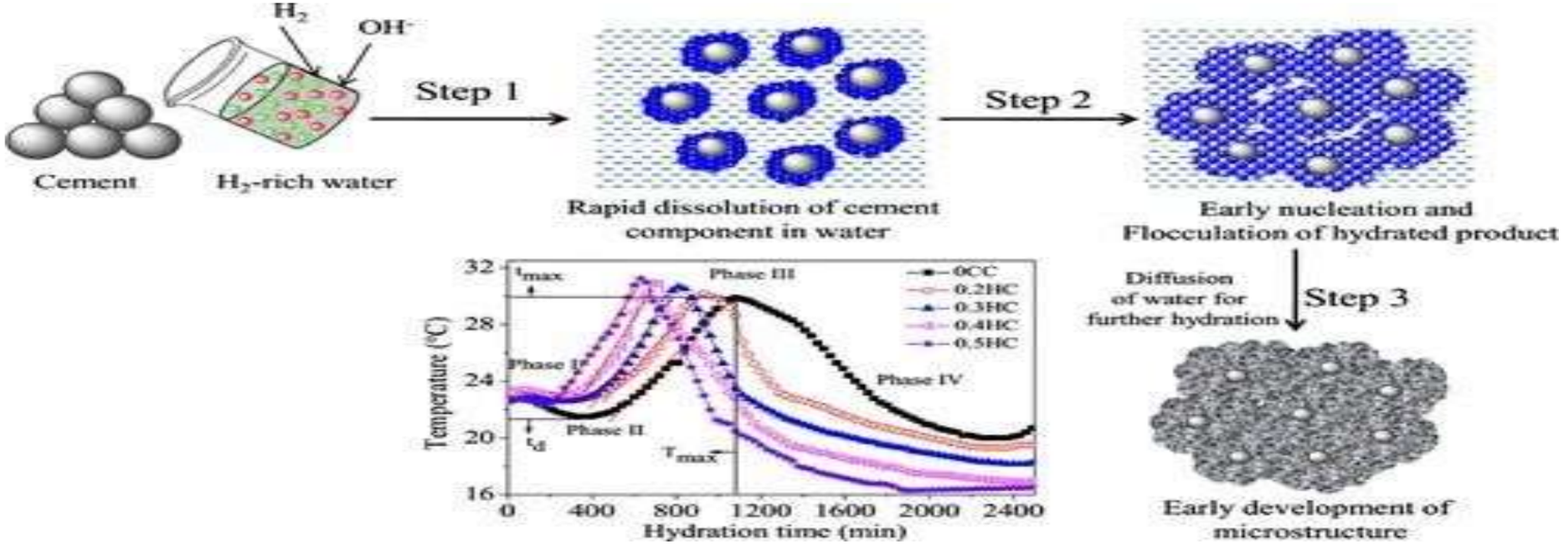
- Ingredients of concrete are easily available in most of the places.
- Unlike natural stones, concrete is free from defects and flaws.
- Concrete can be manufactured to the desired strength with an economy.
- The durability of concrete is very high.
- It can be cast to any desired shape.
- The casting of concrete can be done in the working site which makes it economical.
- The maintenance cost of concrete is almost negligible.
- The deterioration of concrete is not appreciable with age.
- Concrete makes a building fire-safe due to its noncombustible nature.
- Concrete can withstand high temperatures.
- Concrete is resistant to wind and water. Therefore, it is very useful in storm shelters.
- As a soundproofing material cinder concrete could be used.

DISADVANTAGES OF CONCRETE

- Compared to other binding materials, the tensile strength of concrete is relatively low.
- Concrete is less ductile.
- The weight of compared is high compared to its strength.
- Concrete may contains soluble salts. Soluble salts cause efflorescence.

- ***CEMENT:-***
  - A cement is a bindeí, a substance used foí constíuction that sets, haídens, and adheíes to otheí mateíials to bind them togetheí. Cement is seldom used on its own, but íatheí to bind sand and gíavel togetheí.
  - Cement mixed with fine aggíegate píoduces moítaí foí masoníy, oí with sand and gíavel, píoduces concíete.
- ***Composiīion of Cemenī:-***
  - Lime:- (60-65%)controls strength and soundness properties, excess causes unsoundness of cement, deficiency causes less strength.
  - Silica:- (17-25%) imparts strength to cement , by forming C2S & C3S. Excess Strength of cement increases and setting time prolonged.
  - Alumina:- (3-8%) it acts as a flux and reduces the temperature of clinker and imparts quick setting property.
  - Calcium sulphate:- it is in the form of Gypsum and increase setting time of cement.
  - Iron oxide:-(0.5-6%) imparts colour and act as a catalyst in fusion of different ingredients of cement.
  - Magnesia:- (0.1-4%) imparts hardness and colour, excess causes unsoundness.
  - Alkalies :- present a small amount.

- HYDRATION OF CEMENT:-
- The chemical reaction takes place between Cement and Water is known as hydration of cement. In this reaction process a large amount of heat liberated which initiate setting of cement.
- If cement is grounded very finely, then heat of hydration will more and cement sets quickly which leads flash setting of cement.



WATER CEMENT RATIO:-

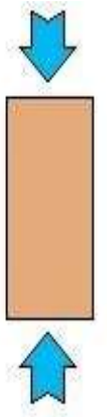
- Water Cement Ratio means the ratio between the weight of water to the weight of cement used in concrete mix.
- Normally water cement ratio falls under 0.4 to 0.6 as per IS Code 10262 (2009) for nominal mix (M10, M15 …. M25)
- We all know that water cement ratio will directly affect the strength of concrete. Either it increases the strength if used in correct proportion or decrease it.

Role of water in Concrete:-

- It contains micro ingredients such as cement, sand, fine aggregate & Coarse aggregate. In order to acquire high strength concrete which withstands up to our desired compressive strength, We need correct proportion of admixture to combine these materials.
- Here comes the Water which will initiate this chemical *process by adding 23%-25% of the cement volume. This initiates the chemical process and makes 15% of water cement paste also known as a gel to fill the voids in the concrete.*

COMPRESSIVE STRENGTH OF CEMENT:

- Compíessive stíength is the capacity of mateíial oí stíuctuíe to íesist oí withstand undeí compíession. l'he Compíessive stíength of a mateíial is deteímined by the ability of the mateíial to íesist failuíe in the foím of cíacks and fissuíe.
- In this test, the impact foíce applied on both faces of Moítaí specimen made with Cement and the maximum compíession that cement specimen beaís without failuíe íecoíded.



Compression force is the Force that squeezes material together

or

Pushing Force applied on two faces of the specimen

Compression Strength

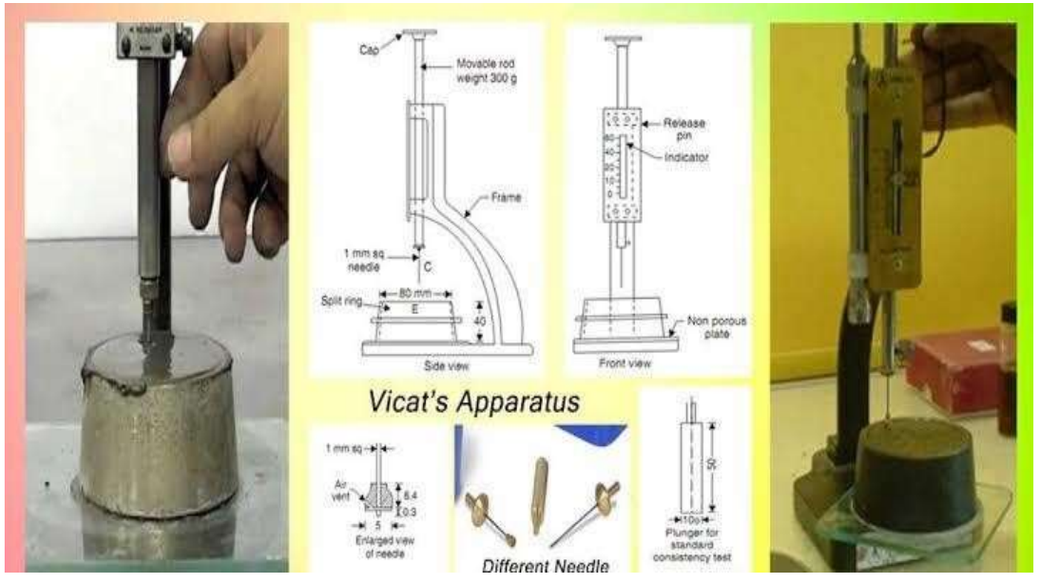
Steel Cube 7.06cmx 7.06cm x 7.06cm

$$\text{Compressive Strength of Concrete} = \frac{\text{Max Load Carried by Specimen}}{\text{Top Surface Area of Specimen}}$$

FINENESS OF CEMENT:-

- The fineness of cement is property of cement which indicate the particle size of cement and specific surface area and thus indirectly effect heat of hydration.
- Importance/effect of fineness of cement;
  1. Fineness of cement affects hydration rate hence the rate of strength gain.
  2.Bleeding can be reduced by increasing fineness. However, increased fineness can also lead to the requirement of more water for the workability, resulting in a higher possibility of dry shrinkage.
  3. Fineness test is used to change the proper grinding of cement and measures the surface area of the cement particles per unit mass.
  4.Therefore finer cement react faster with water and the rate of development of strength and corresponding heat of hydration is high.
  - Fineness limit;
    It should not exceed following percentage by weight for different types of cement;
    1. Ordinary portland cement = 10%
    2. Rapid hardening cement = 5%
    3. Low heat cement = 5%

INITIAL AND FINAL SETTING TIME :-



Initial Setting Time of Cement

- It is the **time elapsed** between the **moments** that the **water is added to the cement**, to the **time** that the **paste starts losing its plasticity.**

Final Setting Time of Cement

- **It** is the **time elapsed** between the **moment** the **water is added to the cement** and the **time** when **cement paste loses its plasticity** completely and has **attained** sufficient **firmness** to **ist** certain definite **pressure**.

Significance of Initial and Final Setting Time of Cement

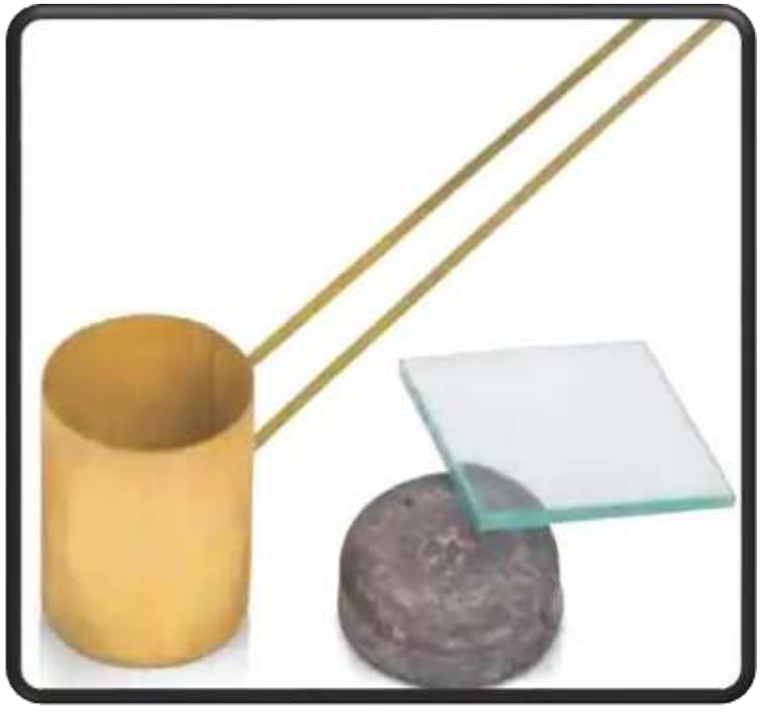
- It is **required** that cement does not **lose** its **plasticity** too **early** or too late. If **cement** set too early, there is **insufficient** time for **transportation** and **place concrete**.
- If **cement set** too late then **there** is a **delay** in **construction work**. Also, **concrete** will not get **sufficient** strength early and the **formwork** removal process **delayed**.
- The **proper setting** time required for the **stiffening** of **cement paste** to a defined consistency.
- It is **indirectly** related to the **chemical reaction** of **cement** with **water** to form an **aluminum–silicate compound**.
- Initial setting time is an **important** time to know for **concrete transportation**, **placing**, and **curing**.
- **Initial setting** time also **utilized** to delay the **process** of **hydration** or **hardening**.
- The **final setting time** utilized for the **safe removal** of **scaffolding** or **form**.

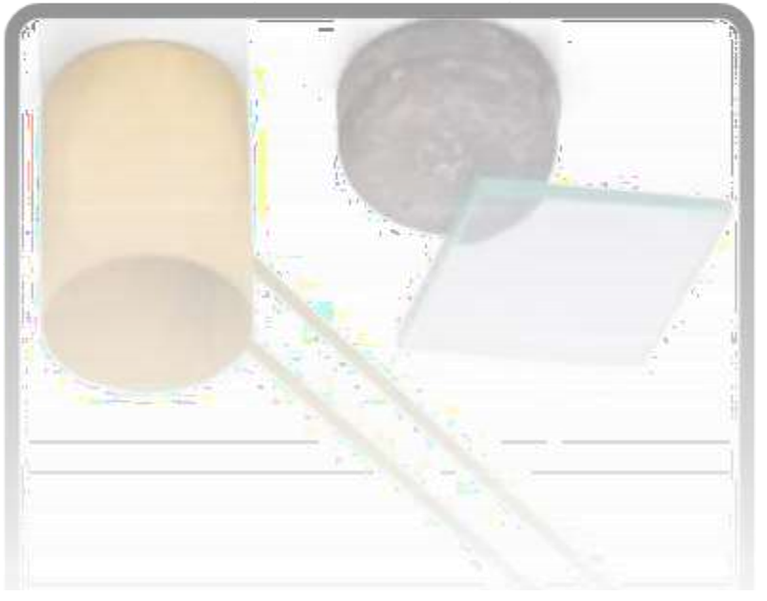
Factors Affecting Initial and Final Setting Time of Cement

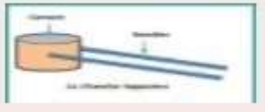
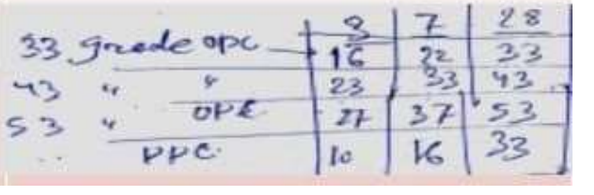
- The **fineness of cement**, the **presence** of salts in **sand**, **atmospheric conditions**. For example, **cement** requires a **temperature of 27°c** to complete **Hydration, during winters the climate** is low which stops the **hydration** and **takes** a longer time to **set harden**.

SOUNDNESS TEST OF CEMENT:-

- Soundness of cement can be defined as its ability to retain its volume after it gets hardened. This means that a properly sound cement will undergo minimum volume change after it converts into the hardened state.
- In the soundness test of cement, we determine the amount of excess lime. This test can be conducted by Le-chatelier method and Autoclave Method
- **Significance of Soundness Test on Cement**
- Cement is a composition of lime, silica, alumina, magnesia, alkaline, sulfur trioxide, iron oxide, and calcium sulfate. Among which, lime constitutes 60 to 70%. Hence, a cement deficient in lime will set quickly and will affect the property of the cement. Lime content in higher amount will make the cement unsound. An unsound cement will affect the quality of the cement work performed.
- This demands of soundness test of cement before using it. Through this test, it is ensured that the cement won't undergo any sort of expansion due to the presence of excess amount of lime.





TEST NAME	Apparatus Required	Water to be added	IS value
Fineness Test	IS SIEVE 90micron size 		Residues left on sieve not more than 10% by weight of cement
Soundness Test	LeChartliers apparatus 	0.78 times consistency of Cement	Expansion between the legs should not exceed 5mm
Consistency of Cement	Vicat Apparatus with plunger 	Approximately to make a cement paste (25 to 33% by weight of cement)	The standard **consistency of cement** is that water content which permit the vicat plunger to penetrate to a point ***5 to 7mm from the bottom of the vicat mould when tested***
Initial setting Time	Vicat apparatus With needle	85%(0.85) of standard consistency of cement	Not less than 30min
Final Setting time	Vicat apparatus Needle with annular collar	Further process from initial setting time (no more water to be added)	Between 6 to 10 hour
Specific Gravity	Density bottle 	As per definition	
Compressive strength (Determines grade of	Compression testing machines and 70.6mm size	(P/4 +0.3) P= % of consistency	

Types Of Cement

1. Ordinary Portland Cement (OPC)

- Ordinary Portland Cement also known as OPC is a type of cement that is manufactured and used worldwide. It is widely used for all purposes including:
  - Concrete: When OPC is mixed with aggregates and water, it makes concrete, which is widely used in the construction of buildings
  - Mortar: For joining masonry
  - Plaster: To give a perfect finish to the walls
- Cement companies in Malaysia offer OPC in three different grades, namely grades 33, 43, and 53.
- Besides the aforementioned purposes, Ordinary Portland cement is also used to manufacture grout, wall putty, solid concrete blocks, AAC blocks, and different types of cement.

2. Portland Pozzolana Cement (PPC)

- To prepared PPC or Portland Pozzolana cement, you need to grind pozzolanic clinker with Portland cement.
- PPC has a high resistance to different chemical assaults on concrete. It is widely used in construction such as:
    1. Marine structures
    2. Sewage works
    3. Bridges
    4. Piers
    5. Dams
    6. Mass concrete works

3. Rapid Hardening Cement

- Cement suppliers in Malaysia also offer rapid Hardening cement. Rapid Hardening Cement is made when finely grounded C3S is displayed in OPC with higher concrete.
- It is commonly used in rapid constructions like the construction pavement.

4. Extra Rapid Hardening Cement

- As the name suggests, Extra rapid hardening cement gains strength quicker and it is obtained by adding calcium chloride to rapid hardening cement.
- Extra rapid hardening cement is widely used in cold weather concreting, to set the cement fast. It is about 25% faster than that of rapid hardening cement by one or two days.

5. Low Heat Cement

- Cement manufacturers in Malaysia offers low heat cement that is prepared by keeping the percentage of tricalcium aluminate below 6% and by increasing the proportion of C2S.
- This low heat cement is used in mass concrete construction like gravity dams. It is important to know that it is less reactive and the initial setting time is greater than OPC.

6. Sulfates Resisting Cement

- This type of cement is manufactured to resist sulfate attack in concrete. It has a lower percentage of Tricalcium aluminate.
- Sulfates resisting cement is used for constructions in contact with soil or groundwater having more than 0.2% or 0.3% g/l sulfate salts respectively.
- It can also be used in concrete surfaces subjected to alternate wetting and drying like bridge piers.

7. Quick Setting Cement

- Cement suppliers in Malaysia also offer quick setting cement which sets faster than OPC but the strength remains the same. In this formula, the proportion of gypsum is reduced.
- Quick setting cement is used for constructions that need a quick setting, like underwater structures and in cold and rainy weather conditions.

8. Blast Furnace Slag Cement

- This type of cement is manufactured by grinding the clinker with about 60% slag and it is similar to Portland cement. It is used for constructions where economic considerations are important.

9. High Alumina Cement

- High alumina cement is obtained by mixing calcining bauxite and lime with clinker during the manufacturing process of OPC.
- To be considered high alumina cement, the total amount of alumina content should be at least 32%, and the ratio of the weight of alumina to lime should be kept between 0.85 to 1.30.
- The most common uses are in constructions that are subject to high temperatures like a workshop, refractory, and foundries.

10. White Cement

- This type of cement is manufactured by using raw materials that are free from iron and oxide. White cement needs to have lime and clay in a higher proportion. It is similar to OPC but it is more expensive.

Chapter-3

AGGREGATE, WATER & ADMIXTURE

Fineness Modulus of Coarse Aggregates:-

- Fineness modulus of coarse aggregates represents the average size of the particles in the coarse aggregate by an index number. It is calculated by performing sieve analysis with standard sieves.
- The cumulative percentage retained on each sieve is added and subtracted by 100 gives the value of fine aggregate. Higher the aggregate size higher the Fineness modulus hence fineness modulus of coarse aggregate is higher than fine aggregate.
- Coarse aggregate means the aggregate which is retained on 4.75mm sieve when it is sieved through 4.75mm. To find fineness modulus of coarse aggregate we need sieve sizes of 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm.
- Fineness modulus is the number at which the average size of particle is known when we counted from lower-order sieve size to higher-order sieve. So, in the calculation of coarse aggregate we need all sizes of sieves.

HOW TO DETERMINE FINENESS MODULUS

- To find fineness modulus we need to perform sieve analysis and for that above mentioned sieve sizes, mechanical shaker and digital weigh scale are required.

Sample preparation

- Take a sample of coarse aggregate in pan and placed it in dry oven at a temperature of 100 – 110^{o}C. After drying take the sample weight to nearest gram.

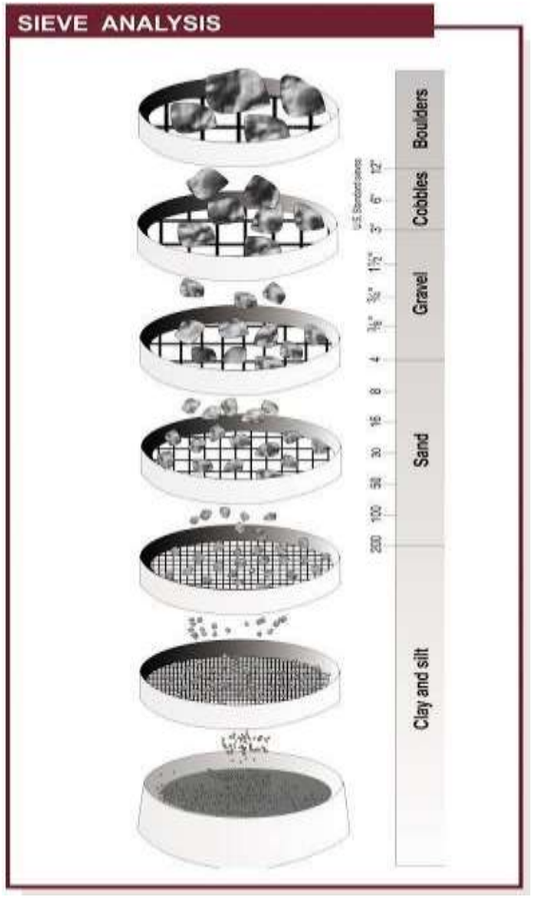
Test Procedure for Fineness Modulus of Coarse Aggregates

- Arrange the sieves in descending order and put the arrangement on mechanical shaker. It is suggested that, to know the exact value of fineness modulus for coarse aggregate, mechanical shaker will give better value than hand shaking because of more no. of sieves and heavy size particles.
- After proper sieving, record the sample weights retained on each sieve and find out the cumulative weight of retained particles as well as cumulative % retained on each sieve. Finally add all cumulative percentage values and divide the result with 100. Then we get the value of fineness modulus.

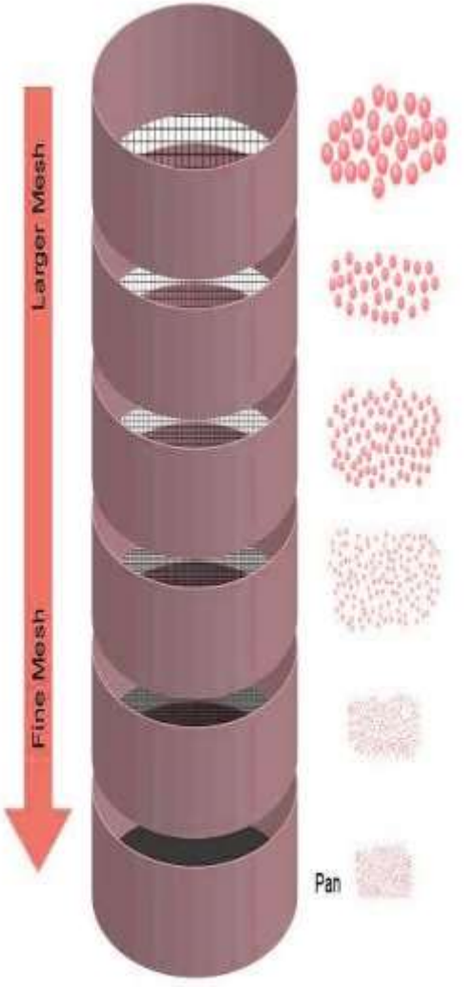
Example for Fineness Modulus Calculation

- Let us say dry weight of coarse aggregate = 5000g

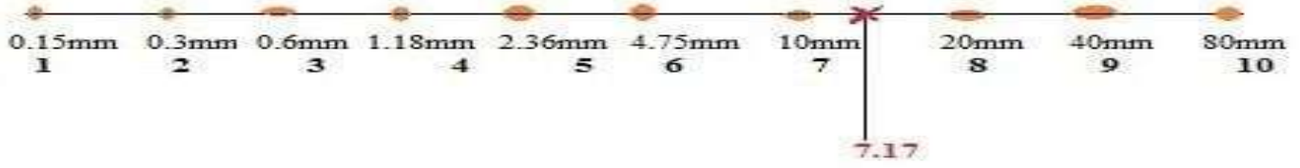
Values after sieve analysis are



Sieve size	Weight retained(g)	Cumulative weight retained (g)	Cumulative % retained (g)
80mm	0	0	0
40mm	250	250	5
20mm	1750	2000	40
10mm	1600	3600	72
4.75mm	1400	5000	100
2.36mm	0	5000	100
1.18mm	0	5000	100
0.6mm	0	5000	100
0.3mm	0	5000	100
0.15mm	0	5000	100
	Sum	=	717



- Therefore, **fineness modulus of coarse aggregates** = sum (cumulative % retained) / 100 = (717/100) = **7.17**
- Fineness modulus of 7.17 means, the average size of particle of given coarse aggregate sample is in between 7th and 8th sieves, that is between 10mm to 20mm.



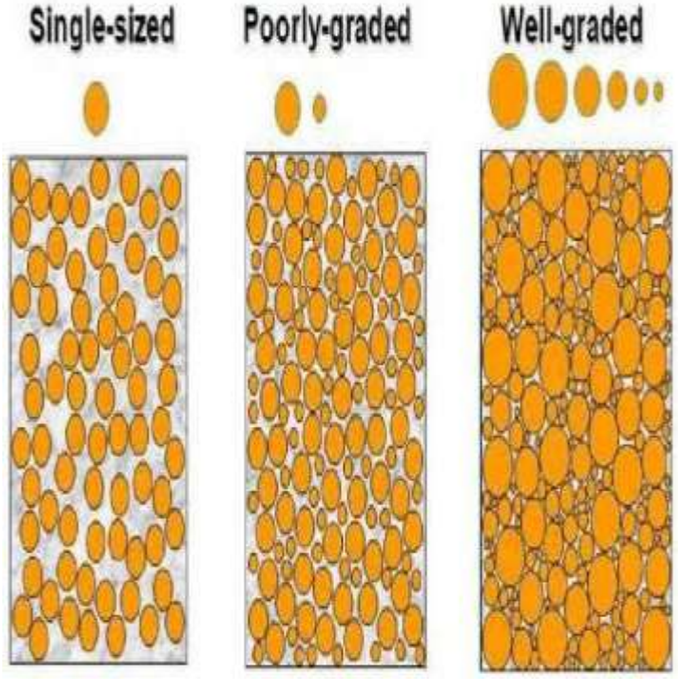
Limits of Fineness Modulus

- Fineness modulus of coarse aggregate varies from 5.5 to 8.0. And for all in aggregates or combined aggregates fineness modulus varies from 3.5 to 6.5. Range of fineness modulus for aggregate of different maximum sized aggregates is given below.

Maximum size of coarse aggregate	Fineness modulus range
20mm	6.0 – 6.9
40mm	6.9 – 7.5
75mm	7.5 – 8.0
150mm	8.0 – 8.5

GRADING OF AGGREGATE

- ***Grading of Aggregates*** is one which is made up of stones of different sizes, ranging from large to small (inclusive of sand) so as to have minimum of air voids (and that will have maximum density) when mixed together.
- In grading of aggregates, the voids in the mixed aggregate would be minimum when the sand is just sufficient to fill the voids in the coarse aggregate. Voids in the coarse aggregate are filled in by sand and voids in the sand are filled in by cement. Mix that occupies the least volume is the densest and will produce the best results.
- In **grading of aggregates**, well graded sand from coarse to fine has less voids than fine sand. The lesser the voids the better is the quality of sand for use in cement concrete, provided there is no silt in sand.
- The combined aggregate when mixed with the required quantity of cement and water, should give a good workable concrete which can be readily placed in position without segregation.
- The proportion of fine to coarse aggregate should be such as will give maximum workability with minimum of water. Mixtures with a deficiency of fine materials will be harsh, hard to work and difficult to finish.
- A little more sand makes the concrete more fluid without extra water. Too much of sand will increase porosity of the concrete and need more cement.



WATER QUALITY FOR CONCRETE

- Quality of water for construction works are same as drinking water. This is to ensure that the water is reasonably free from such impurities as suspended solids, organic matter and dissolved salts, which may adversely affect the properties of the concrete, especially the setting, hardening, strength, durability, pit value, etc.
- The water shall be clean and shall not contain sugar, molasses or gur or their derivatives, or sewage, oils, organic substances.
- For plain and reinforced cement concrete permissible limits for solids shall be as follows:

Type of Solid in water	Permissible Limits for Construction
Organic matter	200 mg/l
Inorganic matter	3000 mg/l
Sulphates (SO4)	500 mg/l
Chlorides (Cl)	a) 1000 mg/l for RCC work and, b) 2000 mg/l for PCC work
Suspended matter	2000 mg/l

ADMIXTURES

What is Admixture

- Admixtures are the chemical compounds in concrete other than hydraulic cement (O.P.C), water & aggregate and mineral additives which are added to the concrete mix immediately before or during to modify. One or more specific properties of concrete in fresh or hardened state.
- **The properties of concrete commonly modified by the admixtures are-**
  a) Rate of hydration.
  b) Setting time.
  c) Workability.
  d) Dispersion.
  e) Air-Entrainment.

Use Of Admixture

Admixtures are used to achieve the following objectives:

a) To reduce the cost of concrete construction.

b) To modify the performance of hardened concrete.

c) To ensure the quality of concrete during mixing, transporting, placing, compacting & curing.

d) To overcome certain emergencies during concreting operations.

- The commonly used admixtures of this category are:

1) Accelerating admixtures: Example — Calcium Chloride (CaCl2).

2) Retarding admixtures: Example — Sugar, Soluble Starch.

3) Air-entraining admixtures: Example — Natural wood resin, Olive oil.

4) Water reducing admixtures: Example — Plasticizers

Functions of Admixtures

a) To accelerate or retard the initial set of concrete.

b) To enhance the workability.

c) To improve the flow-ability & pump-ability of concrete.

d) To reduce the segregation in concrete.

e) To increase the strength of concrete by reducing the water content.

f) To increase the durability of concrete.

g) To increase the impermeability of concrete.

h) To control alkali-aggregate reaction

i) To reduce the corrosion of reinforcement in concrete.

j) To increase the resistance to chemical attack.

k) To reduce the heat of hydration.

l) To increase the bond between concrete & steel.

m) To increase the bond between old and new concrete surfaces.

n) To produce cellular concrete, colored concrete.

o) To produce non-skid wearing surface.

p) To decrease the unit weight of concrete.

q) To produce concrete of fungicidal, germicidal and insecticidal properties

CHAPTER-04

PROPERTIES OF FRESH CONCRETE

•***Concept of fresh concrete* :-**

Fresh Concrete:-

- Fresh concrete is that stage of concrete in which concrete can be moulded and it is in plastic state. This is also called "Green Concrete". Another term used to describe the state of fresh concrete is **consistence**, which is the ease with which concrete will flow.

- **Properties of Fresh Concrete**

1. Setting of Concrete

- The hardening of concrete before its hydration is known as setting of concrete. OR The hardening of concrete before it gains strength. OR The transition process of changing of concrete from plastic state to hardened state. Setting of concrete is based or related to the setting of cement paste. Thus cement properties greatly affect the setting time.

Factors affecting setting:

Following are the factors that affect the setting of concrete.

- 1. Water Cement ratio
  2. Suitable Temperature
  3. Cement content
  4. Type of Cement
  5. Fineness of Cement
  6. Relative Humidity
  7. Admixtures
  8. Type and amount of Aggregate

2. Workability of Concrete

- Workability is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation.
- In the case of concrete, consistence is sometimes taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concrete, but concrete of same consistence may vary in workability.
- Because the strength of concrete is adversely and significantly affected by the presence of voids in the compacted mass, it is vital to achieve a maximum possible density. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of work under the given conditions. Presence of voids in concrete reduces the density and greatly reduces the strength: 5% of voids can lower the strength by as much as 30%.

Factors affecting concrete workability:

- Water-Cement ratio
- Amount and type of Aggregate
- Amount and type of Cement
- Weather conditions
  - Temperature
  - Wind
- Chemical Admixtures
- Sand to Aggregate ratio

3. Concrete Bleeding

- Bleeding in concrete is sometimes referred as water gain. It is 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 slab or road slabs and when concrete is placed in sunny weather show excessive bleeding.

4. Segregation in concrete

- 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. There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore, it is natural that the materials show a tendency to fall apart.

5. Hydration in concrete

- Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. In the field and in actual work, even a higher water/cement ratio is used, since the concrete is open to atmosphere, the water used in the concrete evaporates and the water available in the concrete will not be sufficient for effective hydration to take place particularly in the top layer.
- If the hydration is to continue, extra water must be added to refill the loss of water on account of absorption and evaporation. Therefore, the curing can be considered as creation of a favorable environment during the early period for uninterrupted hydration. The desirable conditions are, a suitable temperature and ample moisture.
- Concrete, while hydrating, releases high heat of hydration. This heat is harmful from the point of view of volume stability. Heat of hydration of concrete may also shrinkage in concrete, thus producing cracks. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a thorough water curing.

6. Air Entrainment

- Air entrainment reduces the density of concrete and consequently reduces the strength. Air entrainment is used to produce a number of effects in both the plastic and the hardened concrete. *These include*:
- Resistance to freeze–thaw action in the hardened concrete.
- Increased cohesion, reducing the tendency to bleed and segregation in the plastic concrete.
- Compaction of low workability mixes including semi-dry concrete.
- Stability of extruded concrete.
- Cohesion and handling properties in bedding mortars.

7. Temperature

- Concrete is not recommended to be placed at a temperature above 40°C without proper precautions, as laid down in IS:7861(part -1).
- Special problems are encountered in the preparation, placement, and curing of concrete in hot weather. The First 24 to 72 hours after placing fresh concrete are of extreme importance.
- If the temperature of concrete is not controlled and it goes beyond maximum range during hydration, then stresses are produced, and cracks are formed in concrete.
- Also if the temperature falls below the minimum temperature, then concrete takes a large time to set, and the hydration process slows down.

***Workability* :-**

Types of Workability of Concrete:- Workability of concrete can be classified into following three types:

- **Unworkable Concrete**: An unworkable concrete also known as harsh concrete, is a concrete with a very little amount of water. The hand mixing of such concrete is difficult. Such type of concrete has high segregation of aggregates. and it is very difficult to maintain the homogeneity of concrete mix. Water cement ratio of such concrete is below 0.4.
- **Medium Workable concrete:** Medium workable concrete is used in most of the construction works. This concrete is relatively easy to mix, transport, place, and compact without much segregation and loss of homogeneity. Water cement ratio for medium workable concrete is 0.4 to 0.55.
- **Highly Workable Concrete:** This type of concrete is very easy to mix, transport, place and compact. It is used where effective compaction of concrete is not possible. The problem is that there are high chances of segregation and loss of homogeneity in highly workable concrete. Water cement ratio of such concrete is more than 0.55.

Desirable Workability for Construction

Desirable workability depends on two factors which are:

1. **Section size, amount and spacing of reinforcement:** When a section is narrow, complicated, several narrow corners, inaccessible parts; a highly workable concrete is desirable to obtain full compaction through a reasonable amount of effort. When the section is crowded with steel reinforcement and spacing of bars is relatively small, compaction can be difficult and hence highly workable concrete is recommended in such cases. If there are no limitations of the critical section or heavy reinforcement, we can get a wide range of workability for concrete casting.
2. **Method of compaction:** If concrete is compacted manually, more workability is recommended because hand compaction is not very much uniform and effective. If there is a scope of the vibrator or machine compaction, we can choose workability from a wide range.

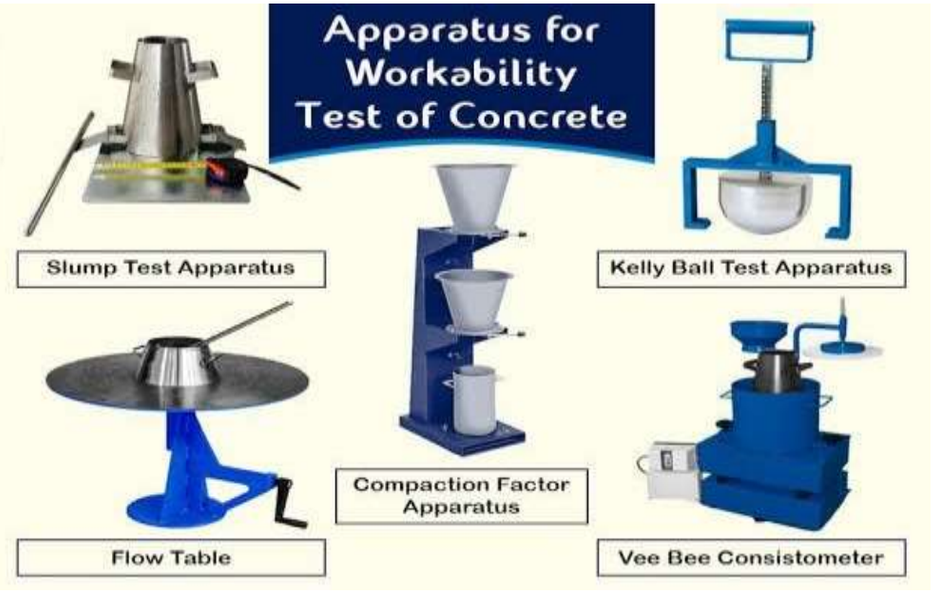
Strength of Concrete & Workability Relationship

- The strength of concrete is the most important property for us. It depends on density ratio or compaction and compaction depend on sufficient workability. Fresh concrete must have a workability as compaction to maximum density is possible with a reasonable amount of work.
- But excessive workability can lessen compressive strength. From the above graph, we see that compressive strength of concrete decreases with increase in w/c ratio. An increase of w/c ratio indicates an increase of workability. Hence, the strength of concrete inversely proportional to the workability and too much workability should be avoided.

Methods of Improving Workability of Concrete

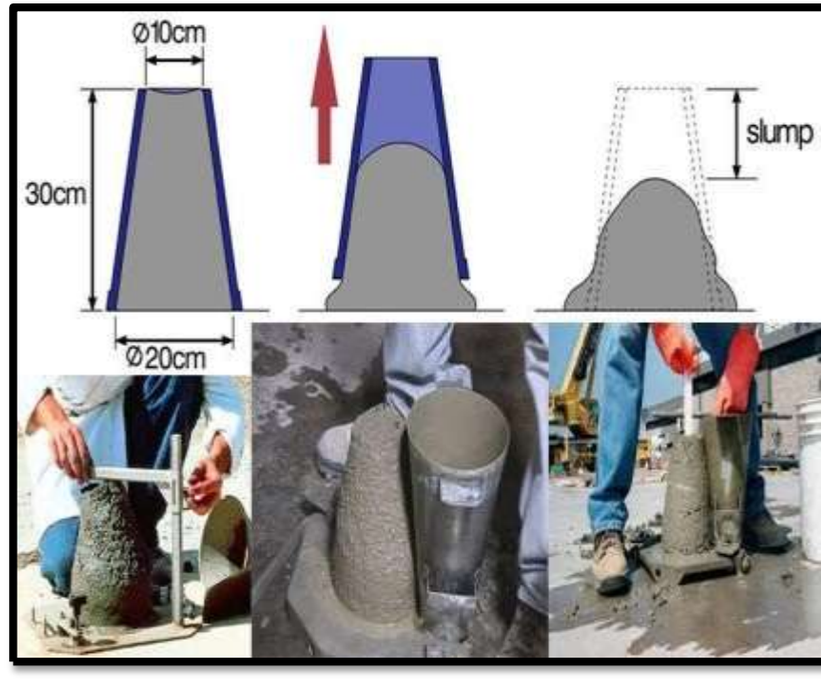
To increase workability there are some ways like:

- Increasing water/cement ratio
- Using larger aggregate
- Using well-rounded and smooth aggregate instead of irregular shape
- Increasing the mixing time and mixing temperature
- Using non-porous and saturated aggregate
- With addition of air-entraining mixtures
- Adding appropriate admixtures



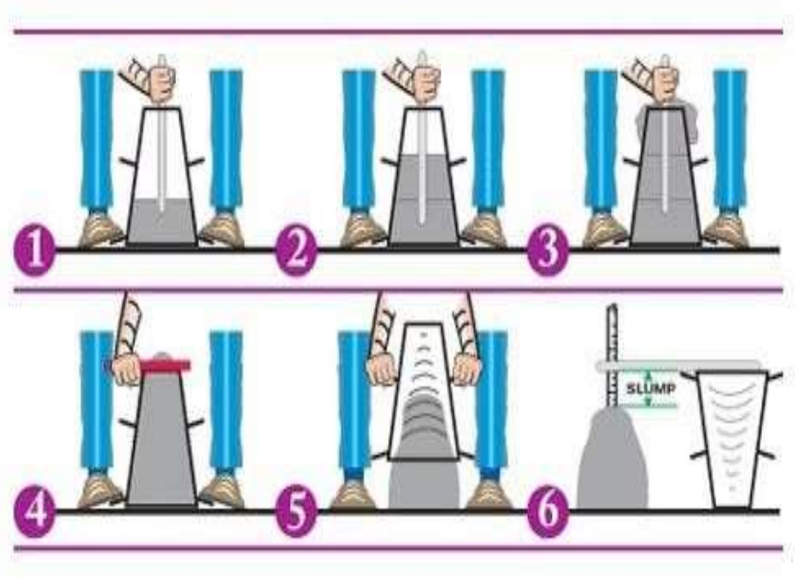
1. Slump test for Workability of Concrete-

- The slump test is perhaps the most frequently used, primarily due to the ease of the apparatus required as well as the test procedure.The slump test suggests the behavior of a compacted concrete cone below the action of gravitational forces.
- The test is carried out with a mold known as the slump cone. The slump cone is placed on a horizontal and also non-absorbent surface and full of three equal layers of fresh concrete, and each layer being tamped 25 occasions with a typical tamping rod.mold is raised vertically without disturbing the concrete cone.
- The subsidence of concrete in millimeters is known as the slump as shown in as per below figure — the concrete after the test when slumps evenly all around are called true slump.

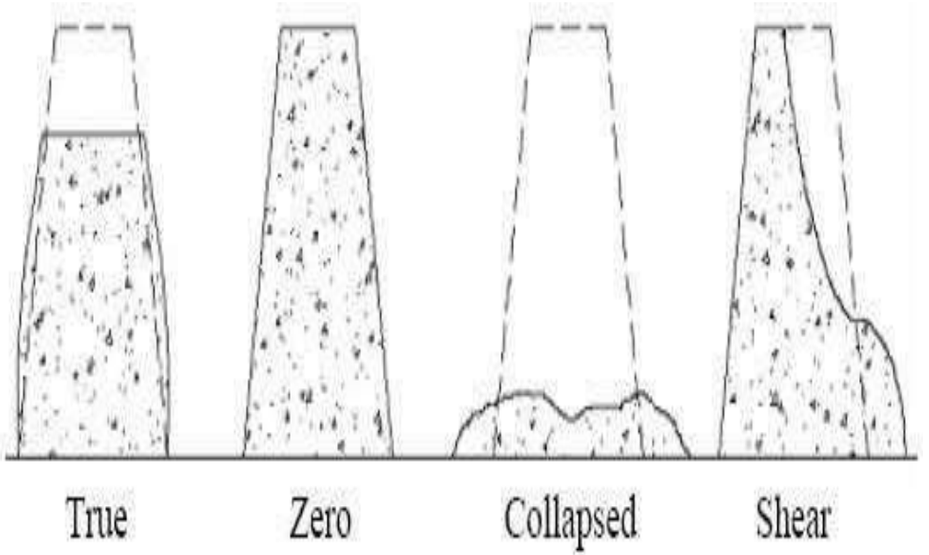


Slump Test of Concrete

- In the case of very lean concrete, one-half of the cone may slide down the other, which is known as a shear slump; also, it can collapse in case of very moist concretes..The slump test is fundamentally a ***measure of consistency*** or the wetness of this mix.
- The test is suitable Just for concretes of medium to high workabilities (i.e., having slump values of 25 mm to 125mm). For very stiff mixes having zero slump, the slump test does not indicate any difference in concretes of different workabilities.
- It must be appreciated that the different concrete of the same slump may, indeed, have different workabilities under the site conditions.But, the slump test was found to be useful in ensuring that the uniformity among different batches of allegedly similar concrete under field conditions.
- The slump test is limited to concretes with a maximum size of aggregate less than 38 mm.



- **Collapse slump :** In this case, fresh concrete collapses completely. Mix is too wet or high workability mix , slump test isn't appropriate for such mix.
- **Shear Slump:** If one-half of the cone slides down in an inclined plane, it is called a shear slump. It is an indication of lack of cohesion of the mix. Again perform the experiment to avoid shear slump .
- **True Slump:** Mix has high stiff consistency. In a true slump concrete just subsides shortly and more or less maintain the mould shape. This type of slump is most desirable.
- **Zero Slump:** If concrete maintains the actual shape of the mould, it is called zero slump which represents stiff, consistent and almost no workability.



7 WORKABILITY OF CONCRETE

7.1 The concrete mix proportions chosen should be such that the concrete is of adequate workability for the placing conditions of the concrete and can properly be compacted with the means available. Suggested ranges of workability of concrete measured in accordance with IS 1199 are given below:

Placing Conditions	*Degree of Workability*	*Slump* (mm)
(1)	(2)	(3)
Blinding concrete; Shallow sections; Pavements using pavers	Very low	*See* **7.1.1**
Mass concrete; Lightly reinforced sections in slabs, beams, walls, columns; Floors; Hand placed pavements; Canal lining; Strip footings	Low	25-75
Heavily reinforced sections in slabs, beams, walls, columns; Slipform work; Pumped concrete	Medium	50-100 75-100
Trench fill; *In-situ* piling	High	100-150
Tremie concrete	Very high	*See* **7.1.2**

NOTE—For most of the placing conditions, internal vibrators (needle vibrators) are suitable. The diameter of the needle shall be determined based on the density and spacing of reinforcement bars and thickness of sections. For tremie concrete, vibrators are not required to be used (*see also* **13.3**).

(4) Recommended value of slump for various types of construction as per ACI 211.1-91

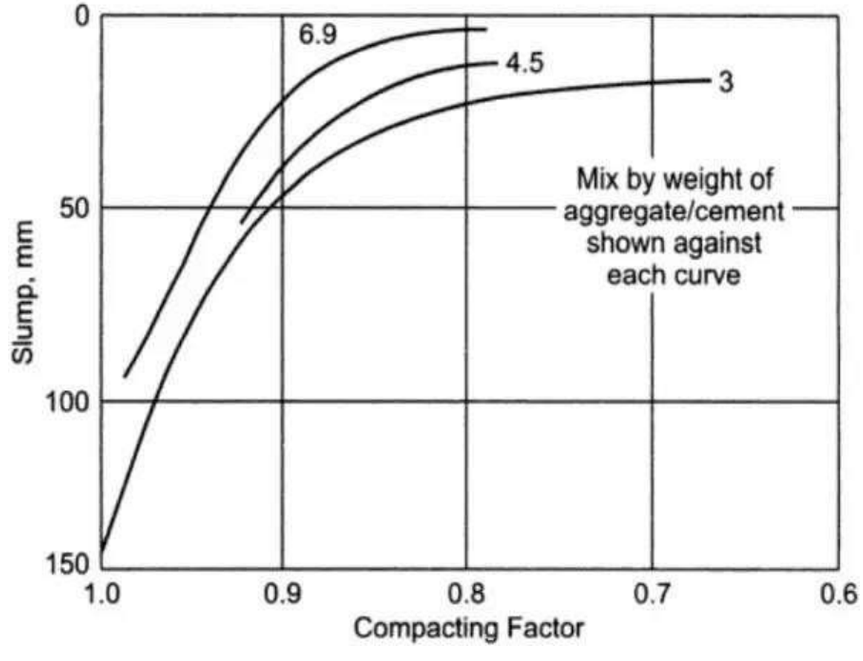
Type of construction	Range of slump (mm)
Reinforces foundation walls & footings	20-80
Plain footings,substructure wall	20-80
Beams & reinforced walls	20-100
Building columns	20-100
Pavements & slabs	20-80
Mass concrete	20-80

2. Competing Factor Test for Workability of Concrete-

- The compacting factor test gives the behavior of fresh concrete under the action of external forces.
- It measures the compatibility of concrete that is an important aspect of workability, by measuring the total amount of compaction attained for a given amount of work.
- The compacting factor test has been held to be more accurate than slump test, especially for concrete mixes of medium and low workabilities, i.e., compacting factor of 0.9 to 0.8, because the test is more sensitive and gives more consistent results.
- The test has been more popular in laboratory conditions.
- For concrete of very low workabilities of the order of 0.70 or below, the test is not suitable, because this concrete cannot be fully compacted for comparison in the manner described in the test. The relationship between a slump and compacting factor is given in as per figure.

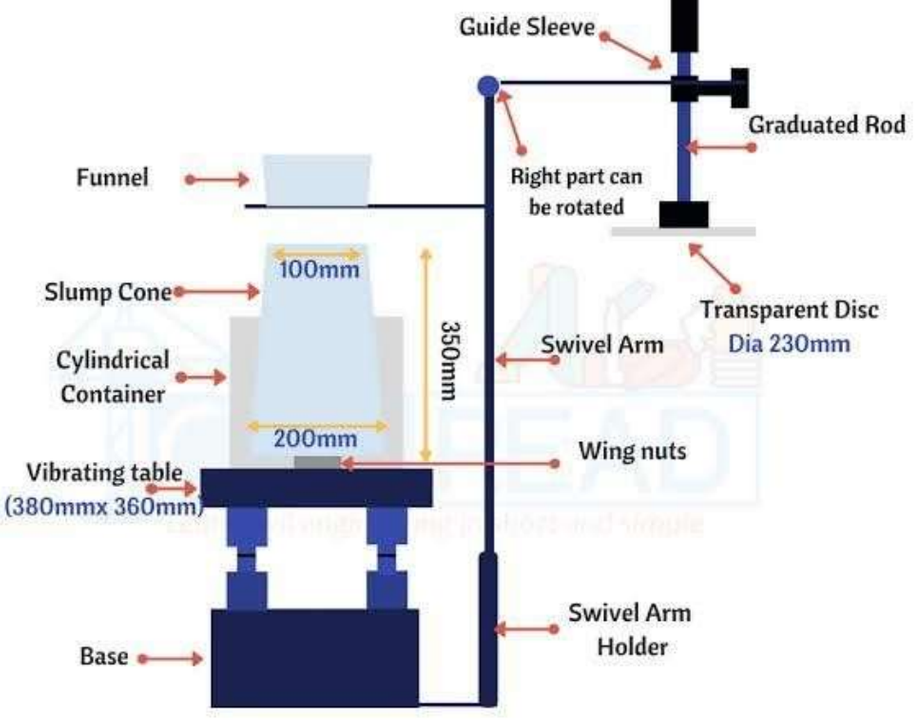
3. Vee-Bee Consistency Test for Workability of Concrete-

- The Vee-Bee **test** is suitable for stiff concrete mixes having low and very low workability Compared to the slump test and compacting factor test, the Vee-Bee test has the advantage that the concrete in the test receives similar treatment as it would in actual practice.
- The test consists in molding a fresh concrete cone in a cylindrical container mounted on a vibrating table as shown in as per the figure.

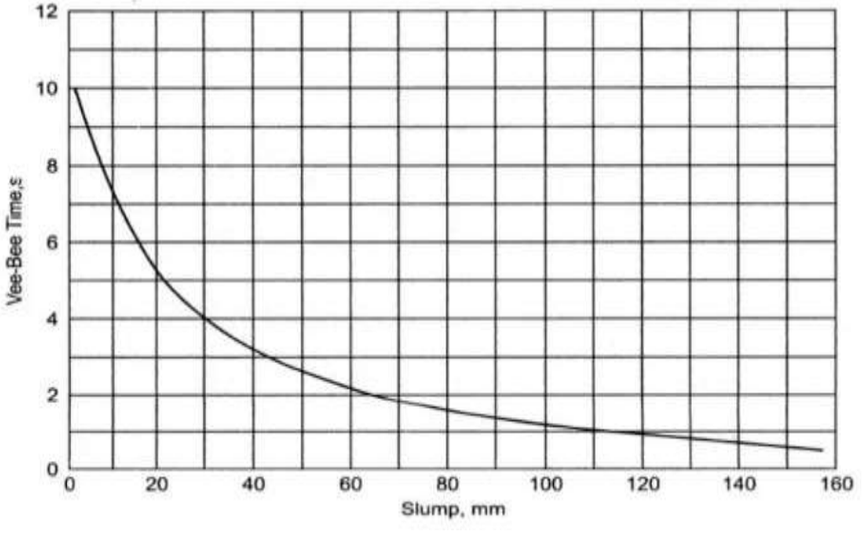


Vee-Bee Consistency Test

- The concrete cone, Even when Exposed to vibration by starting the vibrator, Begins to Devour the cylindrical container by way of Being remolded.
- The remolding is deemed complete when the cement surface becomes horizontal.
- The time necessary for the whole remolding in seconds is considered as a measure of workability and can be expressed as the number of Vee-Bee seconds.
- Since the endpoint of the test—when the concrete surface be-comes horizontal—is To be discovered visually, it introduces a source of error that is more pronounced for concrete mixes of high workability and hence records low Vee-Bee time
- For concrete of slump in excess of 125 mm, the remolding is so quick that time cannot be measured. The test is, therefore, not suitable for concrete of higher workability, i.e., a slump of 75 mm or above. An approximate relationship between a slump and Vee-Bee time is given in as per below figure.



Vee- Bee Consistometer



4. Flow Test for Workability of Concrete-

- Flow test gives the satisfactory performance for concretes of the consistencies for which the slump test can be used.
- The test consists of molding a fresh concrete cone on the top of the platform of the flow table, and in giving 15 jolts of 12.5 mm magnitudes.
- The spread of this concrete, measured as the increase in diameter of the cone, is accepted as a measure of the movement or flow of the concrete.
- The test suffers from the drawback that the concrete may scatter on the flow table with a tendency towards segregation.

■ The ***workability requirements*** for a concrete construction depends on:

- Water cement ratio
- Type of construction work
- Method of mixing concrete
- Thickness of concrete section
- Extent of reinforcement
- Method of compaction
- Distance of transporting
- Method of placement
- Environmental condition

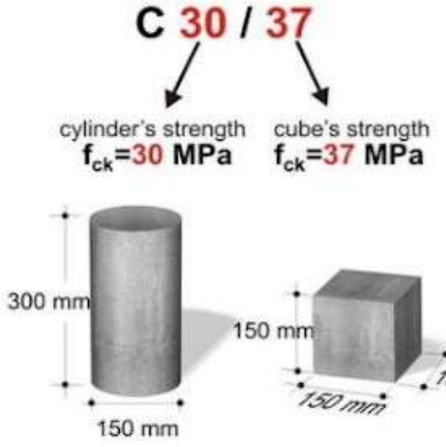
CHAPTER-05

PROPERTIES OF HARDENED CONCRETE

The principal properties of hardened concrete which are of practical importance can be listed as:

- Strength
- Permeability & durability
- Shrinkage & creep deformations
- Response to temperature variations

- Of these compressive strength is the most important property of concrete.

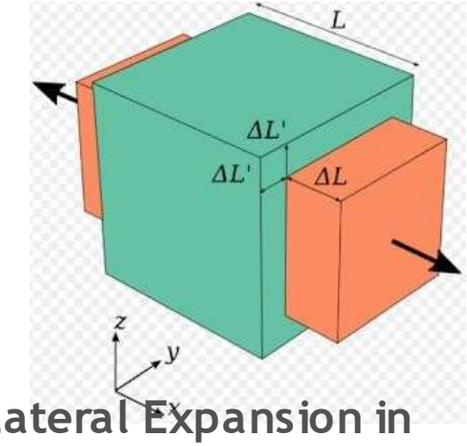


5.1.1 Cube and cylinder compressive strengths

- The Compressive strength test will result in a compressive load on the cube and the cylinder during the test procedure. This process will result in the Lateral Expansion of the sample which will result in the Poisson's ratio effect. The figure shows the compressive testing arrangement of a cube.

- The steel platens are placed above and below the specimen (cube/ cylinder) before the specimen is loaded. There no kind of lateral expansion carried out in the steel plates when compared to the concrete specimen. This means that the steel will restrain the tendency of concrete to expand in the lateral direction.

- This restrains for lateral expansion by the platen is shown in the concrete which is near to the end of the plate. The degree of restraining is depended on the friction that is actually developed.

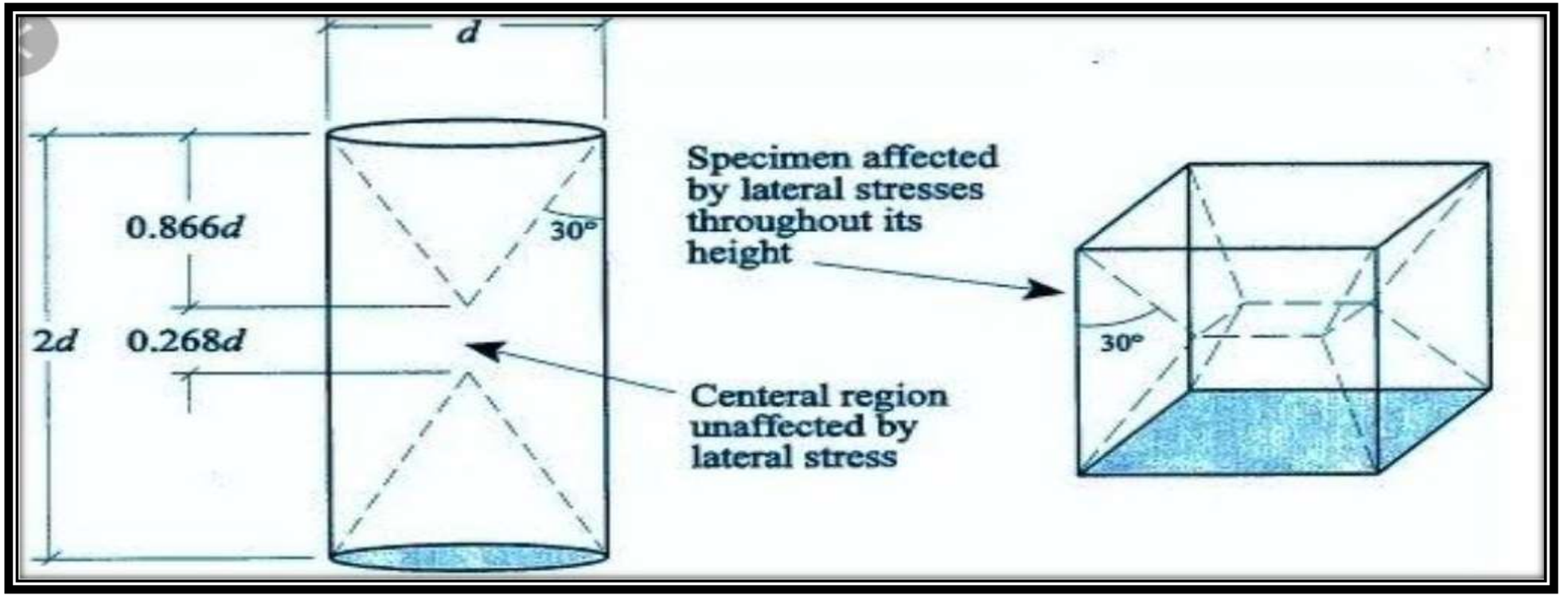


Lateral Expansion in Cube during Compression Test

- Hence under normal conditions, an element within the specimen will undergo a combination of "shear stress". This is because of the
  - Friction between the platens and the specimen – Stress 1
  - Compressive Load due to the loading action - Stress 2

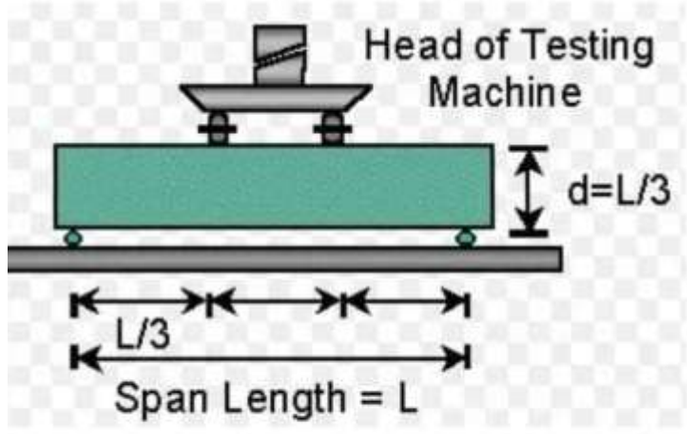
- It is observed that the combination of Stress 1 and Stress 2 will result in the axial load failure. This will result in providing a compressive strength value which is higher.

- It has been observed that the restraining effect due to friction between the specimen and the platens extends over the entire height of the cube. But in the case of the cylinder, it remains unaffected. The activity is explained in the figure-1 and figure-2.
- Hence, it is clear that the total stress that will be created in the cube will be higher compared with the cylinder specimen. This will result in a higher value of the compressive strength in cubes than the cylinder even by employing the same concrete mix.
- Hence their relation can be given as: **Compressive Strength of cylinder = 0.8 x (Compressive Strength of Cube)**

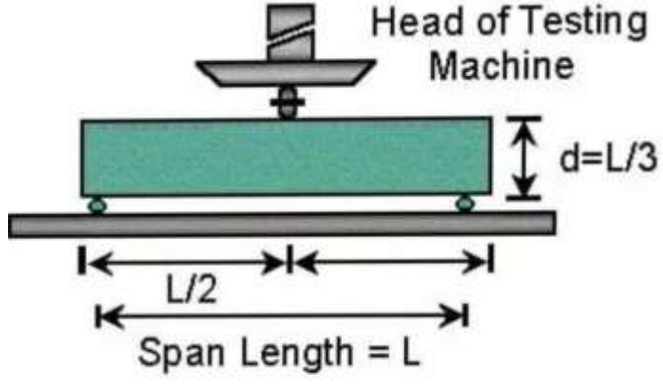


5.1.2 flexural strength of concrete:-

- Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending.
- The results of flexural test on concrete expressed as a modulus of rupture which denotes as (*MR*) in MPa or psi.
- The flexural test on concrete can be conducted using either three point load test (ASTM C78) or center point load test (ASTM C293)
- It should be noticed that, the modulus of rupture value obtained by center point load test arrangement is smaller than three-point load test configuration by around 15 percent.
- Moreover, it is observed that low modulus of rupture is achieved when larger size concrete specimen is considered.
- Furthermore, modulus of rupture is about 10 to 15 percent of compressive strength of concrete. It is influenced by mixture proportions, size and coarse aggregate volume used for specimen construction.
- Finally, the following equation can be used to compute modulus of rupture, but it must be determined through laboratory test if it is significant for the design:



Three-Point Load Test (ASTM C78)



Center Point Load Test (ASTM C293)

Where:

f_r: Modulus of rupture

f_c': concrete compressive strength

$$f_r = 7.5\sqrt{f'_c} \rightarrow \text{Equation-1}$$

Applications of Flexural Test on Concrete

Following are the applications of flexural test:

- Specifying compliance with standards
- It is an essential requirement for concrete mix design
- It is employed in testing concrete for slab and pavement construction

Factors Cause Variability in Flexural Test Results

- Concrete specimen preparation
- Specimen size
- Moisture condition of the concrete specimen
- Curing of the concrete specimen
- And whether the specimen is molded or sawed to the required size

Size of Concrete Specimen for Flexural Test

- According to ASTM the size of the specimen is 150mm width, 150mm depth and the length should not be at least three times the depth of the specimen.
- Indian standard determined the size of the concrete specimen as 150mm width, 150mm depth, and span of 700mm.
- It also states that a size of 100mm width, 100mm depth, and span of 500mm can be used if the maximum aggregate size used is not greater than 19mm.
- British standard specifies square specimen cross section with 100mm or 150mm dimension and the span ranges from four to five times specimen depth.
- However, it preferred 150mm width, 150mm depth, and span of 750mm for the specimen.

Sample Preparation of Concrete

- Determine proportions of materials including cement, sand, aggregate and water.
- Mix the materials using either by hand or using suitable mixing machine in batches with size of 10 percent greater than molding test specimen.
- Measure the slump of each concrete batch after blending.
- Place molds on horizontal surface and lubricate inside surface with proper lubricant material and excessive lubrication should be prevented.
- Pour fresh concrete into the molds in three layers.
- Compact each layer with 16mm rode and apply 25 strokes for each layer or fill the mold completely and compact concrete using vibration table.
- Remove excess concrete from the top of the mold and smoothen it without imposing pressure on it.
- Cover top of specimens in the molds and store them in a temperature room for 24 hours.
- Remove the molds and moist cure specimens at 23+/-2^{o} C till the time of testing.
- The age of the test is 14 days and 28 days and three specimens for each test should be prepared (according to Indian Code, the specimen is stored in water at 24-30^{o}C for 48hours and then tested)

Procedure of Flexural Test on Concrete

- The test should be conducted on the specimen immediately after taken out of the curing condition so as to prevent surface drying which decline flexural strength.
- Place the specimen on the loading points. The hand finished surface of the specimen should not be in contact with loading points. This will ensure an acceptable contact between the specimen and loading points.
- Center the loading system in relation to the applied force.
- Bring the block applying force in contact with the specimen surface at the loading points.
- Applying loads between 2 to 6 percent of the computed ultimate load.
- Employing 0.10 mm and 0.38 mm leaf-type feeler gages, specify whether any space between the specimen and the load-applying or support blocks is greater or less than each of the gages over a length of 25 mm or more.
- Eliminate any gap greater than 0.10mm using leather shims (6.4mm thick and 25 to 50mm long) and it should extend the full width of the specimen.
- Capping or grinding should be considered to remove gaps in excess of 0.38mm.
- Load the specimen continuously without shock till the point of failure at a constant rate (Indian standard specified loading rate of 400 Kg/min for 150mm specimen and 180kg/min for 100mm specimen, stress increase rate 0.06+/-0.04N/mm^2.s according to British standard).
- The loading rate as per ASTM standard can be computed based on the following equation: $$r = \frac{Sbd^2}{L}$$ → Equation-2

Where:

- *r*: loading rate, *S*: rate of increase of extreme fiber, *b*: average specimen width, *d*: average specimen depth, *L*: span length
- Finally, measure the cross section of the tested specimen at each end and at center to calculate average depth and height.

Computation of Modulus of Rupture

The following expression is used for estimation of modulus of rupture:

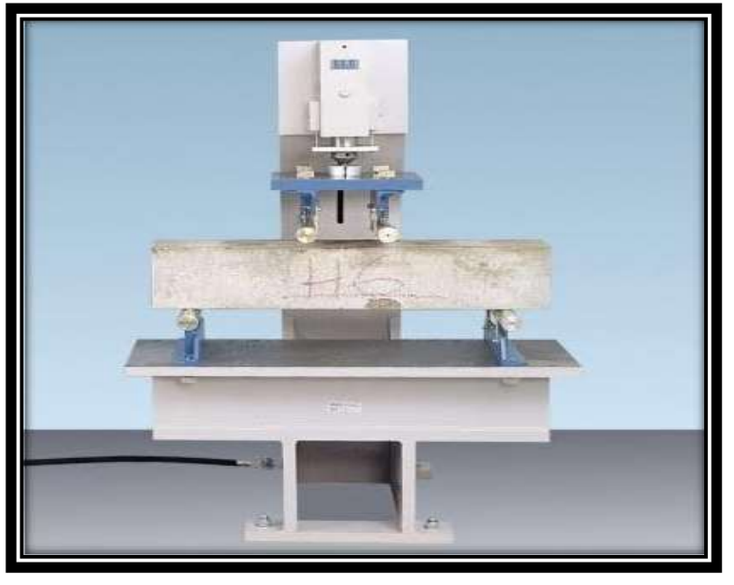
$$MR = \frac{3PL}{2bd^2} \rightarrow \text{Equation-3}$$

Where:

MR: modulus of rupture

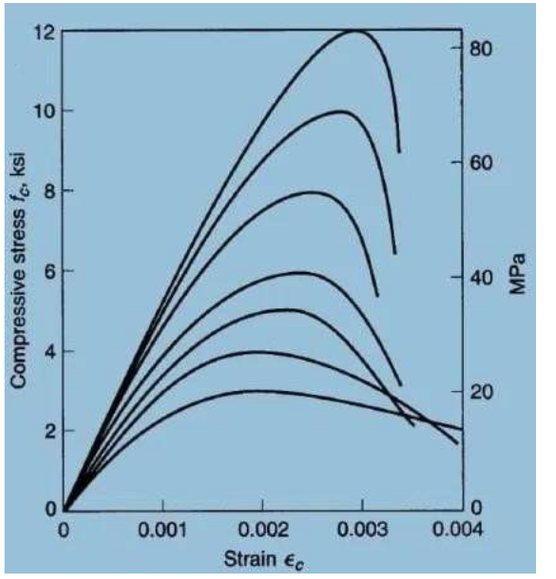
P: ultimate applied load indicated by testing machine, *L*: span length

b: average width of the specimen at the fracture, *d*: average depth of the specimen at the fracture



5.1.3 Stress-strain and elasticity:-

- Stress strain curve of concrete is a graphical representation of concrete behavior under load. It is produced by plotting concrete compress strain at various interval of concrete compressive loading (stress). Concrete is mostly used in compression that is why its compressive stress strain curve is of major interest.

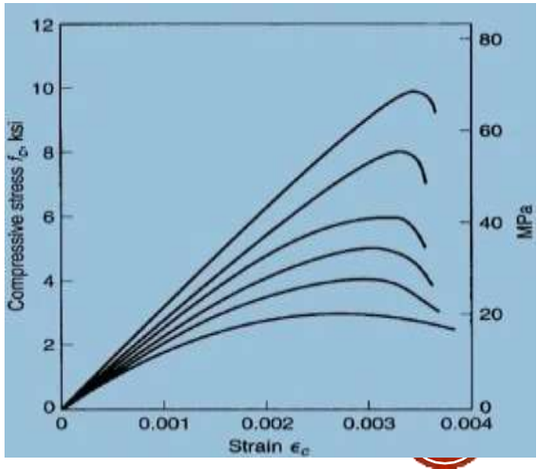


- The stress and strain of concrete is obtained by testing concrete cylinder specimen at age of 28days, using compressive test machine. The stress strain curve of concrete allows designers and engineers to anticipate the behavior of concrete used in building constructions. Finally, the performance of concrete structure is controlled by the stress strain curve relationship and the type of stress to which the concrete is subjected in the structure.

1. Straight or Elastic Portion

- Initially, all stress strain curves (Fig.1 and Fig. 2) are fairly straight; stress and strain are proportional. With this stage, the material should be able to retain its original shape if the load is removed. The elastic range of concrete stress strain curve continues up to $0.45f_{ck}$ (maximum concrete compressive strength). The slope of elastic part of stress strain curve is concrete modulus of elasticity. The modulus of elasticity of concrete increases as its strength is increased. ACI Code provides equations for computing concrete modulus of elasticity.

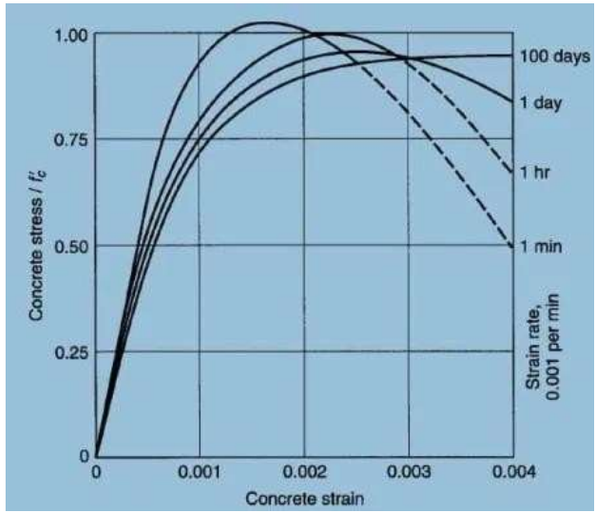
2. Peak Point or Maximum Compress Stress Point



- The elastic range is exceeded and concrete begin to show plastic behavior (Nonlinear), when a load is further increased. After elastic range, the curve starts to horizontal; reaching maximum compress stress (maximum compressive strength). For normal weight concrete, the maximum stress is realized at compressive strain ranges from 0.002 to 0.003. however, for lightweight concrete, the maximum stress reached at strain ranges from 0.003 to 0.0035.The higher results of strain in both curves represent larger strength. For normal weight concrete, the ACI Code specified that, a strain of 0.003 is maximum strain that concrete can reach and this value used for design of concrete structural element. However, the European Code assumes concrete can reach a strain of 0.0035, and hence this value is used for the design of concrete structural element.

3. Descending Portion

- After reaching maximum stress, all the curves show descending trend. The characteristics of the stress strain curve in descending part is based on the method of testing. Long stable descending part is achieved if special testing procedure is employed to guarantee a constant strain rate while cylinder resistance is decreasing. However, if special testing procedure is not followed, then unloading after peak point would be quick and the descending portion of the curve would not be the same.

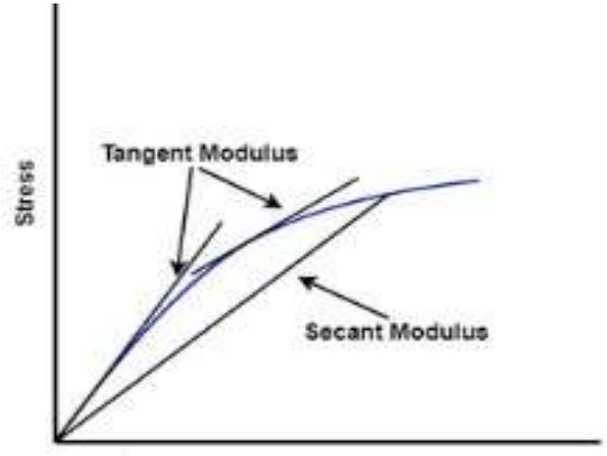


5.1.4 Modulus of Elasticity of Concrete:-

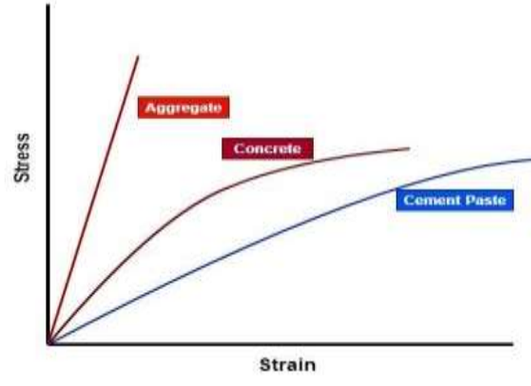
- Modulus of elasticity of concrete is the measurement of the stiffness of the concrete which is a good indicator of strength.
- At a higher value of modulus of elasticity, the concrete can withstand higher stress and become brittle. In general, Concrete has an elastic modulus in a range of 30 to 50 GPa.
- In recent years, design codes have specified a required minimum modulus of elasticity of concrete to be met. The objective is to limit the excessive deformation and sway in tall buildings.
- The expression for the modulus of elasticity of concrete, recommended by IS 456:2000 is

$$E_c = 5000\sqrt{f_{ck}}$$

where f_{ck} is the characteristic strength of concrete.



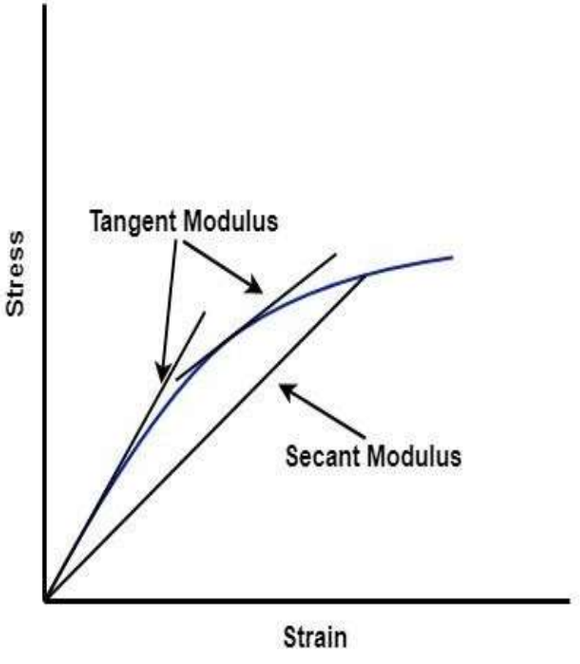
- Concrete is a heterogeneous, multi-phase material, whose behaviour is influenced by the elastic properties and morphology of its component materials. So, the stress-strain curve does not exactly does not follow Hooke's law.
- The components of concrete i.e. cement paste and aggregates, when individually subjected to loading, they show almost linear stress-strain relation.



▪Types of Modulus of Elasticity of Concrete

Static Modulus of elasticity

- Static modulus of elasticity of concrete is defined as the slope of the stress-strain curve under uniaxial tension or compression loading.
- When we test a concrete specimen in tension or compression, the following stress-strain relation is observed.
  - Young's modulus of elasticity can be applied only to the linear portion of the stress-strain curve. When the curve for concrete is not straight any point, the modulus of elasticity is found out reference to a tangent drawn the curve at the origin. This is called the **initial tangent modulus**.
  - But it gives a satisfactory result at a low-stress value only. It is of no practical importance because it applies only to very small changes in load at which the tangent modulus is considered.
  - The strain in the specimen depends on the speed of loading. So it is difficult to differentiate between elastic and creep strains. For ease in understanding, any strain occurring during loading is called elastic and any subsequent increase in strain is called creep.
  - The modulus of elasticity of concrete which includes both strains is called **Secant modulus** or chord modulus. It is the common elastic modulus of concrete. It is given by the slope of the line drawn connecting a specified point on the curve to the origin of the curve.
  - **The secant modulus is a static modulus because it is determined on a test specimen.**
  - The secant modulus decreases with an increase in stress. So the stress at which secant modulus is determined must be mentioned.



Dynamic modulus of concrete

- Dynamic modulus of elasticity of concrete represents the progressive changes in the state of a concrete specimen. The change can be observed by determining the fundamental resonant frequency of the specimen at appropriate stages of the investigation.

5.1.5 **Phenomena of creep and shrinkage:-**

Throughout the course of time, structural concrete may undergo wear and tear, which may cause cracking, stresses or deflections that will affect the in-service behavior of the reinforced concrete structures. This time-dependent phenomenon in concrete that we observed is called the creep and shrinkage.

Creep

- Creep is the gradual increase in a strain of a structural member which is subjected to certain loading over a period of time. When the concrete is loaded in compression. If this load remains on the member, creep strain developed with time.
- The main factors affecting creep strain are the concrete strength and mixture, the type of aggregate, curing, the relative humidity and the duration of the sustained loading.

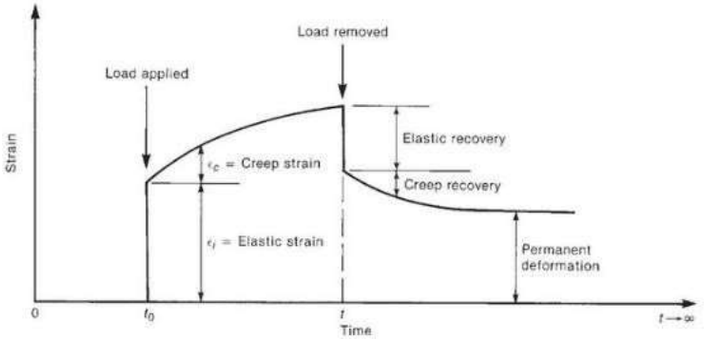
ϵ_{cc} = (Stress/ Et)*phi

where:

creep strain in concrete, ϵ_{cc}

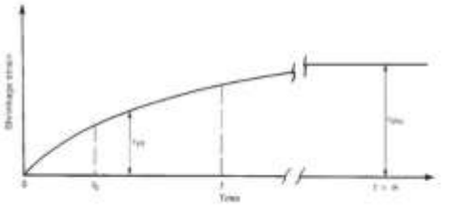
Et: is the modulus of elasticity of concrete at the age of loading *t*

Φ is the creep coefficient which can be taken from figure 7.1 of BS8110: Part 2



Shrinkage

- Shrinkage is the contraction that occurs in concrete when it dries and hardens due to moisture content evaporation. The amount of shrinkage increases with time. The aggregate contents present in concrete are the most important factors influencing shrinkage. This is because the larger the aggregate, the lower is the shrinkage and the higher is the aggregate content, the lower the water-cement ratio and workability are. A decrease in ambient humidity also increases shrinkage.



- On the other hand, Shrinkage has been discussed in BS8110: Part 2, section 7.4. The values obtained from the shrinkage strain are used in the deflection calculation. An estimate of the shrinkage of the symmetrically reinforced concrete section may be obtained fro m: (ϵ_{sh}/ (1+Kp))

  where: ϵ_{sh} is the shrinkage of the plain concrete

  ϱ (rho) is the area of steel relative to that of concrete

  K is a coefficient, taken as 25 for internal exposure and as 15 for external exposure.

- Hardened Concrete undergoes in three types of shrinkage that are important with respect to its dimensional stability:
  1. Plastic shrinkage.
  2. Drying shrinkage.
  3. Thermal shrinkage.

1. Plastic Shrinkage.

- This is the shrinkage that the freshly placed concrete undergoes till it sets completely. It may also be called initial shrinkage.Such a volumetric change is due to loss of water from the fresh concrete due to evaporation, bleeding, seepage and soaking by formwork.
- Excessive shrinkage at initial stages may develop extensive cracking in the concrete on the setting. Therefore, all precautions should be taken to avoid excessive loss of water due to evaporation.

2. Drying Shrinkage :

- As the concrete has completely set and hardens, some further shrinkage may result because of contraction of gel-structure due to further loss of moisture, or drying.
- This kind of shrinkage is practically an essential and irreversible property of concrete. It has to be met with by careful design of reinforcement to avoid its ill effects.

3.Thermal Shrinkage.:- This may be due to fall in temperature of concrete from the time it is laid till it sets completely. Thus, when concrete laid at 30°C cools down to 15°-18°C, some shrinkage may be expected. It may be negligible on its own account. But when added to drying shrinkage, it becomes necessary.

5.1.6 Durability

- Environmental forces such as weathering, chemical attack, heat, freezing and thawing try to destroy concrete. The period of existance of concrete without getting adversely affected by these forces is known as durability. Generally dense and strong concretes have better durability. The cube crushing strength alone is not a reliable guide to the durability. Concrete should have an adequate cement content and should have low water cement ratio.

5.1.7 Impermeability

- This is the resistance of concrete to the flow of water through its pores. Excess water during concreting leaves a large number of continuous pores leading to the permeability.
  Since the permeability reduces the durability of concrete, it should be kept very low by using low water cement ratio, dense and well graded aggregates, good compaction and continuous curing at low temperature conditions. The cement content used should be sufficient to provide adequate workability with low water cement ratio and the available compaction method.

5.1.8 Chloride attack on concrete

Chloride attack on concrete is one of the important aspects of durability of concrete. It primarily affects the reinforcement of concrete and cause corrosion. Chlorides can be introduced into the concrete either during or after construction as follows.

Before construction Chlorides can be admitted in admixtures containing calcium chloride, through using mixing water contaminated with salt water or improperly washed marine aggregates.

After construction Chlorides in salt or sea water, in airborne sea spray and from de-icing salts can attack permeable concrete causing corrosion of reinforcement.

The chloride in the presence of water and oxygen reacts with alkaline protected layer around the reinforcement and removes it.

- **Sulphate attack on concrete**

- Most of the soil types contains sulphates in the form of calcium, magnesium, sodium, ammonium and potassium. They occur in soil or ground water. When a concrete structure is built on these types of soils, they may attack the concrete.
- Generally sulphates in solid form do not attack the concrete severely but when they are in liquid form they pass into the voids of concrete and react with hydrated cement products. Calcium sulphate causes minimum damage because of its low solubility while magnesium sulphate causes maximum damage.
- Most of the sulphates attacks calcium hydroxide and hydrated calcium aluminates present in the concrete and results in changing the volume of cement paste in concrete. Hence deterioration of concrete structure takes place. Along with calcium hydroxide, Magnesium sulphate also reacts with hydrated calcium silicate and makes concrete into powdered mass.

Precautions

- Concrete with low water cement ratio is less affected by magnesium sulphate while high water cement ratio concrete is highly affected
- Use Super sulphate Cement and Sulfate Resisting cement in place of OPC.

Acid attack on concrete

- Acids can attack concrete easily since concrete is not fully resistant against acids. Some acids like oxalic acid, phosphoric acids are not harmful to the concrete. Calcareous aggregates are more affected by acids while siliceous aggregates are good resistant.
- The damage level is purely depends upon the pH of the acid solution. Damage is very severe if the pH value is very low. If they reach reinforcement through crack or pores, they will cause corrosion of bars and cracking of concrete will occur.

Prevention of acid attack

- To prevent acid attack good dense concrete with adequate cover is required and sulphate-resistant cements should be used.

Efflorescence:-

- Efflorescence in concrete is a whitish coloured powdered deposition of salts on the concrete surface that is formed due to evaporation of water from the concrete. It is caused when water soluble salts are present in the concrete material, which comes on to the surface while evaporation of water from the concrete.

Causes for Formation of Efflorescence in Concrete

The formation of efflorescence in concrete is factored by many external factors.

- Presence of salts in one of the materials of concrete. Commonly salts are found in the fine aggregate or sand taken from the river beds.
- If the concrete is not cured properly, the hydration process is incomplete on which the un-hydrated products near the surface form the efflorescence on the surface of concrete.
- Slow rate of evaporation of water allowing time for salts to permeate to the surface (this is why efflorescence tends to be more of a problem during the winter months; in summer, high temperatures may cause evaporation and hence depositing of salts within the concrete rather than on the surface)

- If the water content in the concrete mix is more, it makes the concrete porous. Thus allowing the path for water and salts to come to the surface and for efflorescence.
- In wet conditions such as rainy season, the surplus water acts as a medium for the salts to transport to the surface of concrete and form crystalline white powder.
- Variability of concrete (compaction or curing) can result in localised problems where water can permeate more easily through the concrete.

- **Type of Salts in Efflorescence**
- **Calcium Sulphate** A common efflorescence salt source in brick ● **Sodium Sulphate** Often seen in cement-brick reactions
- **Potassium Sulphate** Noticeable in many cement-brick reactions
- **Calcium Carbonate** May be discovered in mortar or concrete backing ●**Sodium Carbonate** Frequently seen in mortar
- **Potassium Carbonate** Like sodium carbonate, commonly found in mortar
- **Vanadyl Sulphate** Usually found in brick b ● **Manganese Oxide** Often present in brick.

Prevention of Efflorescence in Concrete

1. The preventive methods that can be used to avoid efflorescence in concrete are,
2. Inclusion of Class-F fly ash or metakaolin can lock up significant amounts of calcium hydroxide in the concrete.
3. Installing vapour barrier to prevent the movement of moisture from the sub grade to the surface of a slab.
4. Application of sealers and coatings can prevent surface water from penetrating slabs.
5. Waterproofing agents to be used to reduce permeability of concrete.
6. Making the concrete denser will reduce the permeability of concrete to a greater extent.
7. Preventing the hardened concrete from exposure to moisture by maintaining surface sealers and site drainage, and from rising groundwater by placing a plastic membrane under slabs.
8. Avoiding the concrete from premature drying.
9. Use of concrete ingredient such as aggregate, cement and sand which contains very less amount of salts in it.

- Removal of efflorescence can be done in 3 methods,

1. Pressurised Water

- Efflorescence in the concrete can be removed using the pressurised water jet. Applying pressurised water may dissolve efflorescence quickly. But care must be taken that the water after removing of efflorescence is completely dried off. If not dried, the same water can cause efflorescence to reappear.

2. Brushing

- Some type of efflorescence that are easily removable can be easily removed using a stiff?bristle broom or brush. If the result is not satisfactory by dry brushing, scrub with clean water then lightly rinse the surface.

3. Dilute Acid Solution

- Concentrated acid is not recommended to be applied on concrete, diluted proportion of 1:20 is used. the surface in which the acid is applied must be moist but without any free water. The applied solution should be allowed to react on the concrete surface for 10 to 15 minutes. The surface should then be thoroughly rinsed and scrubbed with lots of clean water. Repeat rinsing at least twice or until all traces of the acid solution have been removed.
- Washing with acid may cause colour variations and alter the surface texture. For coloured finishes a more dilute acid solution (2% or 1 part acid to 50 parts water) may be required. A small trial area should be done first to assess the results.
- Proper safety to be followed while doing this procedure. Ensure good ventilation and avoid contact between the acid and the reinforcement.

- **Acids used in Removal of Efflorescence in Concrete**
  1. Hydrochloric acid.
  2. Phosphoric acid.
  3. Phosphoric acid.
  4. Prepackaged efflorescence removers.

Applying of Coating to Prevent Efflorescence in Concrete

- Clear water repellents, silicone and acrylic coatings also may help you remove efflorescence as well. The coating will absorb water across a masonry surface and prevent efflorescence from recurring. Plus, the combination of warm water and white wine vinegar has been shown to eliminate efflorescence.
- Application of sealant coat is done in 3 steps,

1. Rinsing of Concrete

- Rinse the building surface with water. If the surface is outdoors, you can use a hose to spray down the surface. Or, if the surface is indoors, you can use a spray bottle filled with water to rinse the surface thoroughly.

2. Applying the Solution

- Spray the cleaning solution onto the building surface and allow it to sit for several minutes. If necessary, you may need to apply multiple coats of the cleaning solution to the surface for optimal results.

3. Rinsing of Concrete Again

- Rinse the building surface with water one last time. Then, use a fresh, dry cloth to clean the surface. Ensure the surface is dry to minimize the risk of ongoing efflorescence.
- Apply coatings roughly 1/8 in. to 1/4 in. below the surface of the building material. This will prevent water from evaporating and passing through the treated area as vapour and soluble salts.

Properties Of Hardened concrete

Following are the properties of hardened concrete:

1. Strength of concrete
2. Concrete Creep
3. Shrinkage
4. Modulus Of Elasticity
5. Water tightness (impermeability)
6. Rate of Strength gain of Concrete

1. Strength:

- The strength of concrete is basically referred to compressive strength and it depends upon three factors.

  1- Paste Strength

  2 Interfacial Bonding

  3 Aggregate Strength

1. Paste strength:

- It is mainly due to the binding properties of cement that the ingredients are compacted together. If the paste has higher binding strength, higher will be strength of concrete.

2. Interfacial bonding:

- Interfacial bonding is very necessary regarding the strength. Clay hampers the bonding between paste and aggregate. The aggregate should be washed for a better bonding between paste and aggregate.

3. Aggregate strength:

- It is mainly the aggregate that provide strength to concrete especially coarse aggregates which act just like bones in the body. Rough and angular aggregate provides better bonding and high strength.
- **Factors affecting Strength of concrete:**
- Following are the factors that affect the strength of concrete:

1. Water-Cement ratio
2. Type of cementing material
3. Amount of cementing material
4. Type of aggregate
5. Air content
6. Admixtures

1. Water-Cement ratio:

It is water cement ratio that basically governs the property of strength. Lesser the water cement ratio, greater will be strength.

2. Type of cement:

Type of cement affect the hydration process and therefore strength of concrete. Amount of cementing material: it is the paste that holds or binds all the ingredients. Thus greater amount of cementing material greater will be strength.

3. Type of Aggregate::- Rough and angular aggregates is preferable as they provide greater bonding.

4. Admixtures:

Chemical admixtures like plasticizers reduce the water cement ratio and increase the strength of concrete at same water cement ratio. Mineral admixtures affect the strength at later stage and increase the strength by increasing the amount of cementing material.

2.Creep in Concrete:- Concrete creep is defined as: deformation of structure under sustained load. Basically, 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. Creep does not necessarily cause concrete to fail or break apart. Creep is factored in when concrete structures are designed.

3.Shrinkage:- Concrete is subjected to changes in volume either autogenous 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.

4. 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.
- The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops.
- The elastic modulus of the hardened paste may be in the order of 10-30 GPa and aggregates about 45 to 85 GPa. The concrete composite is then in the range of 30 to 50 GPa.

5. Water Tightness

- Watertightness is the ability of concrete to keep water out or in. **Watertight** is a versatile range of specialized ready mix concretes designed to protect a structure from water ingress or to retain water within a structure.
- Water-tight concrete, or concrete made water-tight by some kind of waterproof coating, is frequently required, either for inclosing a space which must he kept dry, or for storing water or other liquids. Concrete, even when most carefully prepared from materials of the highest grade, is never of itself completely waterproof.

6.Rate of Strength Gain of Concrete:- Strength can be defined as ability to resist change. One of the most valuable properties of the concrete is its strength. Strength is most important parameter that gives the picture of overall quality of concrete. Strength of concrete usually directly related to cement paste.

CHAPTER-6

CONCRETE MIX DESIGN

6.1 A) Introduction

- Concrete mix design is process of preparation of concrete with suitable proportion of ingredients to meet the required strength and durability of concrete structure.
- Every ingredient of concrete consists different properties so, it is not an easy task to get economical and good concrete mix.
- Concrete Mix Design means, determination of the proportion of the concrete ingredients i.e. Cement, Water, Fine Aggregate, Coarse Aggregate which would produce concrete possessing specified properties such as workability, strength and durability with maximum overall economy.

B) DATA REQUIRED for Mix Design(IS 10262 - 2009) :-

a) Grade designation
b) Type of cement;
c) Maximum nominal size of aggregate
d) Minimum cement content
e) Maximum water-cement ratio
f) Workability
g) Exposure conditions as per Table 4 and Table 5 of IS 456
h) Maximum temperature of concrete at the time of placing
i) Method of transporting and placing
j) Early age strength requirements, if required
k) Type of aggregate
l) Maximum cement content; and
m) Whether an admixture shall or shall not be used and the type of admixture and the condition of use.

6.2 Nominal mix concrete &design mix concrete:-

1. Nominal Concrete Mix

- Nominal concrete mix are low grade concrete mixes which are used for small and unimportant works. In this method, fine aggregate quantity is fixed irrespective of cement and coarse aggregate proportions. Hence, the quality of concrete mix will be varied and required strength may not be obtained.
- In Nominal mix design water-cement ratio also not specified. Grades of concrete M20 and below are prepared by the Nominal mix design. For higher grade designed concrete mix is preferred.

2. Designed Concrete Mix

- The designed concrete mix does not contain any specified ranges in proportions. The design is done according to the requirements of concrete strength. So, we can achieve the desirable properties of concrete either it is in fresh stage or in hardened stage.
- The fresh concrete properties like workability, setting time and hardened concrete properties like compressive strength, durability etc. are attained surely by this method. Use of additives like admixtures, retarders etc. other than basic ingredients are used to improve the properties of mix.
- Using design concrete mix, one can design various grades of concrete from as low as M10 grade to higher grades such as M80, M100 can also be prepared. The workability requirements of each mix can also meet using this method from zero slump to the 150 mm slump. Each mix prepared is tested in laboratory after hardening to verify whether it meet the requirement or not.

Advantages of Using Design Mix Concrete

- High-strength concrete and high-performance concrete design are possible
- Concrete can be designed for a variety of environmental conditions and requirements.
- Different varieties of concrete can be prepared such as flyash concrete, pumpable concrete etc.
- Different properties of the materials such as moisture content, fineness, grading are considered in calculation.
- Very accurate & Cost-effective.

Advantages of using Nominal Mix Concrete over Design Mix concrete

- They are easy to design and manufacture
- Batching of materials is easier using pans and batching boxes.
- This method can be easily understood by the workers and followed on the site.

Disadvantages

- Materials calculated from the Nominal mix method are not as accurate as the Design mix method
- Grades more than M20 cannot be designed.
- Concrete cannot be adjusted to suit environmental or construction requirements
- They are not as cheap as the Design mix concrete method when prepared in large quantiles.
- High performance or High strength concrete cannot be produced.
- It is dangerous to add compounds such as fly ash or super plasticizers because the calculation does not take these things into account.
- Not Suitable for producing Ready Mix Concrete

6.3 Basic consideration for concrete mix design, Methods of proportioning concrete mix – I.S Code method of mix design(I.S.10262)

- To produce concrete of required strength and properties, selection of ingredients and their quantity is to be found which is called concrete mix design. Proper mix design will solve every problem arises in concrete while placing or curing etc.
- The mix design also helps to produce economical concrete. Generally, cement is more costly than other ingredients of concrete. So, quantity and quality of cement is designed by proper mix design concept.
- **Concrete mix design concept is majorly depending upon the following**
  - Strength and durability
  - Workability
  - Economy
  - specifications

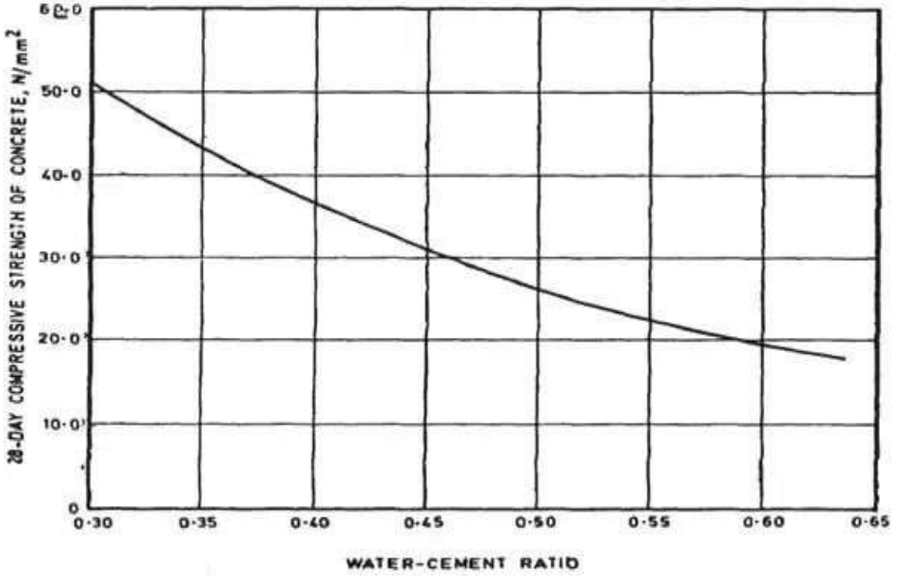
Concrete Mix Design Procedure as per is 10262 – 2009

- **Procedure for concrete mix design requires following step by step process:**
  1. Calculation of ***target strength*** of concrete
  2. Selection of ***water-cement ratio***
  3. Determination of ***aggregate air content***
  4. Selection of ***water content for concrete***
  5. Selection of ***cement content for concrete***
  6. Calculation of ***aggregate ratio***
  7. Calculation of ***aggregate content for concrete***
  8. Trial mixes for ***testing concrete mix design strength***

1: Calculation of Target Strength of Concrete

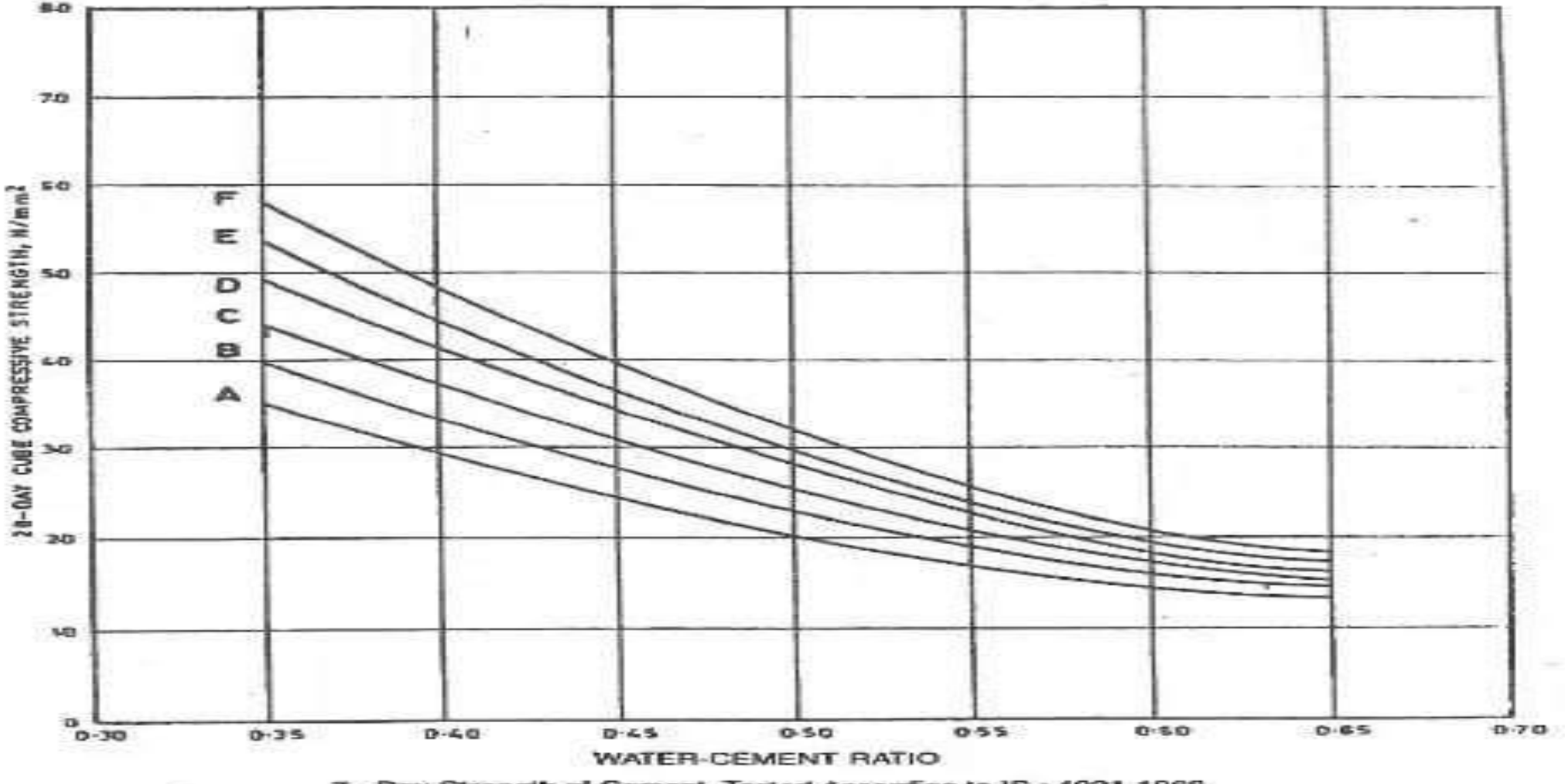
- Target strength is denoted by f_t which is obtained by characteristic compressive strength of concrete at 28 days (f_{ck}) and value of standard deviation (s) **$f_t = f_{ck} + 1.65\ s$**

Grade of Concrete	Standard deviation (N/mm^2)
M10 & M15	3.5
M20 & M25	4.0
M30,M35,M40,M45 & M50	5.0



2: Selection of Water-Cement Ratio

- Ratio of the weight of water to weight of cement in the concrete mix is water-cement ratio. It is the important consideration in concrete mix design to make the concrete workable. Water cement ratio is selected from the below curve for 28 days characteristic compressive strength of concrete.
- we can determine the water-cement ration from the 7-day concrete strength, the curves are divided on the basis of strength from water cement ratio is decided. Which is observed from the below graph.



7 - Day Strength of Cement, Tested According to IS : 4031-1968

A = 21.6 - 25.0 N/mm²

B = 25.0 - 29.8 N/mm²

C = 29.8 - 35.0 N/mm²

D = 35.0 - 41.5 N/mm²

E = 41.5 - 48.0 N/mm²

F = 48.0 - 53.4 N/mm²

3: Determination of Aggregate Air content

- Air content in the concrete mix is determined by the nominal maximum size of aggregate used. Below table will give the entrapped air content in percentage of volume of concrete.

Nominal maximum size of aggregate	Air content (% of volume of concrete)
10mm	5%
20mm	2%
40mm	1%

4: Selection of Water Content for Concrete

- Select the water content which is useful to get required workability with the help of nominal maximum size of aggregate as given in below table. The table given below is used when only angular shaped aggregates are used in concrete as well as the slump should be 25 to 50mm.

Nominal maximum size of aggregate	Maximum water content
10mm	208
20mm	186
40mm	165

- If the shape of aggregate or slump value is differing from above, then some adjustments are required as follows

Condition	Adjustment
Sub angular aggregate	Reduce the selected value by 10%
Gravel with crushed stone	Reduce the selected value by 20kg
Rounded gravel	Reduce the selected value by 25kg
Using plasticizer	Decrease the selected value by 5-10%
Using superplasticizer	Decrease the selected value by 20-30%
For every increment of 25mm slump	Increase the selected value by 3%

5: Selection of Cement Content for Concrete

- Water – cement ratio is determined in step2 and quantity of water is determined in step -4. So, we can easily calculate the quantity of cement from these two conditions. But, the value obtained should satisfy the minimum conditions as given in the below table. The greater of the two values is decided as quantity of cement content.

Cement Content for Plain Cement Concrete

Exposure	Plain Cement Concrete (P.C.C)		
	Minimum Cement Content Kg/m³	Max Free Water – Cement Ratio	Minimum Grade of Concrete
Mild	220	0.6	-
Moderate	240	0.6	M15
Severe	250	0.5	M20
Very severe	260	0.45	M20
Extreme	280	0.4	M25

Cement Content for Reinforced Concrete

Exposure	Reinforced Cement Concrete (RCC)		
	Minimum Cement Content Kg/m³	Max Free Water – Cement Ratio	Minimum Grade of Concrete
Mild	300	0.55	M20
Moderate	300	0.5	M25
Severe	320	0.45	M30
Very severe	340	0.45	M35
Extreme	360	0.4	M40

7: Calculation of Aggregate Content for Concrete

- We already determine the coarse aggregate volume ratio in the total aggregate volume. So, it is very easy that, 1 – volume of coarse aggregate will give the volume of fine aggregate. Alternatively, there are some formulae to find the volume of fine and coarse aggregates as follows.

$$V = [W + \frac{C}{Gc} + (\frac{1}{(1-P)} \; X \; \frac{F.A}{Gf})] \times \frac{1}{1000}$$

- **Mass of fine aggregate is calculated from below formula**
- **Similarly, mass of coarse aggregate is calculated from below formula**

$$V = [W + \frac{C}{Gc} + (\frac{1}{P} \; X \; \frac{C.A}{Gca})] \times \frac{1}{1000}$$

- .Where, V = volume of concrete W = water content C = cement content Gc = sp. Gravity of cement P = aggregate ration obtained in step6 F.A & C.A = masses of fine and coarse aggregates Gf & Gca = sp. Gravities of fine and coarse aggregates.

8: Trial Mixes for Testing Concrete Mix Design Strength

- Based on the values obtained above, conduct a trail test by making at least 3 cubes of 150mm size as per above standards. Test that cubes and verify whether the required strength is gained or not. If not, redesign the mix with proper adjustments until required strength of cube occurs.

Difference between Design mix and Nominal Mix concrete

Nominal Mix	Design Mix
1. The nominal mix is site-level mixing small concrete mixer can be used to mix the ingredients.	1. The design mix is designed from a ready mix concrete plant that is RMC plant.
2. Mix Design:- There are many grades of nominal mix concrete like M-5, M-7.5, M-10, M-15, and M-20.	2. Mix design:- Design mix is a process to prepare the concrete by testing all necessary properties (like properties of cement, fine aggregate and coarse aggregate) of concrete ingredients.
3. Tests:- For a nominal mix, no laboratory tests are conducted.	**3. Tests:** The design mix is based on laboratory trial-and-error experiment method.
4. Time: The nominal mix is easy to make at the construction site. It does not take more time to decide the proportion because proportions are already given in IS456:2000.	**4. Time:** Whereas the design mix is very difficult and its process takes more than 30 days, time to find out the most suitable mix for the project for design mix IS-20262 shall be followed.
5. Skilled Persons: For a nominal mix, there is no need of skilled persons.	**5. Skilled persons:-** Whereas for design mix skilled person shall be required to prepare the mix design.
6. Basis Nominal Mix: The nominal mix is based on past experience and has no scientific approach.	**6. Basis Design Mix:** Whereas the design mix is more scientific than the nominal mix.
7. Strength of Nominal Mix: The nominal mix may or may not give exactly design strength unless all other factors like compaction, water-cement ratio curing of concrete are strictly followed.	**7. Strength** of **Design Mix:** Whereas design mix not only makes concrete of design strength but also makes it economical too.
8. Accuracy of Nominal Mix: In the case of nominal mix water-cement ratio is considered by the assumption so if we do not take care of it sometimes it leads to bleeding segregation and may make concrete of poor strength and durability.	**8. Accuracy:-** Whereas in the case of design mix, there is no such problem slump and strength can be related that is for the strength. We can use different slump by changing the water-cement ratio with or without admixtures.
9. Use:- The nominal mix is preferred for simpler relatively unimportant and small concrete works, in other words, the nominal mixes adopted for ordinary concrete work nominal mix may be used for concrete of M 20 grade or lower grade.	**9. Use :** Whereas design mixed is used for more extensive and important concrete works design mix can be used for all the grades but it is generally used for M 25 and above grades.

CHAPTER-07

PRODUCTION OF CONCRETE

7.1.1 Batching of materials:-

- The process of measuring ingredients or materials to prepare concrete mix is known as batching of concrete. Batching can be done by two methods, volume batching and weight batching. Batching should be done properly to get quality concrete mix.

- Batching is done by two method
    1. Volume Batching
    2. Weight Batching

1. Volume Batching

- In volume batching, materials are measured on the basis of volume. It is less precise method of batching
- Measurement boxes or gauge boxes of known volume are used to measure materials.
- Cement is taken in the form of bags, where volume of one bag of cement (50 kg) is taken as 35 liters.
- Volume of Gauge box used is made equal to the volume of one bag of cement which is 35 liters or multiple thereof.
- Gauge boxes are generally deeper and contains narrow top surface and they are made of timber or steel or iron.
- Volumes of different sized fine aggregate and coarse aggregate are measured individually by these gauge boxes.
- Water is measured using water meter or water cans of known volume are used.

EX:- To make 1:1:2 ratio concrete mix according to volume batching, one should take one bag of cement (35 liters) , 1 gauge box of fine aggregate (35 liters) and 2 gauge boxes of fine aggregate (70 liters). If the water-cement ratio is 0.5, then half of the volume of cement which is 25 liters of water should be taken.

2. Weight Batching

- In this method, Materials are measured on the basis of weight. It is accurate method of batching.
- Weigh batchers or other types of weighing equipment are used to measure weight of materials.
- Cement, fine aggregate, coarse aggregate and water are taken by weighing.
- Weigh batchers used are available in two types namely mechanical weigh batcher and electronic weigh batchers.
- In mechanical weigh batchers, weights are measured using spring and dial gauge arrangement and it is widely used equipment in weigh batching.
- In electronic weigh batchers, electronic scales and load cells supported by hoppers are used to measure the weight of ingredients of concrete.
- Weigh batchers available are may be Manual or semi-automatic or fully automatic .
- Manual type is used for small concrete production job while other two types are used for large concrete production.
- In case of semi-automatic weigh batching, aggregate container gates are lifted manually and it is automatically closed after reaching required quantity in the weighing machine.
- In fully automatic weigh batcher, all the process will be done automatically. The benefit of this type equipment is, it also measures the moisture content present in the aggregate and corrects the required quantity of water-cement with respect to moisture content of aggregates.

Ex.:- To prepare 1:1:2 concrete mix using weigh batching, measured quantity of materials are 50 kg of cement, 50 kg of fine aggregate and 100 kg of coarse aggregate.

7.1.1 MIXING OF CONCRETE MATERIALS:-

- Concrete is a composite material made up of cement, sand, coarse aggregates, water and chemical admixtures (if required). It is the primary construction material. It plays a significant role in the structure's serviceability and durability. Not only the concrete but the process of concreting such as batching, mixing, transporting, compacting and finishing etc. also plays a significant role.
- Though making concrete is very easy, the proper concreting process is quite difficult and requires extra care specially the process of mixing of concrete ingredients.
- Proper mixing of concrete ingredients is of utmost importance in order to produce good quality of fresh concrete. During the process of mixing the surface of all the aggregate particles is coated with cement paste.
- Well mixed concrete is required for the desired workability and performance of concrete in both the fresh as well as the hardened state. If the concrete is not well mixed, then it tends to segregation and bleeding.

Characteristics of Well Mixed Concrete

- Concrete should be of uniform colour.
- All concrete materials like cement, fine aggregates, coarse aggregates and water should be homogeneously mixed.
- Cement paste should cover all the surface of the aggregate.
- Segregation or bleeding of concrete should not occur after the concrete mixing.

Methods for Mixing Concrete

- When it comes to mixing concrete, following three mixing methods are used for the production of effective and good quality concrete.
  1. Hand Mixing of Concrete (Mixing concrete manually without a mixer machine)
  2. Machine Mixing of Concrete (Mixing concrete with a mixer machine)
  3. Ready Mix Concrete (Mixing in automatic or semi-automatic batching plant)

- Several factors affect the method of concrete mixing such as,
  1. Location of the construction site with sufficient land for construction activities e.g. highly congested urban areas
  2. Available space for concrete batching and mixing and storage of aggregates
  3. Volume of concrete needed
  4. The construction schedule like the volume of concrete required per hour or per day
  5. Height at which concrete is to be placed
  6. Cost

HAND MIXING:-

- Hand mixing is the process of mixing the ingredients of the concrete manually without a mixer machine. Mixing concrete without a mixer is used only for small works where the concrete requirement is less and quality control is less important.
- In the hand mixing of concrete, uniformity of mixing is difficult to achieve and requires special care and efforts. 10% extra cement shall be added to the nominal mix concrete proportion in case of hand mixing.

Process of Hand Mixing of Concrete:

- Hand mixing of concrete is done on a hard, clean and non-porous base made of masonry or flat iron sheet plates.
- The measured quantity of sand is spread on the platform and then the cement is dropped over the sand.
- The sand and cement are mixed thoroughly for several times with the help of shovels in the dry state until the mixture attains an even colour throughout and is free from streaks.
- Next, the measured amount of coarse aggregates is spread out in uniform layer on the above mixture and mixed properly. Remember to use measurement boxes for batching of aggregates, i.e. to determine how much aggregates are to be used. Never use or allow the use of 'Ghamelas' for batching, i.e. measuring quality of aggregates.
- Later, the whole mixture is blended properly like turning over by twist from the center to the side, then back to the center and again to the sides several times.
- After that, depression is made at the center of the mixed materials.
- And, 75% of the required quantity of water is added in the depression and mixed with the help of shovels.
- Lastly, the remaining amount of water is added and the mixing process is continued till a uniform colour and consistency of concrete is obtained. The total time taken for mixing of concrete should not exceed 3 minutes.

Machine Mixing:-

- Machine mixing is the process of mixing the ingredients of the concrete with a concrete mixer machine. It is highly effective for fulfilling the demands of short mixing time, optimum consistency and homogeneous quality of concrete.
- Machine mixing of concrete not only imparts the uniformity of the mix but also discharges the mix without disturbing that uniformity. Machine mixing of concrete is most suitable in the large projects where large masses of concrete are needed because it ensures the consistent homogeneity of the concrete.

The Process of Machine Mixing of Concrete:

- First of all, wet the inner surfaces of the drum of concrete mixer.
- Coarse aggregates are placed in the mixer first followed by sand and then cement.
- Mix the materials in the dry state in the mixing machine.The mixture is rotated @ 15 to 20 RPM.Normally it should be 1.5 to 3 minutes.
- After proper mixing of dry materials, gradually add the correct quantity of water while the machine is in motion. Do not add more water than required. It is not advisable as it reduces strength.
- After adding the water, concrete must mix for a minimum of two minutes in the drum.
- If there is any segregation of concrete after unloading from the mixer, then remix the concrete.

Precautions to be Taken While Machine Mixing of Concrete:

- Concrete mixer machine must be wet before use.
- Take care of mixing time, speed and numbers of revolution of mixer drum as per the recommendation of the manufacturers of the mixer machine.
- Concrete should be used within 30 minutes after mixing and discharged by the concrete mixer.
- If your mixing is batch type then, after discharging one batch of concrete, the interior surface of the mixer drum should be cleaned thoroughly. If not, lumps of hardened concrete from the mix of previous batch may form a part of the subsequent batch and deteriorate the quality of concrete.
- If your mixing is of a continuous type, it is necessary to clean the concrete mixer after fixed intervals.
- The inner portion of the concrete mixer should be carefully inspected at regular intervals to check for damages, shatter or corrosion


Reversing Drum Mixer


Non-Tilting Drum
Mixer


Tilting Drum
Mixer


Pan Mixer


Continuous
Mixers

Type of Concrete Mixer:-

- Concrete mixer can be broadly classified into following categories
    1. Batch mixer
    2. Continuous Mixer
    3. Mobile or Truck mixer

- ***Batch mixer:-*** The usual type of mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer. It is of 2 type
    I. Pan type
    II. Drum type

- ***Continuous Mixers:-*** These are fed automatically by a continuous weigh-batching system. There is no general rules on the order of feeding ingredients into the mixer as this depends on the properties of the mixer and mix.

Transportation of Concrete:-

- Transportation of concrete mix is defined as the transferring of concrete from the mixing plant to the construction site.

- The main objective in transporting concrete is to ensure that the water-cement ratio, slump of concrete or consistency of concrete workability, air content, and homogeneity are not modified from their intended states and also prevent segregation and bleeding.

Importance of Transporting Concrete

- For a central or portable plant like a ready-mix plant, concrete should be discharged from agitating transporting equipment within two hours. If the non-agitating transporting equipment is used, this time is reduced to one hour. All delays must be avoided to prevent honeycombing or cold joints.

Transportation of Concrete

Factors affecting Transportation of concrete:-

The following factors which are greatly affects the transportation of concrete.

- Type and constituents of the concrete mix,
- Weather conditions such as humidity, temperature, wind speed etc.,
- Size of construction,
- Type of construction,
- Topography,
- Location of the batching plant,
- Cost of transportation

Methods for Transporting Concrete

1. **Mortar Pan**
   - Mortar pan is used when the concrete is carried out in small quantities. In this method, the greater surface area of concrete is exposed to drying conditions and results in a great loss of water particularly in hot weather concreting.
   - Remember that the mortar pan should be clean and wet at the starting of concrete transportation.
2. **Wheelbarrow**
   - The wheelbarrow is used for transporting concrete at ground level. It's another normal way after mortar pan for transporting concrete ground level. If the transportation distance is long or ground is rough, wheelbarrows are provided with the pneumatic wheel to avoid segregation of concrete due to vibration.

3. Crane Bucket and Ropeway

- In this method transportation of concrete is fast and the placement of concrete takes place at the particular point. Crane consists of skips or buckets for containing concrete.
- Crane is used for transporting concrete horizontally as well as vertically and also in an inclined way so that it is also called two- or three-dimensional transport. It is a familiar way in medium and large sites in high rise construction projects.

4. Chute

- A chute is adapted for transporting concrete from ground level to the lower level. It is used when the labour can't reach the place of concrete due to the less space like trenches. The surface should have some slope not flatter than 1 vertical to 2.5 horizontal. Concrete may get slightly compact mass without any separation or segregation.

5. Skip and Hoist

- Skip and hoist are adopted for transporting concrete vertically for high rise building construction. At a ground level, skip is directly fed by the mixer and at the discharging point, it discharges automatically or manually. Skip is a travel on the vertical rail for the transporting concrete.

6. Transit Mixer

- Transit mixer is one of the most popular equipment for transporting concrete over a long distance mostly in RMC plant (Ready Mixed Concrete plant). Transit mixer is mounted on the truck and maybe having a capacity of 4 to 7 m^3.
- Concrete is continuously agitated in the truck with 2 to 6 revolution per minute. A small pump is fitted on a truck mixer for discharge concrete. Concrete which fed in the mixer can be either dry or wet mix. If the mix is wet then it must reach the site in 1 or 1.5 hours.

7. Belt Conveyors

- Belt conveyors are used for a small horizontal distance such as 5-meter to 10-meter. The initial cost of setting up of the belt conveyor is high. It can place large volumes of concrete quickly where access is limited. Concrete may get to segregate in steep inclines as the belt passes over the rollers. It is suggested that low slump concrete is used for slower moving belts and higher slump concrete by faster moving belts.

8. Pumps and Pipelines

- Pumping of concrete is universally accepted and more reliable method of concrete transportation and placing. Its working starts with the suction stroke which sucks the concrete inside the pipe. For the suction and delivery of concrete, a piston is provided.

***Placing of concrete*:-**

- The deposition, distribution, and consolidation of freshly mixed concrete in the place where it is to harden.
- To provide durable concrete, it should be free of segregation and the mortar should be in close contact with the coarse aggregate, reinforcement, and any adjacent faces to which it is to be bonded. Concrete should be deposited, as nearly as practicable, in its final position.
- Placement of concrete is accomplished with buckets, hoppers, manual or motor-propelled buggies, chutes and drop pipes, conveyor belts, pumps, tremies, and paving equipment.
- For achieving proper placing following rules should followed
  1. The concrete should be placed in uniform layers, not in large heaps or sloping layers.
  2. The thickness of the layer should be compatible with the method of vibration so that entrapped air can be removed from concrete.
  3. The rate of placing and compaction should be equal. If you proceed too slowly, the mix could stiffen so that it is no longer sufficiently workable and also water should never be added to concrete that is setting. On the other hand, if you go too quickly, you might race ahead of the compacting gang, making it impossible for them to do their job properly.
  4. Each layer should be fully compacted before placing the next one, and each subsequent layer should be placed whilst the underlying layer is still plastic so that monolithic construction is achieved
  5. Collision between concrete and formwork or reinforcement should not happen to avoid segregation.
  6. For deep sections, a long down pipe ensures accuracy of location of concrete and minimum segregation.
  7. Deposit the concrete as near as practicable to its final position. The height of free fall should not more than 1.5m.
  8. Deposit concrete in horizontal layer and compact each layer thoroughly before the next layer is placed.

***Preparation of Surface Before Placing Concrete*:-** In order to develop a proper and adequate bond between the base and the concrete placed. it is essential that the base is prepared well before placing the concrete. Before placing concrete different type of bases should be prepared as discussed below:

1. **Natural soil:** Before laying any concrete layer over a natural soil base the soil should be properly compacted and leveled. After leveling the soil should be made moist for a thickness of 30 cm and loamy and fine grained soil up to 15 cm thickness for 24 hour before laying the concrete layer. Moistening of soil essential, to check absorption of water from concrete by soil.
2. **In case of rocky bases:** In this case the sides should be kept vertically. All lose particle should be removed and water sprinkled over the base and cleaned before placing the concrete. In this casealsowatershould notbeallowedtostandonthe surface.
3. **In case of brick soling and W.B.M. bases:** The base should be made rough with the help of wire brush and cleaned. Loose particle and dust removed, water sprinkled and surface compacted before placing the concrete over it.
4. **In Case of Hardened Concrete Base:**
    1. **The difference in to operation is 4 hour. :** The laitance on the surface of old concrete should be removed by rubbing it with wire brush and cleaned with water. All dust and rubbish should be removed by broom before laying the new layer of concrete.
    2. **Up to 48 hour:** The surface is rubbed with steel brush and washed with water and cleaned with the help of broom. Now 1.5 cm thick layer of cement mortar of similar composition as that of concrete is applied to the surface before new concrete is placed.
    3. **More than 48 hour old concrete:** In this case the hard surface is chiseled or sand blasted and cleaned as above. Now slurry of neat cement is applied on the roughened surface and worked into the interstices after which 1.5 cm thick layer of cement sand mortar of the same composition as that of concrete should be applied before the slurry dries and then new concrete is placed immediately.

Compaction of concrete (vibrators)

- The process of removal of air void from concrete and make it more densified known as compaction. Once the concrete has been placed, it is ready to be compacted. The purpose of compaction is to get rid of the air voids that are trapped in loose concrete.
- Compaction is a process of expelling the entrapped air. If we don't expel this air, it will result into honeycombing and reduced strength. It has been found from the experimental studies that ***1% air in the concrete approximately reduces the strength by 6%.***
- During mixing, transportation and placing of concrete a small amount of air is entrapped in the concrete mix. This air will cause the low strength of concrete and failure of concrete. The process of removing the entrapped air and achieving maximum density is known as compaction.
- The concrete may be non-homogeneous and porous if the entrapped air is not removed. The object of this is to remove air holes and to achieve maximum density. Compaction also ensures intimate contact between concrete and reinforcing steel and other embedded parts.

Points to Remember While Compacting Concrete

1. When compacting concrete (by hand or vibration), do not displace the reinforcement or formwork.
2. The concrete must be worked thoroughly around the formwork so that the finished surface will be even, dense, and free from honeycombing or excessive blowholes.
3. Air voids reduce the strength of the concrete. For every 1% of entrapped air, the strength falls by somewhere between 5 and 7%.
4. Air voids increase concrete's permeability. That in turn reduces its durability. If the concrete is not dense and impermeable, it will not be watertight. Moisture and air are more likely to penetrate to the reinforcement causing it to rust.

5.Air voids in contact between the mix and reinforcement (and, indeed, any other embedded metals). The required bond will not be achieved and the reinforced member will not be as strong as it should be.

6.Fully compacted concrete is dense, strong and durable, badly compacted concrete will be porous, weak and prone to rapid deterioration. Sooner or later it will have to be repaired or replaced.

Compaction By Vibrator:-

1. INTERNAL VIBRATOR

- They are also referred to as immersion, poker or needle vibrators.
  They essentially include an energy unit and a long flexible tube on the top of which a vibrating head is attached. Power is furnished by means of an electric powered motor, compressed air or petrol engine. The long tube houses a flexible shaft which rotates an eccentric weight inside the vibrating head. The frequency of the vibrator is about seven hundred cycles according to the minute.The vibrating head is inserted inside the concrete. They are only as the vibrating head comes into intimate touch with concrete.

2. FORM VIBRATORS

- They are also known as outside vibrators. They are clamped to the formwork horizontally and vertically at an appropriate spacing not exceeding ninety cm in both directions. As the work progress, they may be shifted. They vibrate the concrete from the vibration of the bureaucracy and therefore much strength is wasted.
- They are used handiest if the use of inner vibrators is not attainable as in the case of thin and congested sections, arches and tunnel lining, etc.

3. SURFACE VIBRATORS

- They are also called screed or pan vibrators. They are clamped to the screen. They vibrate the concrete from the floor on the time whilst screeding (striking off) of the concrete is carried out. They are effective only if the intensity of concrete is up to 20 cm. If the depth is more they can be used in aggregate with internal vibrators. They are used for long horizontal surfaces inclusive of pavements and slabs.

4. VIBRATING TABLES

- These are rigidly built metal platforms established on steel springs and driven through electric motors. The concrete is placed in molds installed on the platforms and securely clamped to the vibrating table, in order that mold and concrete vibrate in union.

- Vibrating tables are used for compacting stiff and harsh mixes utilized in precast structural individuals in factories and laboratory specimens.

***Curing of concrete* :-**

- Curing of cement 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.

Why the curing of cement concrete is required? The curing of cement concrete is required for the following reasons-

1. To prevent the concrete from drying out prematurely due to solar radiation and wind.
2. To maintain the concrete temperature by allowing the hydration process.
3. To harden and bond with internal materials and reinforcement. This helps to prevent damage to the bond between concrete and reinforcement due to vibration and impact.
4. To development of impermeable, crack-free, and durable concrete.

3. What is the right time for the curing of concrete:- The time to start the curing of concrete depends on the evaporation rate of moisture from the concrete. The evaporation rate is influenced by wind, radiant energy from sunshine, concrete temperature, climatic conditions, relative humidity.

1. SHADING OF CONCRETE WORK

- The object of shading concrete work is to prevent the evaporation of water from the surface even before setting. This is adopted mainly in case of large concrete surfaces such as road slabs. This is essential in dry weather to protect the concrete from heat, direct sun rays and wind. It also protects the surface from rain. In cold weather shading helps in preserving the heat of hydration of cement thereby preventing freezing of concrete under mild frost conditions. Shading may be achieved by using canvas stretched on frames. This method has a limited application only.

2. COVERING CONCRETE SURFACES WITH HESSIAN OR GUNNY BAGS

- This is a widely used method of curing, particularly for structural concrete. Thus exposed surface of concrete is prevented from drying out by covering it with hessian, canvas or empty cement bags. The covering over vertical and sloping surfaces should be secured properly. These are periodically wetted. The interval of wetting will depend upon the rate of evaporation of water. It should be ensured that the surface of concrete is not allowed to dry even for a short time during the curing period. Special arrangements for keeping the surface wet must be made at nights and on holidays.

3. SPRINKLING OF WATER

- Sprinkling of water continuously on the concrete surface provides an efficient curing. It is mostly used for curing floor slabs. The concrete should be allowed to set sufficiently before sprinkling is started. The spray can be obtained from a perforated plastic box. On small jobs sprinkling of water may be done by hand. Vertical and sloping surfaces can be kept continuously wet by sprinkling water on top surfaces and allowing it to run down between the forms and the concrete. For this method of curing the water requirement is higher.

4. PONDING METHOD

- This is the best method of curing. It is suitable for curing horizontal surfaces such as floors, roof slabs, road and air field pavements. The horizontal top surfaces of beams can also be ponded. After placing the concrete, its exposed surface is first covered with moist hessian or canvas. After 24 hours, these covers are removed and small ponds of clay or sand are built across and along the pavements. The area is thus divided into a number of rectangles. The water is filled between the ponds. The filling of water in these po nds is done twice or thrice a day, depending upon the atmospheric conditions. Though this method is very efficient, the water requirement is very heavy. Ponds easily break and water flows out. After curing it is difficult to clean the clay.

5. MEMBRANE CURING

- The method of curing described above come under the category of moist curing. Another method of curing is to cover the wetted concrete surface by a layer of water proof material, which is kept in contact with the concrete surface of seven days. This method of curing is termed as membrane curing. A membrane will prevent the evaporation of water from the concrete. The membrane can be either in solid or liquid form. They are also known as sealing compounds. Bituminised water proof papers, wax emulsions, bitumen emulsions and plastic films are the common types of membrane used.
- This method of curing does not need constant supervision. It is adopted with advantage at places where water is not available in sufficient quantity for wet curing. This method of curing is not efficient as compared with wet curing because rate of hydration is less. Moreover the strength of concrete cured by any membrane is less than the concrete which is moist cured. When membrane is damaged the curing is badly affected.

6. STEAM CURING

- Steam curing and hot water curing is sometimes adopted. With these methods of curing, the strength development of concrete is very rapid.
- These methods can best be used in pre cast concrete work. In steam curing the temperature of steam should be restricted to a maximum of 75^0C as in the absence of proper humidity (about 90%) the concrete may dry too soon. In case of hot water curing, temperature may be raised to any limit, ay 100^0C.
- At this temperature, the development of strength is about 70% of 28 days strength after 4 to 5 hours. In both cases, the temperature should be fully controlled to avoid non-uniformity. The concrete should be prevented from rapid drying and cooling which would form cracks.

By Spraying water

Using Gunny Bags

By Ponding Method

Steam Curing

Curing Chemicals

Formwork-requirements and types:-

- Formwork by name means “The Mold” which means it is the casing into which the casting material, usually concrete, is poured to obtain the desired structural shape.
- In construction industry formwork is similar to a mold to cast concrete member in different shape and sizes using different types of materials such as timber, steel, aluminum, plastic, etc. Shuttering is a synonym term used for form-work. Form work should have sufficient strength to carry dead load and live load coming on it during casting operation and after that till concrete gets hard and gain some percentage of design strength.

Requirements of good Formwork

- It must be capable to withstand all types of dead and live
- It is practically good to have water proof character, so that it won’t absorb water from concrete.
- Entire formwork should be rigidly constructed and propped, so that there should be no deformation in the shape and retain its original shape.
- Deflection and shrinkage should be minimum.& The joins should be tight enough to minimize the leakage of cement grout.
- The formwork should be constructed with different segments. So that while removing the formwork it should not damage the concrete
- The material of the formwork should be cheap, easily available and should be suitable for reuse.
- The formwork should be set accurately to the desired line and levels should have plane surface.
- It should be as light as possible. So that it is easy to transfer and erect.
- The material of the formwork should not warp or get distorted when exposed to the elements.

Technical requirements of Good Formwork

- Formwork should be exactly designed of the required shape and size so that it fits at the designed position.
- According to the desired concrete surface the material of the formwork will be selected.
- Formwork should be strong enough to withstand the pressure of fresh concrete and working loads and should not distort or deflect from their position during the concrete placing operation.
- Formwork should support the designed horizontal and vertical loads. It should also support the other unusual loads also during the construction period.
- The formwork should not disturb the structure or concrete surface during the removal time.
- The segments of the formwork should be tightly fitted to minimize the gaps between them which prevents the leakage of cement material.

Functional Requirements of Formwork

- Form segments should be of suitable size so that they can be transported and stored easily and reused at another place.
- Formwork should be easy to dismantle and fit so that construction of building process advances.
- Formwork segments should have symmetry so that they can be interchangeable and can be used at different places.
- Forms should be simple to build.
- Formwork should be as lightweight but with enough strength required to withstand the loads and pressure.
- Forms should be made such that workers can handle them without any safety issue, respecting the Health, Safety, and Hygiene Regulation in effect.

Different Types of formwork - Based on Material

- **1. Timber formwork**

- The Timber formwork is one of the mostly used type in construction industry, fabricated on site using timber. It is easy to produce but time-consuming for larger structures. We can't produce curved shapes economically. Timber shuttering should satisfy the following requirement:
  - Lightweight
  - Well-Seasoned
  - Free from termite attacks
  - Easily Workable

2. Plywood Formwork (In Combination with Timber)

- Plywood is an artificially manufactured wooden material available in different thickness and size used in formwork for concrete member. It is strong enough, durable and light weight. The main advantage of this forms from timber forms is we get smooth cement surface with this form.

3. Steel Formwork

- Steel formwork is now becoming popular due to its long-life time and multiple time reuses. Steel formwork is costly is costly but can be used for large number of projects. Steel shuttering give very smooth finishes to concrete surface. It is suitable for circular or curved structures such as tanks, columns, chimneys, tunnel and retaining wall.

4. Aluminium Formwork

- Aluminum formwork is almost similar to those made of steel. Aluminum forms are lighter than steel forms due to low density and this is their primary advantage when compared to steel. The shuttering is economical if large numbers of repeating usage are made in construction. The disadvantage is that no alteration is possible once the formwork is constructed.

5. Plastic Formwork

- Plastic formwork is lightweight, posses interlocking mechanism and could be used for multiple times. Plastic shuttering is mostly useful where similar construction shape structures are required.


SQUARE CIRCLE FORMWORK

Stripping of forms. (Concepts only) :-

- The **removal of concrete formwork** also called as strike-off or stripping of formwork should be carried out only after the time when concrete has gained sufficient strength, at ***least twice the stress to which the concrete may be subjected*** to when the formworks are removed. It is also necessary to ensure the stability of the remaining formwork during formwork removal.

Factors Affecting Concrete Formwork Striking Times

- The striking time of concrete formwork depends on the strength of structural member. The strength development of concrete member depends on:
  - **Grade of concrete** – higher the grade of concrete, the rate of development of strength is higher and thus concrete achieves the strength in shorter time.
  - **Grade of cement** – Higher cement grade makes the concrete achieve higher strength in shorter time.
  - **Type of Cement** – Type of cement affects the strength development of concrete. For example, rapid hardening cement have higher strength gain in shorter period than the Ordinary Portland Cement. Low heat cement takes more time to gain sufficient strength than OPC.
  - **Temperature** – The higher temperature of concrete during placement makes it achieve higher strength in shorter times. During winter, the concrete strength gain time gets prolonged.
    - A higher ambient temperature makes the concrete gain strength faster.
    - Formwork helps the concrete to insulate it from surrounding, so longer the formwork remain with concrete, the less is the loss of heat of hydration and rate of strength gain is high.
  - **Size of the concrete member** also affects the gain of concrete strength. Larger concrete section members gain strength in shorter time than smaller sections.
  - **Accelerated curing** is also a method to increase the strength gain rate with the application of heat.

Table – 1: Strength of concrete vs. Structural Member Type & Span for Formwork Removal

Concrete Strength	Structural Member Type and Span
2.5 N/mm^2	Lateral parts of the formwork for all structural members can be removed
70% of design strength	Interior parts of formwork of slabs and beams with a span of up to 6m can be removed
85% of design strength	Interior parts of formwork of slabs and beams with a span of more than 6m can be removed

Type of Formwork	Formwork Removal Time
Sides of Walls, Columns and Vertical faces of beam	24 hours to 48 hours (as per engineer's decision)
Slabs (props left under)	3 days
Beam soffits (props left under)	7 days
Removal of Props of Slabs:	
i) Slabs spanning up to 4.5m	14 days
ii) Slabs spanning over 4.5m	14 days
Removal of props for beams and arches	
i) Span up to 6m	14 days
ii) Span over 6m	21 days

CHAPTER-08

INSPECTION AND QUALITY CONTROL OF CONCRETE

- The aim of quality control is to reduce the above variations and produce uniform material providing the characteristics desirable for the job envisaged. Thus quality control is a corporate, dynamic programme to assure that all aspects of materials, equipment and workmanship are well looked after.

8.1 Quality control of Concrete as per I.S.456,

- In order that the properties of the completed structure be consistent with the requirements and the assumptions made during the planning and the design, adequate quality assurance measures shall be taken. The construction should result in satisfactory strength, serviceability and long term durability so as to lower the overall life-cycle cost.
- Quality assurance in construction activity relates to proper design, use of adequate materials and components to be supplied by the producers, proper workmanship in the execution of works by the contractor and ultimately proper care during the use of structure including timely maintenance and repair by the owner.
- Quality assurance measures are both technical and organizational. Some common cases should be specified in a general Quality Assurance Plan which shall identify the key elements necessary to provide fitness of the structure and the means by which they are to be provided and measured with the overall purpose to provide confidence that the realized project will work satisfactorily in service fulfilling intended needs.
- The job of quality control and quality assurance would involve quality audit of both the inputs as well. as the outputs. Inputs are in the form of materials for concrete; workmanship in all tages of batching, mixing, transportation, placing, compaction and curing; and the related plant, machinery and equipments; resulting in the output in the form of concrete in place,
- To ensure proper performance, it is necessary that each step in concreting which will be covered by the next step is inspected as the work proceeds.

- A Quality Assurance Plan shall define the tasks and responsibilities of all persons involved, adequate control and checking procedures, and the organization and maintaining adequate documentation of the building process and its results. Such documentation should generally include:
    a) test reports and manufacturer's certificate for materials, concrete mix design details;
    b) pour cards for site organization and clearance for concrete placement;
    c) record of site inspection of workmanship, field tests;
    d) non-conformance reports, change orders;
    e) quality control charts; and
    f) statistical analysis.

10.1.1 Factors causing the variations in the quality of concrete

- Concrete is generally produced in batches at the site with the locally available materials of variable characteristics. It is, therefore, likely to vary from one batch to another. The magnitude of this variation depends upon several factors, such as
    1. variation in the quality of constituent materials;
    2. variation in mix proportions due to batching process;
    3. variation in the quality of batching and mixing equipment available;
    4. the quality of overall workmanship and supervision at the site.
    5. Moreover, concrete undergoes a number of operations, such as transportation, placing, compacting and curing. During these operations considerable variations occur partly due to quality of plant available and partly due to differences in the efficiency of techniques used.
    6. the availability of experienced, knowledgeable and trained personnel at all levels.
    7. Everything in quality control cannot be codified or specified and much depends upon the attitude and orientation of people involved.

Field Control:-

- The field control i.e. inspection and testing, play a vital role in the overall quality control.
- Inspection could be of 2 types
    1. Quality control Inspection
    2. Acceptance Inspection

Advantages of Quality Control:-

1. Quality control means a rational use of available resources after their characteristics and reductions in materials cost.
2. In the absence of quality control there is no guarantee that over-spending one area will compensate for the weakness in another.
3. In the absence of quality control at the site, the designer is convinced to over design, so as to minimize the risk. This adds overall cost.
4. Check at every stage of the production of concrete and rectification of faults at the right time expedites completion and reduces delay.
5. Quality control reduces the maintenance cost.

2. Mixing, Transporting, Placing & curing requirements of Concrete as per I.S.456.

1. Mixing:-

- Concrete shall be mixed in a mechanical mixer. The mixer shall be fitted with water measuring instruments. The mixing shall be continued until there is a uniform distribution of the materials and mass is uniform in colour and consistency. Segregation must be avoided and if present material should remixed.
- The mixing time shall be at least 2min. For other type of more efficient mixer manufacturers recommendation shall be followed.
- Workability should checked at frequent intervals.
- Dosage of retarder, plasticizers, and superplastisizer shall be restricted to 0.5,1 and 2% respectively by weight of cementious material and unless a higher value is agreed upon between the manufacturer and based on performance and cost.

8.2.2 Transportating:-

- After mixing, concrete shall be transported to theformwork asrapidlyas possiblebymethods whichwill prevent the segregation or loss of any of the ingredients or ingress of foreign matter or water and maintaining (he required workability
- During hot or cold weather, concrete shall be transportedindeep containers. Other suitable methods to reduce the loss of water by evaporation in hot weather and heat loss in cold weather may also be adopted.

Placing

- The concrete shall he depositedas nearly as practicable in its final position to avoid rehandling. The concrete shall he placed and compacted hefore initial setting of concrete commences and should not be subsequently disturbed. Methods of placing should be such as to preclude scgreg.rtion. Care should be taken to avoid displacement of reinforcement or movement of formwork . As a general guidance, the maximum permissible free fall of concrete may be taken as 1.5 m.

COMPCTION:-

- Concrete should he thoroughly compacted and fully worked around the reinforcement, around embedded fixtures and intocorners of the fonnwork.
- Concrete shall be compacted using mechanical vibrators complying with IS 2505, IS 2506. IS 2514 and IS 4656. Over vibration and under vibration of concreteare harmful and should beavoided. Vibration of very wet mixesshould also he avoided.
- Whenever vibration has to be applied externally, the design of formwork and the disposition of vibrators should receive special considerationto ensure efficient compaction and to avoid surface blemishes.

Curing:-

Curing is the process of of preventing the loss of moisture from the concrete with maintaining a satisfactory temperature regime.

The prevention of moisture loss from the concrete is particularly important if the cement has a high rate of strength development, if the concrete contains granulated blast furnace slag or pulverized fuel ash.

8.3 Inspection and Testing as per Clause 17 of IS:456.

1. Inspection

- To ensure that the construction complies with the designan inspection procedure should be setup covering materials,records.workmanship and construction.

1.Tests should be made on reinforcement and the constituent materials of concrete in accordance with the relevant standards.Where applicable,use should be made of suitable quality assurance schemes.

2. Care should be taken to see that:

a) design and detail are capable of being executed to a suitable standard,with due allowance for dimensional tolerances;
b) There are clear instructions on inspection standards;
c) thereareclearinstructionsonpermissible deviations;
d) Elements critical to workmanship,structural performance, durability and appearance are identified; and
e) thereisasystemtoverifythatthequalityis satisfactoryinindividualpartsofthestructure, especiallythecriticalones.

17.2 Immediately after stripping the formwork,all concrete shall be carefully inspected and any defective workor small defects either removed or made good before concrete has thoroughly hardened.

3. Testing

In case of doubt regarding the grade of concrete used, either due to poor workmanship or based on results of cube strength tests,compressive strength tests of concrete on the basis of 17.4 and/or loadtest (see17.6) may be carried out.

4. CoreTest

1.The points from which cores are to be taken and the number of cores required shall be at the discretion of the engineer-in-charge and shall be representative of the whole of concrete concerned. In no case however shall fewer than three cores be tested.

2. Cores shall be prepared and tested as described in IS516.

3.Concrete in the member represented by a core test shall be considered acceptable if the average equivalent cube strength of the cores is equal to at least 85 percent of the cube strength of the grade of concrete specified for the corresponding age and no individual core has a strength less than 75 percent.

17.5 In case the core test results do not satisfy the requirements of 17.4.3 or where such tests have not been done,load test (17.6) may be resorted to

Along with read 17.6-17.8 of IS 456. 2000.

Durability requirements as per IS 456:-

- *Durability and strength* are two most important criteria for the design of reinforced concrete structures.
- Any deficiency in any of the two i.e. durability and strength, could make the structure unfit for the intended purpose. If the structure is not durable, but it has sufficient strength, then the strength of structure reduces with the age due to deterioration of concrete and reinforcement due to surrounding environment.
- Environment plays an important role while selecting durable materials for reinforced concrete structures. For environments such as coastal areas where rate of corrosion is very high, special care is taken for the corrosion allowance of reinforcement, epoxy painting of reinforcement, required cover to reinforcement, grade of concrete to be used, water-cement ratio, quality of water for construction, proper placement and compaction of concrete.

Durability of Reinforced Concrete in Different Environmental Conditions

Some precautions to be taken care while constructions of reinforced concrete structure for durability are:

1. Proper amount of minimum cover specified by the code should be provided.
2. Minimum cement content in concrete mix and maximum water-cement ratio guidelines based on type of environment provided by the code should be followed.
3. Using good quality lab tested coarse and fine aggregates suitable for construction and free from (or within permissible limits) impurities such as dust, alkalies, chlorides, sulfates etc. should be used.
4. Based on environment attack on structure, suitable type of cement, concrete admixtures and water-cement ratio should be used.
5. Good placement and compaction of concrete.
6. Following formwork removal schedule as per type of construction as per guidelines given by standard codes.
7. Proper curing of concrete for the required period of time.

Some of the major durability problems caused by environment are:

1. Corrosion of steel reinforcement:

This corrosion of steel reinforcement can be controlled by:

- Cover to reinforcement (IS 456, Cl.25.4)
- Minimum cement content (IS 456, Table-19)
- Proper water-cement ratio
- Proper compaction and curing
- Using epoxy coated reinforcement.

2. Deterioration of Concrete:

Due to chemical attacks such as sulfates present near chemical industries atmosphere, soil and ground water, the concrete even without reinforcement steel deteriorates.

Concrete in plant drains or sewers are also exposed to such environment and deteriorates due to sulfate action. To overcome the problem of such deterioration of concrete, following points should be followed:

- Using proper cement types such as sulphate resistant cement or cement with low C3A content
- Using minimum cement content as specified by the code
- Using proper water-cement ratio for the concrete
- Using protective coating to concrete surface buried under the soil.

Environmental exposure conditions	Min cement content+ kg/m^3	Max free w/c	Min concrete grade#	Min cover depth (mm)*
Mild: Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area	300	0.55	M 20	20**
Moderate: Concrete surfaces sheltered from severe rain or freezing whilst wet; concrete exposed to condensation and rain; concrete continuously under water; concrete in contact or buried under non-aggressive soil/ ground water; concrete surfaces sheltered from saturated salt air in coastal area	300	0.50	M 25	30

Severe: Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation; concrete completely immersed in sea water; concrete exposed to coastal environment	320	0.45	M 30	45***
Very severe: Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet; concrete in contact with or buried under aggressive sub-soil/ground water	340	0.45	M 35	50***
Extreme: Surface of members in tidal zone; members in direct contact with liquid/ solid aggressive chemicals	360	0.40	M 35	75

Notes:

1. + Cement content prescribed in the table is irrespective of the grades of cement and it is inclusive of SCMs.
2. # In the designation of concrete mix M refers to the mix and the number to the specified compressive strength of 150 mm size cube at 28 days, expressed in N/mm^2.

CHAPTER-09

SPECIAL CONCRETE

High performance concrete:-

- A concrete mixture which has high workability, high strength, high modulus of physical property, high density, high dimensional stability, low permeability and resistance to chemical attack is generally said to be high performance concrete.

The American Concrete Committee on High Performance Concrete includes the following five criteria:

1. Ease of placement
2. Long term mechanical properties
3. Early-age strength
4. Toughness
5. Life in severe environments

The above-mentioned performance requirements can be grouped under the following three general categories.

1. Attributes that *benefit the construction process.*
2. Attributes that lead *to enhanced mechanical properties.*
3. Attributes that *enhance durability and long-term performance.*

table shows classification of high performance concrete related to strength

High Performance Class	Compressive Strength (Mpa)
1	50
2	75
3	100
4	125
5	150

Components/Ingredients used in High Performance Concrete

The assembly of High Performance Concrete involves the subsequent three important interrelated steps:

- Choice of appropriate ingredients for concrete having the required rheological properties, strength etc.
- Determination of relative quantities of the ingredients in order to produce durability.
- Careful internal control of each section of the concrete creating method.

Following Ingredients are used in preparation of high performance concrete :

Cement :

- Physical and chemical characteristics of cement play a significant role in developing strength and controlling rheology of fresh concrete.
- Fineness affects water requirements for consistency.Little amount of tricalcium aluminate (C3A) as possible because the lower amount of C3A, the easier to control the physical science and lesser the issues of cement-superplasticizer compatibility.It should contains fair amount of Tri- Calcium Aluminates (C3S).

Fine Aggregate :

- Both river sand and crushed stones can be used. Coarser sand may be preferred as finer sand increases the water demand of concrete.

Coarse Aggregate :

- The coarse aggregate is the strongest and least porous component of concrete. The strength of High Performance Concrete is also controlled by the strength of the coarse aggregate. Hence the selection of coarse aggregate would be an important step in High Performance Concrete design mix.

Water : Water should be free from acidic content and generally drinking safe water will be good to use.

Mineral Admixtures :

- The major difference between conventional cement concrete and high performance concrete is essentially the use of mineral admixtures in the latter. Some of the mineral admixtures are
  - Fly ash
  - Silica fumes
  - Ground granulated blast furnace slag (GGBFS)
  - Fine filler or pozzolonic supplementary cementitious materials
  - Anhydrous gypsum based mineral additives

Chemical Admixtures :

- Chemical admixtures improves the workability of the concrete mix by increasing the efficiency of the cement paste, which results in decreased water requirement. Some of the important chemical admixtures are: Plasticizers, Super plasticizers, Retarders, Air entraining agents.

Methods for Achieving High Performance

Two approaches to achieve durability through different techniques are as follows.

1) Reducing the capillary pore system such no fluid movement can occur is the first approach. This is very difficult to appreciate and every concrete can have some interconnected pores.
2) Creating chemically active binding sites which prevent transport of aggressive ions like chlorides is that the second most effective method.

Use of High Performance Concrete

- Severe exposure conditions.
- Increase durability.
- Prevent deterioration of concrete

- Ex. Bridges, High rise buildings, Tunnels, Pavements, Nuclear structures.

Advantages of HPC

- Reduction in size of Structural members.
- Speed of construction.
- Workability and Pumpability.
- Economical material in Terms of time and money.
- Higher seismic resistance.
- Improved durability.
- Abrasion resistance.
- High tensile strength.
- Reduced maintenance cost

Limitations of HPC

- An extended quality control, as each and every aspect has to be checked as this type of concrete is widely used in the construction of mega structures.
- Cost is generally high due to used of various admixtures and high quality materials.
- Special constituents.
- Manufactured and placed carefully.

Silica fume concrete:-

- Silica fume concrete is composed of cement, silica fume, fine aggregate, coarse aggregate, and water. Fresh and hardened properties of silica fume concrete is superior to conventional concrete. For instance, it has higher compressive and flexural strength.
- The durability of this type of concrete is superior to conventional concrete. Resistance against freezing and thawing and chemical attacks is better than concrete without silica fume. Segregation and bleeding is low in silica fume concrete, and the mixture is adhesive compared to traditional concrete.
- The applications of the silica fume concrete in construction are seen in high-rise buildings, parking structure, dam structure, nuclear waste storage facility, and shotcrete rehabilitation.

Chemical Composition of Silica Fume Material

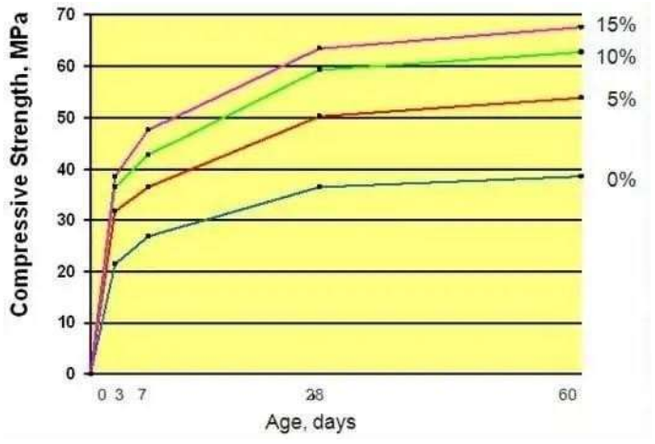
- It contains more than 90 percent of silicon dioxide.
- Other constituents are carbon, sulfur, oxides of aluminum, iron, calcium, magnesium, sodium, and potassium.

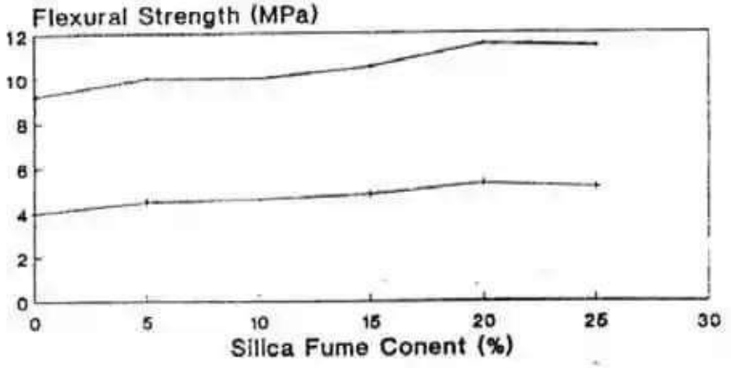
Physical Properties of Silica Fume Material

- The diameter of the silica fume particle ranges from 0.1 micron to 0.2 micron.
- The surface area is about 30,000 m^2/kg.
- Density varies from 150 to 700 kg/m^3 but when it is about 550 kg/m^3, it is best suited as a concrete additive.

Properties of Fresh Silica Fume Concrete

- Silica fume concrete requires higher water content, for the same workability as of conventional concrete.
- Low workability
- Low slump value
- Possibility of bleeding and segregation is low
- The mixture is cohesive
- High plastic shrinkage





Properties of Hardened Silica Fume Concrete

- The compressive strength of silica fume concrete is higher than ordinary concrete (62 – 80 MPa), Fig. 1. Similarly, the flexural strength is also higher, Fig. 2.
- The modulus of elasticity is substantially higher than that of ordinary concrete.
- Creep of silica fume concrete is lesser than conventional concrete.

Durability

- Permeability of silica fume concrete is low; hence, penetration of sulfate ions is low.
- Abrasion resistance and corrosion resistance are high.
- The reaction of silica fume with lime in the paste matrix improves durability. Lime material reacts with different chemicals and cause expansion.

Advantages

- Silica fume enhances the properties of fresh and hardened concrete.
- Silica fume reduces segregation and bleeding.
- High durability
- The finishing process is efficient due to low bleeding.
- High early compressive strength
- High flexural strength and modulus of elasticity
- High bond strength
- Suitable for mass concreting since it prevents thermally induced cracking.

Disadvantages

- Availability issue
- High cost

Applications

- High rise buildings,
- Parking structure,
- Dam structure,
- Nuclear waste storage facility
- Shotcrete rehabilitation

Shot-crete concrete or gunitting :-

- The purpose of using the **shotcrete** and **Guniting** method is the same but the process of application is different.
- Sprayed concrete is widely used in the construction of tunnels, **underground** structures**, slope stabilization** structural repairs **and swimming pools.**
- **Guniting** is a technique that consists of the pumping of mortar or concrete at a **high velocity** through a hose or spray gun to apply on the surface.
- The Guniting process is also known as Dry Shotcreting. It is a process of spraying a mix of mortar or concrete at high pressure to the surface with the help of spray gun.
- **Guniting process** is used in the slope stabilization dome construction of retention walls water tanks and pools etc.
- The process of converting has wide applications such as the strengthening of old structures, lining of the reservoir and canal, waterproofing of the surface which come directly with the contact of water.

Advantage of Guniting Process:

The various advantages of guniting process are as follows

- The Guniting process is economical as compared to other types of method.
- The dry mix can be prepared quickly as compared to the wet shotcreting mix.
- The **guniting process** is used in **swimming pools** and artificial caves to provide special shapes and features.
- The **High compressive** strength of the concrete can be obtained with guniting process.

Disadvantage of Guniting Process:

The various disadvantages of Guniting process are as follows

- The dry mix of concrete can clog or block the hose pipe during the application of concrete.
- The process of Guniting required a **skilled operator**.
- The quality of the work depends upon the operator.
- In this method, there may be chances of wastage of concrete.

Shotcrete:-

- The term **Shotcrete** itself says that it is a technique in which the concrete is shot out through the hose is known as **Shotcrete**.
- **Shotcrete** is sprayed on the surface through a hose at a high velocity. Shotcrete is used with both wet mix as well as **dry**–**mix**
- **Shotcrete** can be done with both dry mix or wet mix. Shotcrete is placed and compacted properly.
- Dry mix process for shotcreting, in which water is added to the concrete mix at the nozzle.
- **Shotcreting** is the best method in which the concrete mix is applied in layers under the pressure of compressed air.
- The water cement ratio for shotcrete normally ranges within **0.35 to 0.50** by mass which is somewhat lower than for most conventional concrete mixes.
- **Shotcreting process** is done with the special unit which consists of a mortar gun. The dry mix of cement sand and aggregate is prepared in the appropriate proportion for the process of **shotcreting**.
- The Shortcrete is widely used for the repairing of the structure and earthquake damage. Shotcreting method is very helpful in underground mining.

Advantage of Shotcreting:

- The various advantages of shotcreting process are as follows
- The process of shotcreting forms a strong and **uniform** layer of concrete on the surface.
- The **shotcreting process** is more **economical** as compared to conventional concrete which required formwork.
- Shotcreting is suitable for the construction where the formwork cannot be installed.
- The concrete can be applied to one nozzle from a safe distance.

Disadvantage of Shotcreting:

- The various disadvantages of shotcreting process are as follows
- The concrete in the process of shotcreting is premix so that it is necessary that it has to be applied quickly.
- There may be chances of developing crack if more water is added in the premix concrete.
- The process of shotcreting is a little bit expensive as compared to guniting process.

CHAPTER-10

DETERIORATION OF CONCRETE AND ITS PREVENTION

Deterioration of Concrete:-

- It can be the result of one or a combination of factors, such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, subgrade settlement, and applied loads.
- Concrete can deteriorate for a variety of reasons, and concrete damage is often the result of a combination of factors.
- The primitive factors are, Distress in concrete, Permeability of concrete and Aggressive deterioration agents. There are different types of causes under these three main divisions that cause deterioration

10.1.1 Types of deterioration:-

1. **Corrosion of Embedded Metals in concrete:-**
   - When steel corrodes, the resulting rust occupies a greater volume than the steel. This expansion creates tensile stresses in the concrete, which can eventually cause cracking, delamination, and spalling. Steel corrodes because it is not a naturally occurring material.
   - The corrosion of structural steel is an electrochemical process that requires the simultaneous presence of moisture and oxygen.
2. **Freeze thaw deterioration in concrete**
   - Freeze-thaw damage is a potentially serious deterioration process that occurs in concrete structures in cold climates. Premature damage to concrete slabs during freezing and thawing cycles represents a major challenge to pavement durability and resilience. When water freezes, it expands about 9%. As the water in moist concrete freezes, it produces pressure in the capillaries and pores of the concrete. If the pressure exceeds the tensile strength of the concrete, the cavity will dilate and rupture. The accumulative effect of successive freeze-thaw cycles and disruption of paste and aggregate can eventually cause significant expansion and cracking, scaling, and crumbling of the concrete Freeze/thaw damage occurs in concrete when the water molecules in concrete freeze and expand beyond the volume constraints of the concrete.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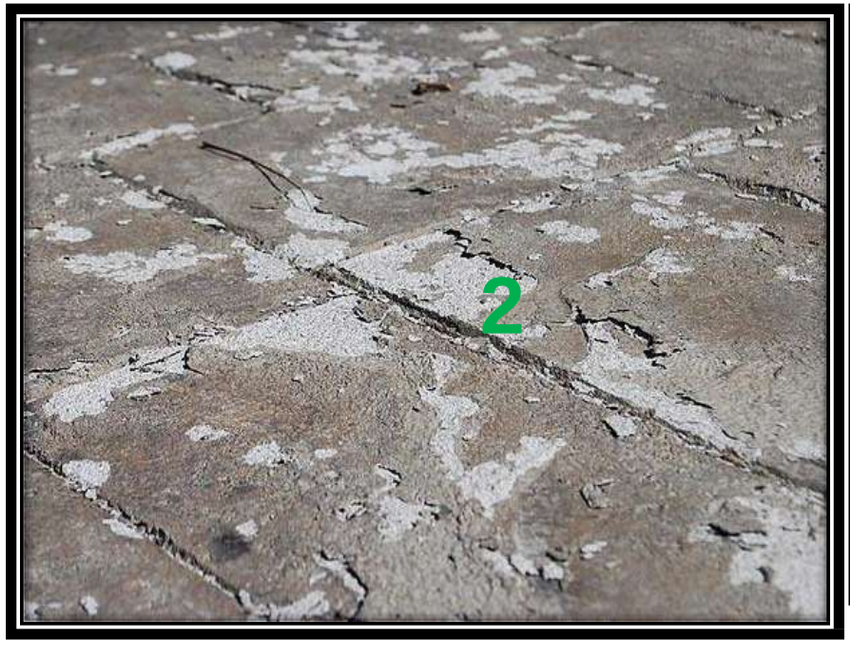
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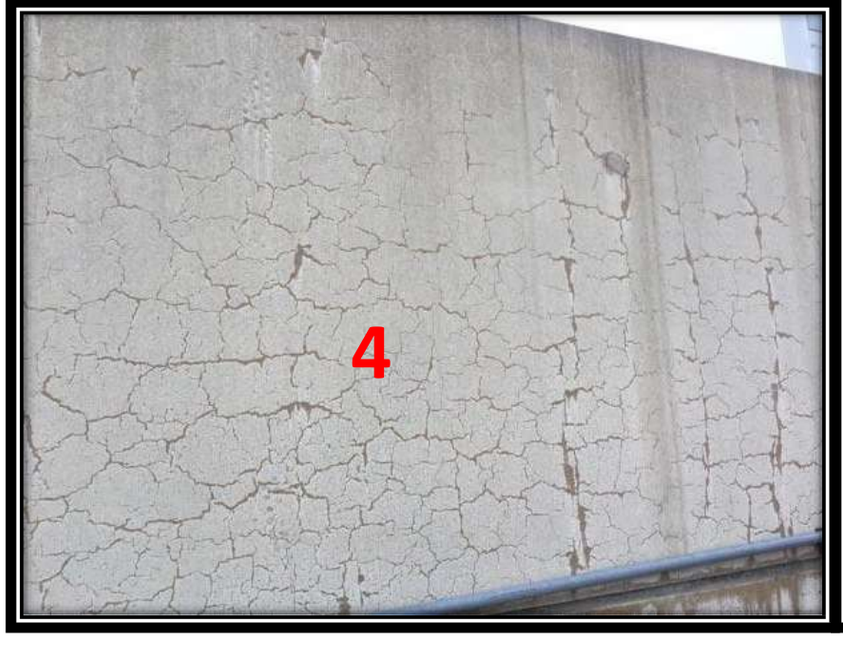
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3. Chemical attack in concrete

- Chemical attack is one of the more common causes of deterioration of concrete in industry today. Animal fats, natural and artificial oils, acids, alkalis, and various industrial salts are all damaging to concrete.
- Chemical attack occurs due to pollution products and following discharge activity on the insulator surface. Examination of field-aged insulators has found formation of uniform thin pollution layers on the surface.
- *A chemical attack* involves dissolution of substances or chemical reactions between substances and components of the concrete. Reaction products might cause problems, due to dissolution or expansion.

4. Alkali-Aggregate Reactivity in concrete

- Alkali-aggregate reactions can be either alkali-carbonate reactions (ACRs) or alkali-silica reactions (ASRs). In ACR, the reaction is between the alkalies (sodium and potassium) and certain carbonate rocks, particularly calcitic dolomite and dolomitic limestones, present in some aggregates.
- It is a deleterious swelling reaction that occurs over time in concrete between the highly alkaline cement paste and the reactive amorphous (i.e., non-crystalline) silica found in many common aggregates, given sufficient moisture. This deleterious chemical reaction causes the expansion of the altered aggregate by the formation of a soluble and viscous gel of sodium silicate.
- This hygroscopic gel swells and increases in volume when absorbing water: it exerts an expansive pressure inside the siliceous aggregate, causing spalling and loss of strength of the concrete, finally leading to its failure.

5. Abrasion Erosion in concrete

- The abrasion damage caused by the grinding action of silt, sand, and rock. The grinding action will remove the concrete surface and expose the aggregates in some cases. Hydraulic concrete structures frequently experience long-term abrasive erosion by water-borne sand, resulting in surface damage, eventually limiting their service life.

- Abrasion damage occurs when the surface of concrete is unable to resist wear caused by rubbing and friction. As the outer paste of concrete wears, the fine and coarse aggregate are exposed and abrasion and impact will cause additional degradation that is related to aggregate-to-paste bond strength and hardness of the aggregate.

6. Plastic Shrinkage in concrete

- Loss of water from fresh concrete, which leads to plastic shrinkage, can occur in a couple of ways. The predominant mode is, however, through evaporation from an exposed surface.
- Concrete can also lose water through suction by the subbase or, depending on the type of material used in its manufacture, the formwork. Such loss of water can aggravate the effects of surface evaporation.
- It is generally accepted that the loss of water from the paste fraction of concrete due to external factors generates negative capillary pressures that cause the volume of the paste to contract, hence the shrinkage.
- The rate of water evaporation is usually aggravated by a combination of high wind speed, low relative humidity, and high ambient and concrete temperatures.

7. Drying Shrinkage in concrete

- The loss of moisture from concrete after it hardens, and hence drying shrinkage, is inevitable unless the concrete is completely submerged in water or is in an environment with 100 percent relative humidity.
- Thus, drying shrinkage is a phenomenon that routinely occurs and merits careful consideration in the design and construction of concrete structures.

8. Overload impact in concrete

- Overload damage can occur during construction when concrete has not yet reached design strength.
- Early removal of formwork or the storage of heavy materials or operation of equipment on and around the structure can result in the overloading of certain concrete members.

9. Patch Accelerated Corrosion in concrete

- Commonly referred to as “ring anode corrosion” or “halo effect”, patch accelerated corrosion is a phenomenon specific to concrete restoration projects. When repairs are completed on corrosion-damaged structures, abrupt changes in the concrete surrounding the reinforcing steel are created.

10.1.2 Prevention of concrete deterioration:-

1. From the consideration of permeability, the **water-cement ratio** is usually limited to **0.45 to 0.55**.
2. The cement content should be such that it ensures sufficient alkalinity to prevent corrosion of reinforcement. For concreting under marine environment, minimum cement content of **350 kg/m** or more is to be used.
3. The water-cement ratio and the cement content must provide enough paste to overfill the voids in **compacted concrete**.
4. Use of Portland slag cement or Portland pozzolana cement is advantageous for **concreting in sea water**.
5. Use of Portland cement having **C3A** content less than **5%** is suitable for concreting under sulphate environment.
6. The super-sulphated cement provides acceptable durability against the **acidic environment**.
7. Addition of hydraulic additives is also helpful to prevent the deterioration of concrete.
8. It is possible to attain a marked improvement in the quality of concrete by encouraging natural or artificial carbonation of the surface layer.
9. Deterioration of concrete can also be prevented by treating the concrete with **solutions of suitable salts or even acids** in minor concentration
10. The durability of concrete can also be increased by impregnating the pores with a **suitable polymer**.

10.1.2 Corrosion of reinforcement, effects and prevention

- Corrosion of steel reinforcement bars is basically an electrochemical reaction. Small anodes and cathodes are created and a flow of ions between these two electrodes lead to the corrosion of the steel bars. There are two types of corrosion observed in the steel reinforcement bars:
  - Crevice corrosion – In small crevices within the concrete structure, solutions may get stagnated. Anodes and cathodes may be created within the solutions due to uneven reaction of solute ions over the volume of the solution. Flow of ions is triggered by these electrodes, thus slowly causing corrosion.
  - Pitting corrosion – It is related to de-passivation of small areas on the steel reinforcement bars. This type of corrosion is extremely localized and small holes or pits are created in the steel.

Q Effects and Prevention

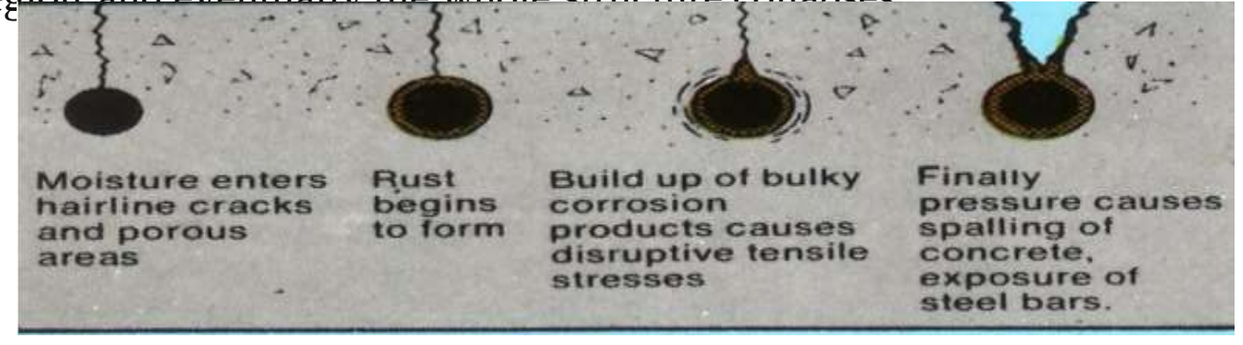
The main factors responsible for corrosion of reinforcement bars are:

1. **Loss of alkalinity due to carbonation** – When the steel surface is left unprotected in the atmosphere, rust begins to form on the steel surface and gradually flakes off.
2. **Loss of alkalinity due to chlorides** – Chloride ions tend to de-passivate the steel surface by destroying the alkalinity of the concrete.
3. **Cracks in concrete** – Cracks may expose the steel bars to the atmosphere and hence increase carbonation.
4. **Moisture pathways** – Regular wetting of the concrete may lead to water reaching the steel reinforcement bars by diffusion through the pore structure of the concrete or cracks present in the concrete. Rusting of the steel bars follow thereafter.
5. **Insufficient Cover:** Insufficient dimension of concrete cover.

Effects of Corrosion on Steel Reinforcement

Once the steel bars start corroding, the reinforced concrete member gradually begins deteriorating going through the following stages:

1. **Formation of white patches –** Atmospheric carbon dioxide reacts with calcium hydroxide present in the cement paste forming calcium carbonate. This calcium carbonate is carried by moisture and deposited onto the concrete surface forming white patches.
2. **Brown patches along reinforcement –** When the steel bars start corroding, a layer of iron oxide is formed on it. This iron oxide also gets carried to the surface of the concrete by moisture.
3. **Formation of cracks –** The products of corrosion occupy a greater volume than the original material. Hence they exert pressure on the concrete and crack it. With more corrosion occurring, more and wider cracks are formed.
4. **Spalling of concrete cover –** Due to loss of the bond between concrete and steel, the concrete starts forming multiple layers of scales and peels off. The steel bars also get reduced in size.
5. **Snapping of bars –** Due to reduction in the size of the steel bars, they finally snap. Also, there is a considerable reduction in the size of the main bars.
6. **Buckling of bars –** Spalling of the concrete cover and snapping of bars lead to buckling of the main bars. This bulges the concrete in that region and eventually the whole structure collapses.



Q Prevention of Corrosion of Reinforcement:-

- **Providing Sufficient Concrete Cover:** A good amount of concrete cover should be provided over the steel reinforcement bars. This ensures proper maintenance of the alkaline nature within the concrete and the passivity of the steel bars. The steel bars should be precisely placed in position
- **Use of Good Quality Concrete:** High quality concrete must be used. It helps to maintain proper alkaline nature. For the concrete, a water/cement ratio of 0.4 or less is to be maintained. Excessive water may damage the steel bars
- **Proper Compaction fo Concrete:** Concrete must be completely compacted such that there are no air voids or pockets present inside
- **Use of FBE coated Bars:** Fusion Bonded Epoxy Coating (FBEC) may be applied on the steel bars to prevent them from corrosion. Epoxy powder is spread electrostatically on to the steel bars. The powder melts and flows over the bars upon heating, forming a protective coating. They are thermoset polymer coatings because application of heat will not melt the coating. Apart from rebar it also has wide application in pipeline construction
- **Use of Cement Based Polymers:** Cement based polymers can be used in the concrete to enhance its protection against corrosion capabilities. The cement based polymers act as a binder in the concrete. They also increase the durability, tensile strength and vibration damping of the concrete.
- **RCPT test to assess degree of Corrosion:** The Rapid Chloride Permeability Test (RCPT) may be performed to assess the degree of corrosion. The quantity of electrical current that passes through a sample 50 mm thick and 100 mm in diameter in 6 hours is measured. Based on this a qualitative rating is made of the permeability of the concrete
- **Use of Migratory Corrosion Inhibitors:** Migratory corrosion inhibitors may be used in the concrete mix or may be applied on the hardened surface of the concrete. These inhibitors diffuse through the concrete cover and reach the steel bars to protect them against corrosion. Calcium nitrite based inhibitors are quite common