LECTURE NOTE ON

"TH-4 "_CONCRETE TECHNOLOGY"

6TH SEMESTER

DEPARTMENT OF

CIVIL ENGINEERING

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CHAPTER:-01-Concrete as a construction material-

1.1- GRADES OF CONCRETE

- **Concrete is generally graded according to its compressive strength. The various grades of concrete as stipulated in IS: 456-2000 and IS: 1343-1980 are given in Table 1.1.**
- **In the designation of concrete mix, the letter M refers to the mix and the number to the specified characteristic strength of 150 mm work cubes at 28 days, expressed in MPa (N/mm^2).**
- **The concrete of grades M5 and M7.5 is suitable for lean concrete bases, simple foundations, foundations for masonry walls and other simple or temporary reinforced concrete constructions. These need not be designed.**
- **The concrete of grades lower than M15 is not suitable for reinforced concrete works and grades of concrete lower than M30 are not to be used in the prestressed concrete works.**

Table 1.1 Grades of concrete

Group	Ordinary concrete			Standard concrete							High strength concrete			
Grade designation	M10	M15	M20	M25	M30	M35	M40	M45	M50	M55	M60	M65	M70	M75	M80
Specified characteristic strength at 28 days, MPa	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80

1.2-ADVANTAGES AND DISADVANATGES OF CONCRETE-

ADVANTAGES OF CONCRETE

Concrete as a construction material has the following advantages:

1. **Concrete is economical in the long run as compared to other engineering materials. Except cement, it can be made from locally available coarse and fine aggregates.**

2. **Concrete possesses a high compressive strength, and the corrosive and weathering effects are minimal. When properly prepared its strength is equal to that of a hard natural stone.**

3. The green or newly mixed concrete can be easily handled and molded or formed into virtually any shape or size according to specifications. The formwork can be reused a number of times for similar jobs resulting in economy.

4. It is strong in compression and has unlimited structural applications in combination with steel reinforcement. Concrete and steel have approximately equal coefficients of thermal expansion.

5. Concrete can even be sprayed on and filled into fine cracks for repairs by the guniting process.

6. Concrete can be pumped and hence it can be laid in difficult positions also.

7. It is durable, fire resistant and requires very little maintenance.

DISADVANTAGES OF CONCRETE

The following are the disadvantages of concrete:

1. Concrete has low tensile strength and hence cracks easily. Therefore, concrete is to be reinforced with steel bars or meshes or fibers.

2. **Fresh concrete shrinks on drying and hardened concrete expands on wetting. Provision for construction joints has to be made to avoid the development of cracks due to drying shrinkage and moisture movement.**

3. **Concrete expands and contracts with the changes in temperature. Hence, of expansion joints have to be provided to avoid the formation of cracks due to be thermal movement.**

4. **Concrete under sustained loading undergoes creep, resulting in the reduction of prestress in the prestressed concrete construction.**

5. **Concrete is not entirely impervious to moisture and contains soluble salts which may cause efflorescence.**

6. **Concrete is liable to disintegrate by alkali and sulphate attack.**

7. **The lack of ductility inherent in concrete as a material is disadvantageous with respect to earthquake resistant design.**

*****End*****

CHAPTER:-02 -Cement

Introduction:

- **Cement is a building material for binding bricks, stones or aggregates.**
- **It has cohesive and adhesive properties in the presence of water.**
- **Cement was inverted by ' Joseph Aspdin ' in England in 1824.**
- **Used for making mortar or concrete.**
- **Natural cement:-burning and crushing of stones and lime.**
- **Artificial cement:-burning at high temperature and gypsum is added.**

2.1-COMPOSITION OF ORDINARY CEMENT

- **The ordinary cement contains two basic ingredients, namely, argillaceous and calcareous.**
- **In argillaceous materials, the clay predominates and in calcareous materials, the calcium carbonate predominates.**

Ingredient	Percentage	Range
Lime	(CaO)........... 62	62 to 67
Silica	(SiO_2)........... 22	17 to 25
Alumina	(Al_2O_3) 5	3 to 8
Calcium sulphate	($CaSO_4$)........... 4	3 to 4
Iron oxide	(Fe_2O_3).............3	3 to 4
Magnesia	(MgO)..............2	1 to 3
Sulphur	(S) 1	1 to 3
Alkalies	….................... 1	0.2 to 1
	Total..............100	

Hydration of Cement

- The chemical reaction that takes place between cement and water is referred to as hydration of cement.
- This reaction is exothermic in nature i.e., considerable amount of heat is liberated in this reaction, which is called as heat of hydration.

- **The hydration of cement is not an instantaneous one. The reaction is faster in the early periods and continues indefinitely at a decreasing rate.**
- **During hydration, C_3S and C_2S react with water and calcium silicate hydrate (C-S-H) is formed along with calcium hydroxide [$Ca(OH)_2$].**

$$2\,C_3S + 6H \rightarrow C_3S_2\,H_3 + 3Ca(OH)_2$$

$$2C_2S + 4H \rightarrow C_3S_2\,H_3 + Ca(OH)_2$$

- **Calcium silicate hydrate is the most important product of hydration and it determines the good properties of cement.**
- **It can be seen from the above reactions that C_3S produces more quantity of calcium than C_2S.**
- **It has been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. As this 23% of water chemically combines with cement, it is called as bound water.**
- **A certain quantity of water is imbibed within the gel pores. This water is known as gel water. The bound water and gel water are complementary to each other.**
- **It has been estimated that 15% water by weight of cement is required to fill up the gel pores.**

- **Therefore, a total of 38% of water by weight of cement is required for the complete chemical reaction of cement and occupy the space within gel pores.**
- **If water equal to 38% by weight of cement is only used then it can be notices that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities.**

Water-Cement Ratio:

- **It is defined as the ratio of the weight of free water available to that of the weight of cement in a mix.**
- **Cement being the binding agent in Concrete, the strength of concrete mainly depends on the strength of the cement paste.**
- **The strength of the cement paste in turn depends on the percentage of cement present in it. Thus the strength of concrete decreases with increase in water cement ratio, as the percentage of cement present in the cement paste decreases with increase in water cement ratio.**
- **This relationship is known as Abram's law.**
- **This law states that the compressive strength of hardened concrete is inversely proportional to the water cement ratio, provided the mix is workable.**

- **It has to be noted here that with a decrease in water-cement ratio the strength of the concrete increases, but it will become more and more difficult to achieve complete compaction of concrete.**
- **Further, when the water-cement ratio is below a practical limit, the strength of the concrete falls rapidly as some cement will be left unreacted and air voids are introduced.**
- **Generally, the water - cement ratio lies in the range of 0.35 to 0.65.**

Compressive strength:

- **It is one of the important properties of cement.**
- **The strength tests, generally carried out in tension on samples of neat cement, are of doubtful value as an indication of ability of the cement to make concrete strong in compression.**
- **Therefore, these are largely being superseded by the mortar cube crushing tests and concrete compression tests.**
- **These are conducted on standardized aggregates under carefully controlled conditions and therefore give a good indication on strength qualities of cement.**

- **Cement mortar cubes (1:3) having an area of 5000 mm^2 are prepared and tested in compression testing machine.**
- **For ordinary Portland cement, the compression strength at three and seven days curing shall not be less than 16 MPa and 22 MPa, respectively.**

Fineness:

- **The fineness of a cement is a measure of the size of particles of cement and is expressed in terms of *specific surface of cement.***
- **It can be calculated from particle size distribution or one of the air permeability methods.**
- **It is an important factor in determining the *rate of gain of strength and uniformity of quality.***
- **For a given weight of cement, the surface area is more for a finer cement than for a coarser cement.**
- **The finer the cement, the higher is the rate of hydration, as more surface area is available for chemical reaction. This results in the early development of strength.**

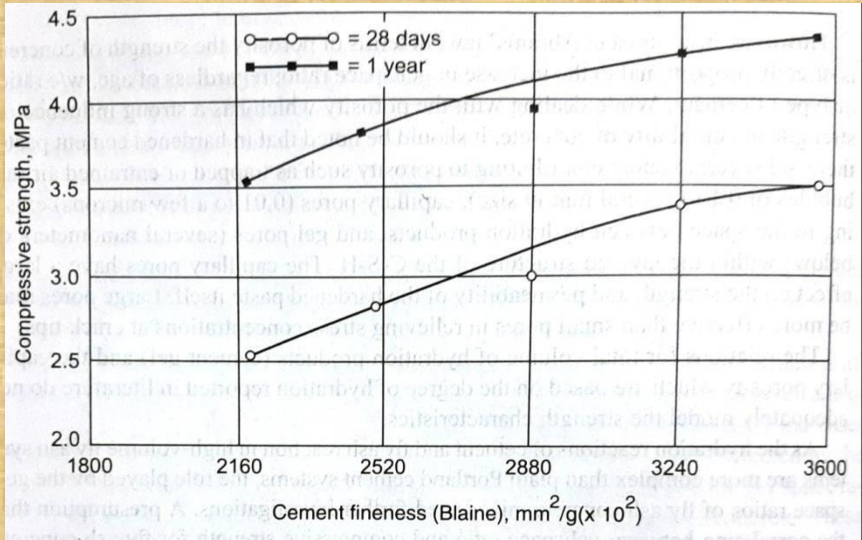


Fig. 2.13 *The effect of fineness of cement on the compressive strength of concrete*

- **The effect of fineness on the compressive strength of cement is shown in Fig. 2.13.**
- **If the cement is ground beyond a certain limit, its cementative properties may be adversely affected due to prehydration by atmospheric moisture.**
- **As per Indian Standard Specifications, the residue of cement should not exceed 10 percent when sieved on a 90-micron IS sieve.**
- **In addition, the amount of water required for constant slump concrete decreases with the increase in the fineness of cement.**

Setting time:

- **Cement when mixed with water forms paste which gradually becomes less plastic, and finally a hard mass is obtained.**
- **In this process of set this stage of setting, a stage is reached when the cement paste is sufficiently rigid to withstand a definite amount of pressure.**
- **The time to reach this stage is termed as *setting time*. The time is reckoned from the instant when water is added to the cement.**

- **The setting time is divided into two parts, namely, the *initial and the final setting times.***
- **The time at which the cement paste loses its plasticity is termed the *initial setting time.***
- **The time taken to reach the stage when the paste becomes a hard mass is known as the final setting time.**
- **It is essential for proper concreting that the initial setting time be sufficiently long for finishing operations, i.e., transporting and placing the concrete.**
- **The setting process is accompanied by temperature changes. The temperature rises rapidly from the initial setting to a peak value at the final setting.**
- **The setting time decreases with rise in temperature up to 30°C and vice versa.**
- **For an ordinary Portland cement, *the initial setting time should not be less than 30 minutes* and *final setting time should not be more than 600 minutes.***

Soundness:

- **The unsoundness of cement is caused by the undesirable expansion of some of its constituents, sometimes after setting.**

- **The large change in volume accompanying expansion results in disintegration and severe cracking.**
- **The unsoundness is due to the presence of free lime and magnesia in the cement.**
- **The free lime hydrates very slowly because it is covered by the thin film of cement which prevents direct contact between lime and water.**
- **After the setting of cement, the moisture penetrates into the free lime resulting in its hydration.**
- **Since slaked lime occupies a larger volume, the expansion takes place resulting in severe cracking.**
- **The unsoundness due to the presence of magnesia is similar to that of lime.**
- **The unsoundness may be reduced by**

  (a) limiting the MgO content to less than 0.5 per cent,

  (b) fine grinding,

  (c) allowing the cement to aerate for several days, and

  (d) thorough mixing.

- **The chief tests for soundness are the Le Chatelier and Autocalve tests.**

- The expansion carried out in the manner described in IS: 269-1989 should not be more than 10 mm in the Le Chatelier test and 0.8 per cent in Autoclave test.

TYPES OF CEMENT

In addition to ordinary cement, the following are the other important varieties of cement:

(1) Acid-resistant cement

(2) Blast furnace cement

(3) Coloured cement

(4) Expanding cement

(5) High alumina cement

(6) Hydrophobic cement

(7) Low heat cement

(8) Pozzolana cement

(9) Quick setting cement

(10) Rapid hardening cement

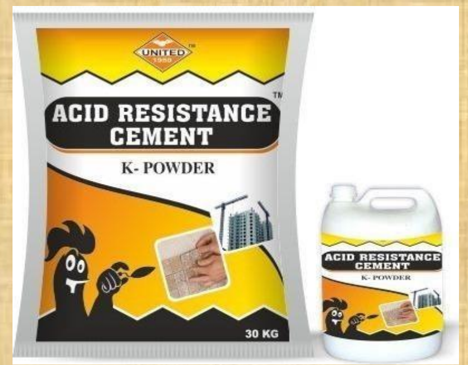
(11) Extra rapid hardening cement

(12) Sulphate resisting cement

(13) White cement.

(1)* Acid-resistant cement:** ***An acid-resistant cement is composed of the following:

(i) acid-resistant aggregates such as quartz, quartzites, etc.;



(ii) additive such as sodium fluosilicate $Na_2 SiF_6$; and

(iii) aqueous solution of sodium silicate or soluble glass.

- The acid-resistant cement is used for acid-resistant and heat-resistant coatings of installations of chemical industry.
- By adding 0.50 per cent of linseed oil or 2 per cent of ceresit, its resistance to the water is increased and it is then known as the *acid and water resistant cement*.

(2) Blast furnace cement:

- For this cement, the slag as obtained from blast furnace is used.
- The slag is a waste product in the manufacturing process of pig-iron and it contains the basic elements of cement, namely, alumina, lime and silica.
- The clinkers of cement are ground with about 60 to 65 per cent of slag.
- The properties of this cement are more or less the same as those of ordinary cement.
- Its strength in early days is less and hence it requires longer curing.

(3) Coloured cement:

- The cement of desired colour may be obtained by intimately mixing mineral pigments with ordinary cement.
- The amount of colouring material may vary from 5 to 10 per cent. If this percentage exceeds 10 per cent, the strength of cement is affected.
- The chromium oxide gives green colour. The cobalt imparts blue colour. The iron oxide in different proportions gives brown, red or yellow colour. The manganese dioxide is used to produce black or brown coloured cement.
- The coloured cements are widely used for finishing of floors, external surfaces, artificial marble, window sill slabs, textured panel faces, stair treads, etc.

(4) Expanding cement:

- This type of cement is produced by adding an expanding medium like sulpho-aluminate and a stabilising agent to the ordinary cement. Hence, this cement expands whereas other cements shrink.
- The expanding cement is used for the construction of water retaining structures and also for repairing the damaged concrete surfaces.

(5) High alumina cement:

- This cement is produced by grinding clinkers formed by calcining bauxite and lime. The bauxite is an aluminium ore.
- It is specified that total alumina content should not be less than 32 per cent and the ratio by weight of alumina to the lime should be between 0.85 and 1.30.

(6) Hydrophobic cement:

- This type of cement contains admixtures which decrease the wetting ability of cement grains.
- The usual hydrophobic admixtures are acidol, naphthenesoap, oxidized petrolatum, etc. These substances form a thin film around cement grains.

- When hydrophobic cement is used, the fine pores in concrete are uniformly distributed and thus the frost resistance and the water resistance of such concrete are considerably increased.

(7) Low heat cement:

- The considerable heat is produced during the setting action of cement. In order to reduce the amount of heat, this type of cement is used.
- It contains lower percentage of tricalcium aluminate C_3A of about 5% and higher percentage of dicalcium silicate C_2S of about 46%.

- **The initial setting time is about one hour and final setting time is about 10 hours.**
- **It is mainly used for mass concrete work.**

(8) Pozzolana cement:

- **The Pozzolana is a volcanic powder. The percentage of Pozzolana material should be between 10 to 30.**
- **This cement is used to prepare mass concrete of lean mix and for marine structures. It is also used in sewage works and for laying concrete under water.**

(9) Quick setting cement:

- **This cement is produced by adding a small percentage of aluminium sulphate and by finely grinding the cement.**
- **The addition of aluminium sulphate and fineness of grinding are responsible for accelerating the setting action of cement.**
- **The setting action of cement starts within five minutes after addition of water and it becomes hard like stone in less than 30 minutes or so.**
- **The extreme care is to be taken when this cement is used as mixing and placing of concrete are to be completed in a very short period.**

- This cement is used to lay concrete under static water or running water.

(10) Rapid hardening cement:

- The initial and final setting times of this cement are the same as those of ordinary cement. But it attains high strength in early days.
- It contains high percentage of tricalcium silicate C_3S to the extent of about 56%.
- This cement is used for the formwork of concrete that can be removed earlier.

(11) Extra rapid hardening cement:

- It is obtained by inter-grinding calcium chloride with rapid hardening Portland cement.
- The normal addition of calcium chloride should not exceed 2% by the weight of rapid hardening cement.
- This type of cement should be transported, placed, compacted and finished within 20 minutes after mixing.

(12) Sulphate resisting cement:

- **It is a cement with low C_3A content and comparatively lower C_4AF content. The percentage of C_3A (tricalcium aluminate) is kept below 5 per cent and it results in the increase in resisting power against sulphate attack.**
- **Sulphate resisting cement is used for the structures which are likely to be damaged by severe alkaline conditions such as canal linings, culverts, siphons,etc.**

(13) White cement:

- **It is prepared from such raw materials which are practically free from colouring oxides of iron, manganese or chromium.**
- **It is white in colour and it is used for floor finish, plaster work, ornamental work, etc.**

*****end*****

CHAPTER:-03-Aggregate, Water and Admixtures

Introduction:

- **In the construction industry, aggregates are used as filler material in the production of concrete and mortar.**
- **Aggregates occupy around 70 to 80 percent of the volume of the concrete, reduce shrinkage effects and minimize costs.**

3.1-Classification of Aggregates:

A. Based on Geological Origin:

On the basis of origin, aggregates can be classified into *natural aggregates and artificial aggregates.*

(i) Natural Aggregates:

The aggregates which are obtained by crushing igneous, sedimentary or metamorphic rocks are called natural aggregates. Aggregates obtained from igneous rocks have the best engineering properties; hence they are the most widely used aggregates.

(ii) Artificial Aggregates:

The aggregates which are obtained from man-made processes are called artificial aggregates. Surkhi (powdered broken brick), Blast furnace slag aggregates and synthetic aggregates are some of the examples of artificial aggregates.

B. Based on Size:

According to size, aggregates can be classified as *coarse aggregates and fine aggregates.*

(i) Coarse Aggregates:

The aggregates which pass through the 80 mm sieve and are retained on the 4.75 mm sieve are called as coarse aggregates.

(ii) Fine Aggregates:

All the aggregates which pass through the 4.75 mm sieve are called as fine aggregates. On the basis of particle size distribution, the fine aggregates are classified into four zones (i.e.) Zone I to Zone IV. The grading zones are progressively finer from grading Zone I to grading Zone IV.

C. Based on Shape:

Based on the shape of the aggregates, they are classified as rounded, irregular, angular and flaky.

(i) Rounded Aggregates:

The aggregates which are obtained from river or sea shores are generally close to spherical in shape and are called as rounded aggregates. These aggregates have minimum surface area to the volume and have poor interlocking bond, making them unsuitable for the production of concrete.

(ii) Irregular Aggregates:

These aggregates are irregular in shape and require more cement paste compared to rounded aggregates. Because of the irregularity in shape, these aggregates form good interlocking bond and are suitable in the production of concrete.

(iii) Angular Aggregates:

These aggregates are sharp, have angular shape and rough texture. These aggregates are best suited for the preparation of high strength concrete.

(iv) Flaky Aggregates:

The aggregates whose thickness is less than 0.6 times the mean dimension are called are Flaky Aggregates.

(v) Elongated Aggregates:

The aggregates whose length is 1.8 times the mean dimension are called as Elongated Aggregates.

Characteristics of Aggregates:

1. Strength of aggregate:

- **The strength of concrete cannot exceed that of the bulk of aggregate contained therein. Therefore, so long as the strength of aggregate is of an order of magnitude stronger than that of the concrete made with them, it is sufficient.**
- **Generally three tests are prescribed for the determination of strength of aggregate, namely, aggregate crushing value, aggregate impact value and 10 per cent fines value.**
- **Crushing strength of good coarse aggregate is about 200 N/mm^2.**

2. Particle shape and texture:

- The physical characteristics such as *shape, texture and roughness of aggregates,* significantly influence the mobility (i.e., the workability) of fresh concrete and the *bond* between the aggregate and the mortar phase.
- Rounded particles produce smoother mix for a given water cement ratio.
- Angular or flaky particles reduce workability and demand more cement and water to give specified strength of concrete mix.

3. Specific gravity:

- The specific gravity of an aggregate is defined as the ratio of the mass of solid in a given volume of sample to the mass of an equal volume of water at the same temperature.
- Since the aggregate generally contains voids, there are different types of specific gravities.
- The average specific gravity of majority of natural aggregates lie between 2.5 and 2.8.

4. Bulk density:

- **The bulk density of an aggregate is defined as the mass of the material in a given volume and is expressed in kilograms/liter.**
- **The bulk density of an aggregate depends on how densely the aggregate is packed in the measure.**
- **The other factors affecting the bulk density are the particle shape, size, the grading of the aggregate and the moisture content.**
- **The shape of the particles greatly affects the closeness of the packing that can be achieved.**
- **For a coarse aggregate of given specific gravity, a higher bulk density indicates that there are fewer voids to be filled by sand and cement.**

5. Voids:

- **The empty spaces between the aggregate particles are termed voids.**
- **It is the difference between the gross volume of aggregate mass and the volume occupied by the particles alone.**

6. Porosity and absorption of aggregates:

- **Due to the presence of air bubbles which are entrapped in a rock during its formation or on account of the decomposition of certain constituent minerals by *atmospheric action, minute holes or cavities* are formed in it which are commonly known as *pores.***
- **The percentage of water absorbed by an aggregate when immersed in water is termed the *absorption of aggregate.***
- **The porosity of some of the commonly used rocks varies from 0 to 20 per cent.**
- **The *permeability and absorption* affect the bond between the aggregate and the cement paste.**

7. Moisture content of aggregate:

- **The surface moisture expressed as a percentage of the weight of the saturated surface dry aggregate is termed as moisture content.**
- **Since the absorption represents the water contained in the aggregate in the saturated-surface dry condition and the moisture content is the water in excess of that, the total water content of a moist aggregate is equal to the sum of absorption and moisture content.**

- **A high moisture content will increase the effective water-cement ratio to an appreciable extent and may make the concrete weak unless a suitable allowance is made.**

8. Bulking of fine aggregate:

- **The increase in the volume of a given mass of fine aggregate caused by the presence of water is known as *bulking.***
- **The bulking of fine aggregate is caused by the films of water which push the particles apart. The extent of bulking depends upon the percentage of moisture present in the sand and its fineness.**
- **With ordinary sands the bulking usually varies between 15 and 30 per cent.**
- **Finer sand bulks considerably more and the maximum bulking is obtained at a higher water content than the coarse sand.**
- **In extremely fine sand, the bulking may be of the order of 40 per cent at a moisture content of 10 per cent but such a sand is unsuitable for concrete.**
- **In the case of coarse aggregate, the increase in volume is negligible due to the presence of free water.**

Fineness Modulus (FM):

- **The *fineness modulus* is a numerical index of fineness, giving some idea of the *mean size* of the particles present in the entire body of the aggregate.**
- **Fineness modulus is determined by sieve analysis.**
- **FM = The ratio of the cumulative percentage of material retained on each sieve / 100.**
- **The value of fineness modulus is higher for coarser aggregate.**
- **For the aggregates commonly used, the fineness modulus of *fine aggregate* varies between 2.0 and 3.5, for *coarse aggregate* it varies between 5.5 and 8.0.**

Grading of aggregate:

- **The *particle size distribution* of an aggregate as determined by sieve analysis is termed *grading of the aggregate*.**
- **Sieve analysis is used for gradation.**
- **Sieve sizes 80 mm to 150 μ are used in the sieve analysis.**
- **The *grading* of fine aggregate has a much greater effect on workability of concrete than does the grading of the coarse aggregate.**

3.2-QUALITY OF MIXING WATER

- **The water used for the mixing and curing of concrete should be free from injurious amounts of deleterious materials.**
- **The unwanted situations, leading to the distress of concrete, have been found to be a result of, among others, the mixing and curing water being of inappropriate quality.**
- **Potable water from the sources is generally considered satisfactory for mixing concrete.**
- **In the case of doubt about the suitability of water, particularly in remote areas or where water is derived from sources not normally utilized for domestic purposes, water should be tested.**

CURING WATER

- **The use of water in curing the concrete is intended to penetrate the concrete.**
- **If steps are taken to prevent loss of water from the concrete, no added water will be needed as a part of curing process except in the circumstances:**

  (i) when the water-cement ratio is less than 0.4; and

  (ii) when the concrete is produced using expansive cement.

- The water which is satisfactory for mixing concrete can also be used for curing it but should not produce any objectionable stain or unsightly deposit on the surface.
- According to IS: 456-2000, the presence of tannic acid or iron compounds in curing water is objectionable.
- It is generally recommended that the seawater should not be used as mixing water for hydraulic-cement concrete works containing corrodible embedded ferrous metals.

Admixtures:

- To modify the properties of concrete as per special requirements.

3.3-FUNCTIONS OF ADMIXTURES-

Some of the important purposes for which the admixtures could be used are the following:

1. To accelerate the initial set of concrete, i.e., to speed up the rate of development of strength at early ages.

2. To retard the initial set, i.e., to keep concrete workable for a longer time for placement.

3. To enhance the workability.

4. To improve the penetration (flow ability) and pump ability of concrete.

5. To reduce the segregation in grout and concrete mixtures.

6. To increase the strength of concrete by reducing the water content and by densification of concrete.

7. To increase the durability of concrete, i.e., to enhance its resistance to special conditions of exposure.

8. To decrease the capillary flow of water through concrete and to increase its impermeability to liquids.

9. To control the alkali-aggregate expansion or alkali-silica reactivity (ASR).

10. To inhibit the corrosion of reinforcement in concrete.

11. To increase the resistance to chemical attack.

Classified as:

(i) Accelerating admixtures

(ii) Retarding admixtures

(iii) Water Reducing admixtures

(iv) Air entraining admixtures

(i) Accelerating admixtures:

- **To shorten the time of setting or increases the rate of hardening or strength development**
- **Eg: Calcium Chloride.**
- **Uses: (i) Repair works**

  (ii) Precast Production

  (iii) Cold Weather

(ii) Retarding admixtures:

- **To delay the setting of cement.**

- **Eg: Sugar, carbohydrate derivatives, soluble zinc salts gypsum and lignosulphates, etc.**
- **Used in hot weather**

(iii) Water Reducing admixtures:

- **To increase workability without increasing the water content.**
- **Useful for very heavily reinforced sections or where repaid placing of concrete is desired.**
- **Eg: soda, calcium soaps, vegetable oils, fats, waxes, coal tar, ammonium state, Oleate.**

(iv) Air entraining admixtures:

- **Air to be incorporated in the form of minute bubbles in concrete during mixing to increase the workability and resistance to freezing and thawing.**
- **Eg: Vinsol Resin, Aluminum powder, Hydrogen peroxide**

*****end*****

CHAPTER:-04-Properties of fresh concrete-

4.1-CONCEPT OF FRESH CONCRETE-WORKABILITY:

It defines that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, compacted and finished.

Ease: It is related to rheology of fresh concrete which includes performance parameters of stability, mobility and compactability.

- Workability of fresh concrete is a complex system of two critical parameters, consistency and homogeneity.

Consistency: It is the relative mobility or ability of a freshly mixed concrete to flow and the usual measurements are: slump for concrete, flow for mortar or grout, and penetration resistance for neat cement paste.

Major factors affecting consistency are: water content; cement content and its characteristics; plasticity of the cement paste; aggregate content and its

characteristics: air content; temperature; mixing conditions; chemical admixtures and mineral additives used.

Homogeneity: Which means uniform and stable distribution of cement, aggregate and water, and resistance to segregation is a critical physical property of plastic concrete.

- **Low viscosity is essential for ease of placement with cohesion, and for resistance to segregation and bleeding that is necessary for homogeneity.**
- **The addition of super plasticizer improves the wetting out and mixability of the concrete mix. It reduces yield stress which means less mixing energy and time are required. It improves homogeneity of the various mineral additives and admixtures.**

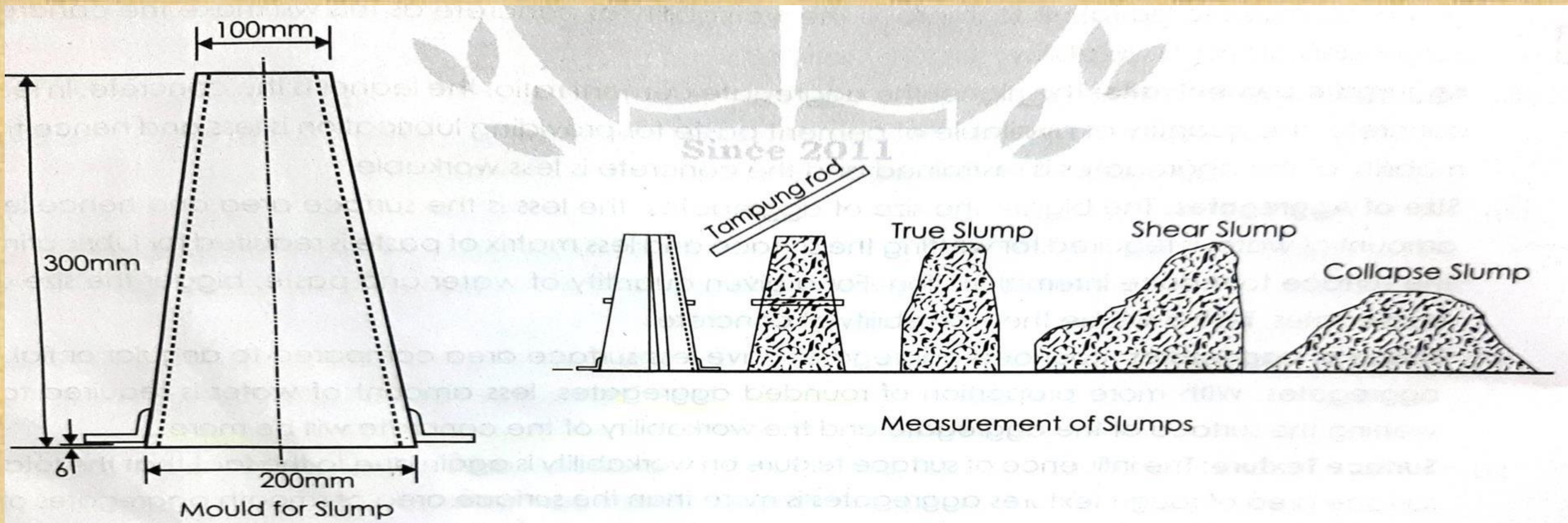
MEASUREMENT OF WORKABILITY

1. **Slump test**
2. **Compacting factor test**
3. **Vee-Bee consistency test**
4. **Flow test**

1. Slump test:

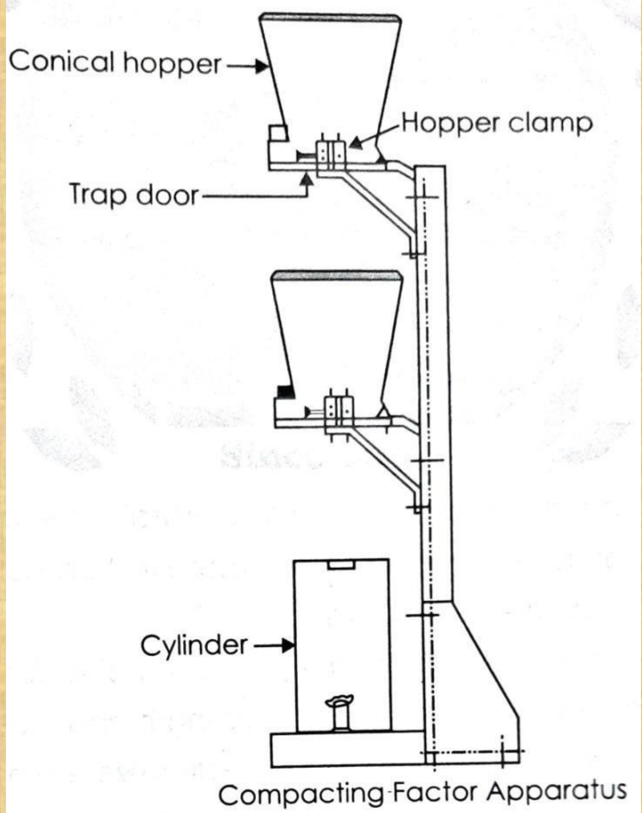
- **Of these four tests, the slump test is perhaps the most widely used, primarily because of the simplicity of the apparatus required and the test procedure.**
- **The slump test indicates the behavior of a compacted concrete cone under the action of gravitational forces.**
- **The test is carried out with a mold called the slump cone.**
- **The slump cone is placed on a horizontal and non-absorbent surface and filled in three equal layers of fresh concrete, each layer being tamped 25 times with a standard tamping rod.**
- **The top layer is struck off level and the mold is lifted vertically without disturbing the concrete cone. The subsidence of concrete in millimeters is termed *the slump*.**
- **The concrete after the test when slumps evenly all around is called true slump.**
- **In the case of very lean concrete, one-half of the cone may slide down the other which is called a shear slump; or it may collapse in case of very wet concretes.**
- **The slump test is essentially a measure of consistency or the wetness of the mix.**

- **The test is suitable only for concretes of medium to high workabilities (i.e., having slump values of 25 mm to 125 mm).**



2. Compacting factor test:

- **This test is more suitable for concrete mixes of medium and low workability.**
- **This test is primarily designed for laboratory, but can also be used at site of work.**
- **The sample of concrete is placed in the top hopper and levelled.**
- **The Trap-door of the top hopper is opened to allow the concrete to fall into the lower hopper.**



- **Now the Trap-door of the lower hopper is opened to allow the concrete to fall into the cylinder.**
- **The concrete over the top of the cylinder is removed.**
- **The weight of the concrete in the cylinder is measured and is known as the weight of the partially compacted concrete.**
- **The cylinder is refilled with concrete from the same sample in layers of 50 mm.**
- **Each layer is rammed heavily or preferably vibrated to get 100% compaction.**
- **The top surface of the fully compacted concrete is carefully struck off level with the top of the cylinder.**
- **The mass of the concrete in this cylinder is measured and is called as the mass of the fully compacted concrete.**
- **C.F= Weight of partially compacted concrete / Weight of fully compacted concrete**

3. Vee-Bee consistency test:

- In this method the workability of concrete is assessed based on the time required for transforming a concrete specimen in the shape of a conical frustum into a cylinder.
- The apparatus consists of a vibrating table, a metal pot, Slump cone and standard tamping rod.
- The concrete specimen is placed in the slump cone in a manner similar to that in the slump cone test.
- The slump cone is placed inside the cylinder of the vibrating table.
- The cone is then lifted up and the electric vibrator is switched on and the concrete is allowed to spread into the cylinder.

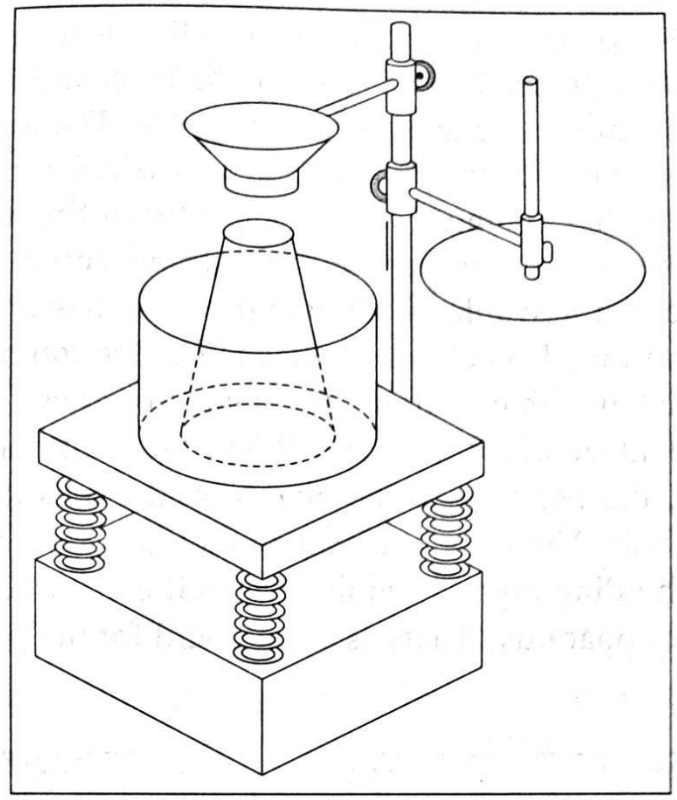
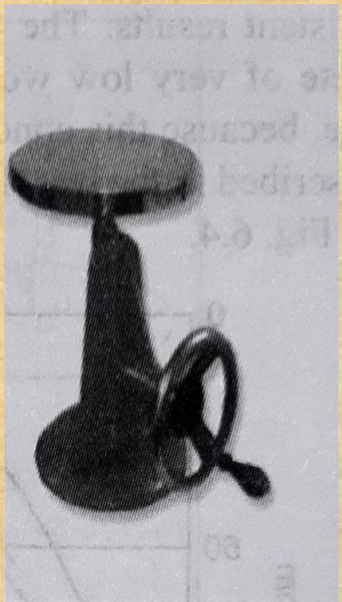


Fig. 6.5 Vee-Bee consistency test apparatus

- The time taken for the concrete specimen to take the shape of the cylinder is noted down.
- The consistency of the concrete is expressed in VB degree which is equal to the recorded time in seconds.

4. Flow test:



(c) The flow table (Manual)

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

REQUIREMENTS OF WORKABILITY

- The workability of fresh concrete should be such that it can be placed in the formwork and compacted with minimum effort, without causing segregation and bleeding.
- The choice of workability depends upon the type of compacting equipment available, the size of the section and concentration of reinforcement.
- Compaction by hand using rodding and tamping is not possible when compacting factor is less than 0.85.
- Ordinary techniques of vibration are not applicable if the compacting factor falls below 0.70. In such cases, techniques like vibro-pressing have to be adopted.

- **For heavily reinforced sections or when the sections are narrow or contain inaccessible parts or when the spacing of reinforcement makes the placing and compaction difficult, the workability should be high to achieve full compaction with a reasonable amount of effort.**
- **The ranges of values indicated are considered suitable for concretes having aggregate of a nominal maximum size of 20 mm.**
- **The value of workability will generally increase with the increase in the size of aggregate and will be somewhat lower for aggregate of smaller size than indicated.**
- **The aim should have the minimum possible workability consistent with satisfactory placement and compaction of concrete.**
- **An insufficient workability may result in incomplete compaction, thereby severely affecting the strength, durability and surface finish of concrete and may indeed prove to be uneconomical in the long run.**

*****End*****

CHAPTER:-05-Properties of hardened concrete-

5.1-Cube and cylinder Compressive Strengths-

- **Of the various strengths of concrete, the determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive stresses.**
- **Cubes, cylinders and prisms are the three types of compression test specimens used to determine the compressive strength on testing machines.**
- **The cubes are usually of 100 mm or 150 mm side, the cylinders are 150 mm diameter by 300 mm height; the prisms used in France are 100mm x 100 mm x 500 mm in size.**
- **The specimens are cast, cured and tested as per standards prescribed for such tests.**
- **Eg: M15, M20, M25**
- **Cube strength = 1.25 × cylinder strength.**

Flexural Strength

- The determination of flexural tensile strength is essential to estimate the load at which the concrete members may crack.
- As it is difficult to determine the tensile strength of concrete by conducting a direct tension test, it is computed by flexure testing.
- The modulus of rupture is determined by testing standard test specimens of 150 mm x 150 mm x 700 mm over a span of 600 mm or 100 mm x 100 mm x 500 mm over a span of 400 mm, under symmetrical two-point loading.
- The results are affected by the size of the specimens; casting, curing and moisture conditions; manner of loading (third point or central point loading); rate of loading, etc.
- The test is conducted and the strength determined according to the prescribed standards.

STRESS AND STRAIN CHARACTERISTICS OF CONCRETE

- A typical stress and strain curve of concrete in compression is shown in Fig. 8.16.

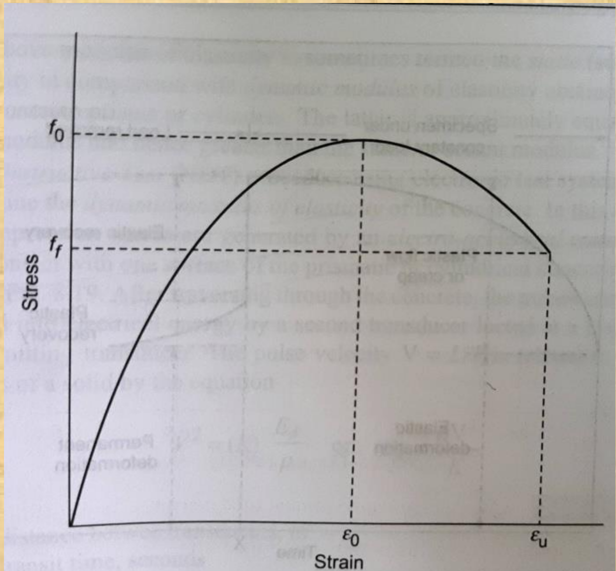


Fig. 8.16 Stress–strain relationship for concrete

- The relation is fairly linear in the initial stages but subsequently becomes non linear reaching a maximum value and then a descending portion is obtained before concrete finally fails.
- The curve is usually obtained by testing a cylinder with a height-to-lateral dimension ratio of at least 2, the test being conducted under uniform rate of strain.
- If a uniform rate of stress is adopted, it will not be possible to obtain the descending portion of stress and strain curve beyond the maximum stress.

Modulus of Elasticity

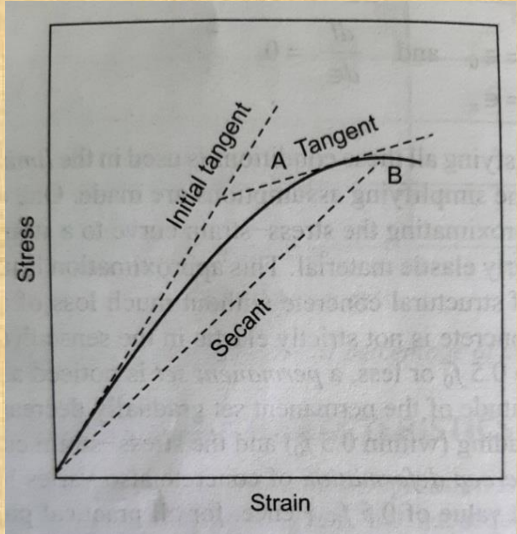


Fig. 8.18 *Different modulii of elasticity*

- The modulus of elasticity of concrete would be a property for the case when the material is treated as elastic.
- If we consider the stress-strain curve of the first cycle, the modulus could be defined as initial tangent modulus, secant modulus, tangent modulus or chord modulus, as shown in Fig. 8.18.
- In the laboratory determination of the modulus of elasticity of concrete, a cylinder is loaded and unloaded (stress not exceeding one-third of f_0)

for three or four cycles, the stress-strain curve is plotted after residual strain has become almost negligible and the average slope of stress-strain curve is taken.

- Non-Destructive Test (NDT) procedure using electronic test system can be used to determine the dynamic modulus of elasticity of the concrete.

Shrinkage of concrete

- It is used to describe the various aspects of volume change in concrete due to loss of water (or) moisture at different stages due to different reasons.

Types of shrinkage:

Two types of shrinkage strains are recognized, namely, *plastic and drying shrinkage.*

1. Plastic Shrinkage

- The hydration of cement causes a reduction in the volume of the system of cement plus water to an extent of about one per cent of the volume of dry cement.

- **This contraction is plastic strain and is aggravated due to loss of water by evaporation from the surface of concrete, particularly under hot climates and high winds.**
- **This can result in surface cracking.**

2. Drying Shrinkage

- **The shrinkage that takes place after the concrete has set and hardened is called drying shrinkage and most of it takes place in the first few months.**
- **Withdrawal of water from concrete stored in unsaturated air voids causes drying shrinkage.**

CREEP OF CONCRETE

- **The increase of strain in concrete with time under sustained stress is termed *creep.***
- **The shrinkage and creep occur simultaneously and they are assumed to be additive for simplicity.**
- **All the factors which influence shrinkage, influence creep also in a similar way.**

- **Types of aggregate, cement, and admixtures, entrained air, mix proportions, mixing time and consolidation, age of concrete, level of sustained stress, ambient humidity, temperature, and the size of the specimen are among the important factors influencing creep.**

PERMEABILITY OF CONCRETE

- **When excess water in concrete evaporates, it leaves voids inside the concrete element creating capillaries which are directly related to the concrete porosity and permeability.**
- **The volume of moisture which may pass through the concrete depends on its permeability.**
- **Permeability is governed by porosity, which in turn is a direct consequence of the water-cement ratio of the concrete mix.**

DURABILITY OF CONCRETE

- **A durable concrete is one that performs satisfactorily under anticipated exposure (working) conditions during its service life span.**

- **The materials and mix proportions used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.**
- **Concrete is a durable material requiring a little or no maintenance in normal environment but when subjected to highly aggressive or hostile environments it has been found to deteriorate resulting in premature failure of structures or reach a state requiring costly repairs.**
- **One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulfate and other potentially deleterious substances.**

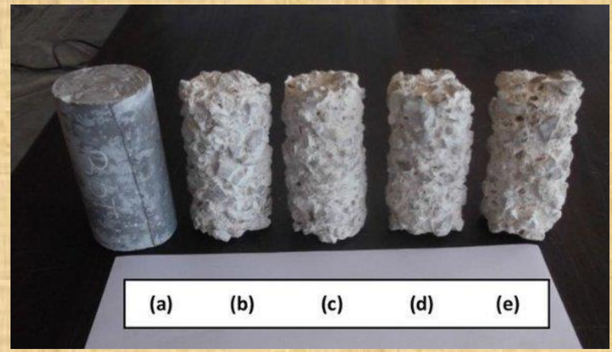
Sulphate Attack

- **Most soils contain some sulphate in the form of calcium, sodium, potassium and magnesium.**
- **Water used in concrete cooling towers can also be a potential source of sulphate attack on concrete.**
- **Solid sulphates do not attack the concrete severely but when the chemicals are in solution, they find entry into porous concrete and react with the hydrated cement products.**

- **Of all the sulphates, magnesium sulphate causes maximum damage to concrete.**
- **A characteristic *whitish* appearance is the indication of sulphate attack.**
- **The rate of sulphate attack increases with the increase in the strength of solution.**

Chloride Attack

- **Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete.**
- **Chloride attack is particularly important because it primarily causes corrosion of reinforcement.**
- **Statistics have indicated that over 40 per cent of failure of structures is due to corrosion of reinforcement.**
- **Chloride enters the concrete from cement, water, aggregate and sometimes from admixtures.**
- **Chloride can enter the concrete by diffusion from environment.**
- **The Bureau of Indian Standard earlier specified the maximum chloride content in cement as 0.05 per cent.**



Acid Attack

- **Concrete is not fully resistant to acids.**
- **Most acid solutions will slowly or rapidly disintegrate Portland cement concrete depending upon the type and concentration of acid.**
- **Concrete can be attacked by liquids with pH value less than 6.5. But the attack is severe only at a pH value below 5.5. At a pH value below 4.5, the attack is very severe.**
- **As the attack proceeds, all the cement compounds are eventually broken down and leached away.**
- **If acids or salt solutions are able to reach the reinforcing steel through cracks or porosity of concrete, corrosion can occur which will cause cracking.**

EFFLORESCENCE

- **The water leaking through cracks or faulty joints or through the areas of poorly compacted porous concrete, dissolves some of the readily soluble calcium hydroxide and other solids, and after evaporation leaves calcium carbonate as white deposit on the surface.**

- **These deposits on the surface of concrete resulting from the leaching of calcium hydroxide and subsequent carbonation and evaporation, are termed efflorescence.**
- **Unwashed seashore aggregate, gypsum and alkaline aggregate also cause efflorescence.**
- **Many kinds of salts have been detected in samples of efflorescence.**

*****End*****

CHAPTER:-06-Concrete Mix Design-

6.1-Introduction

- Concrete of different qualities can be obtained by using its constituents namely, cement, water, fine and coarse aggregates, and mineral additives, in different proportions.
- The common method of expressing the proportions of the materials in a concrete mix is in the form of parts, of ratios of cement, the fine and coarse aggregates with cement being taken as unity.
- For example, a 1:2:4 mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate.
- The amount of water, entrained air and admixtures, if any, are expressed separately.
- The proportion should indicate whether it is by volume or by mass.

6.2-Concrete Mixes:

Nominal Mix:

Mixes of fixed proportions generally by *'volume'* which ensures adequate strength. As per IS: 456-2000, up to M20 can be designed by Nominal mix method.

Standard Mix:

As published in IS 456, set of mixes specified in terms of '*dry weights*' of ingredients.

For eg: M10- 1:3:6 M15 -1: 2:4, M20 - 1:1.5:3,

Design Mix:

The proportions is by 'weight'. No fixed proportions for a specified strength.

For mixes > M25 design mix is a must As per IS: 456-2000 up to M55 - ordinary concrete $\geq$ M60 high strength concrete.

6.3-BASIC CONSIDERATIONS FOR CONCRETE MIX DESIGN

- **The concrete mix design is a process of selecting suitable ingredients for concrete and determining their proportions which would produce, as economically as possible, a concrete that satisfies the job requirements, i.e., concrete having a certain minimum compressive strength, workability and durability.**
- **The proportioning of the ingredients of concrete is an important phase of concrete technology as it ensures quality and economy.**
- **The proportioning of concrete mixes is accomplished by the use of certain empirical relations which afford a reasonably accurate guide to select the best combination of the ingredients so as to achieve the desired properties.**
- **The design of plastic concretes of medium strengths can be based on the following assumptions.**

1. **The compressive strength of concrete is governed by its water-cement ratio.**
2. **For the given aggregate characteristics, the workability of concrete is governed by its water content.**

METHODS OF CONCRETE MIX DESIGN

1. **Trial and adjustment method of mix design**

2. **British DoE mix design method**

3. **ACI mix design method**

4. **Concrete mix proportioning-IS Guidelines**

5. **Rapid method for mix design**

Concrete mix proportioning-IS Guidelines

- **IS 10262: 2009 gives guidelines for concrete mix design.**
- **The procedure for mix design has the following steps.**

1. **Determination of basic characteristics of available fine and coarse aggregates.**

2. **Selection of free water-cement ratio.**

3. **Selection of free water content**

4. **Selection of cement content**

5. Estimation of volume proportion of coarse aggregate in total aggregate

6. Computation of total absolute volume of aggregates

7. Determination of absolute volumes of fine and coarse aggregates

8. Adjustments for aggregate moisture and determination of final proportions

9. Preparation of trial batches and testing

10. Final mix proportions

*****End*****

CHAPTER:-07-Production of Concrete-

Introduction

- **The design of a satisfactory mix proportion is by itself no guarantee of having achieved the objective of quality concrete work.**
- **The batching, mixing, transportation, placing, compaction, finishing and curing are very complimentary operations to obtain desired good quality concrete.**
- **Good quality concrete is a homogeneous mixture of water, cement, aggregates and other admixtures.**

The production of concrete of uniform quality involves the following phases.

7.1-BATCHING OF MATERIALS

- **A proper and accurate measurement of all the materials used in the production of concrete is essential to ensure uniformity of proportions and aggregate grading in successive batches. All the materials should be measured to the tolerances indicated in Table.**

Material	Accuracy of measurement
Aggregates, cement and water	$\pm$3 per cent of batch quantity
Admixtures	$\pm$5 per cent of batch quantity

- **For most of the large and important jobs the batching of materials is usually done by weighing.**
- **The factors affecting the choice of proper batching system are: (i) size of job, (ii) required production rate, and (iii) required standards of batching performance.**
- **The batching equipment falls into three general categories, namely, *manual, semi-automatic, and fully automatic systems.***

1. Manual batching:

- **In this sort of batching all operations of weighing and batching of concrete ingredients are done manually. Manual batching is acceptable for small jobs having low batching rates.**

2. Semi-automatic batching:

- **This batching is one in which the aggregate bin gates for charging batchers are opened by manually operated switches. Gates are closed automatically when the designated weight of material has been delivered.**

- **The system contains interlocks which prevent batcher charging and discharging occurring simultaneously.**
- **Provision is made for the visual inspection of the scale reading for each material being weighed. All the weighing hoppers should be constructed in a manner facilitating their easy inspection.**

3. Automatic batching:

- **Automatic batching is one in which all scales for the materials are electrically activated by a single switch and complete autographic records are made of the weight of each material in each batch.**
- **However, interlocks interrupt the batching cycle when preset weighing tolerances are exceeded.**

MIXING OF CONCRETE MATERIALS

- **The object of mixing is to coat the surface of all aggregate particles with cement paste, and to blend all the ingredients of concrete into a uniform mass.**
- **The mixing action of concrete thus involves two operations:**

  (i) a general blending of different particle sizes of the ingredients to be

uniformly distributed throughout the concrete mass, and

(ii) a vigorous rubbing action of cement paste on to the surface of the inert aggregate particles.

- Concrete mixing is normally done by mechanical means called mixer, but sometimes the mixing of concrete is done by hand.
- Machine mixing is more efficient and economical compared to hand mixing.
- In the mixing process, the cement paste is formed first with simultaneous absorption of water in the aggregates.
- In the second stage, the cement paste coats the aggregate particles.
- The mixing process should be continued till a thoroughly and properly mixed concrete is obtained.
- At the end of this stage the concrete appears to be of uniform colour and grading.
- The uniformity must be maintained while discharging the concrete from the mixer.
- As a matter of fact the classification of the mixers is based on the technique of discharging the mixed concrete as follows:
  1. Tilting type mixer
  2. Non-tilting type
  3. Pan or stirring mixer

TRANSPORTATION OF CONCRETE

- **Concrete from the mixer should be transported to the point where it has to be placed as rapidly as possible by a method which prevents segregation or loss of ingredients.**
- **The concrete has to be placed before setting has commenced. Attempts have been made to limit the time lapse between mixing and compaction within the forms.**
- **The specifications, however, permit a maximum of two hours between the introduction of mixing water to the cement and aggregates, and the discharge, if the concrete is transported in a truck mixer or agitator.**
- **In the absence of an agitator, this figure is reduced to one hour only.**
- **The temperature of concrete, when deposited, is not less than 5 °C or more than 32 °C.**

The requirements to be fulfilled during transportation are:

1. No segregation or separation of materials in the concrete.

2. Concrete delivered at the point of placing should be uniform and of proper consistency.

The principal methods of transporting concrete from the mixer are the following:

1. **Barrows**
   - **(a) Wheel barrows and handcarts**
   - **(b) Power barrows or powered buggies or dumpers**
2. **Tippers and lorries**
3. **Truck mixers and agitator lorries**
4. **Dump buckets**
5. **The monorail system or trolley or rails**

PLACING OF CONCRETE

- **The methods used in placing concrete in its final position have an important effect on its homogeneity, density and behavior in service.**
- **The same care which has been used to secure homogeneity in mixing and the avoidance of segregation in transporting must be exercised to preserve homogeneity in placing.**

- **The forms must be examined for correct alignment and adequate rigidity to withstand the weight of concrete, impact loads during construction without undue deformation.**
- **The forms must also be checked for tightness to avoid any loss of mortar which may result in honeycombing.**
- **Before placing the concrete, the inside of the forms are cleaned and treated with a release agent to facilitate their removal when concrete is set.**
- **While concreting in walls, footings and other thin sections of appreciable height, the concrete should be placed in horizontal layers not less than 150 mm in depth, unless some other thickness is specified. The concreting should start at the ends or corners of forms and continue towards the center.**
- **In large openings, concrete should be placed first around the perimeter.**
- **On a slope, concreting should begin at the lower end of slope to avoid cracking due to settlement.**
- **While concreting a slab, the batches of concrete should be placed against or towards preceding ones, not away from them.**

COMPACTION OF CONCRETE

- **During the manufacture of concrete a considerable quantity of air is entrapped and during its transportation there is a possibility of partial segregation taking place.**
- **If the entrapped air is not removed and the segregation of coarse aggregate not corrected, concrete may be porous, non-homogeneous and of reduced strength.**
- **The process of removal of entrapped air and of uniform placement of concrete to form a homogeneous dense mass is termed compaction.**
- **Compaction is accomplished by doing external work on the concrete. The density and, consequently, the strength and durability of concrete depend upon the quality of this compaction.**
- **Therefore, thorough compaction is necessary for successful concrete manufacture. The concrete mix is designed on the basis that after being placed in forms it will be thoroughly compacted with available equipment.**
- **The presence of even 5 per cent voids in hardened concrete left due to incomplete compaction may result in a decrease in compressive strength by about 35 per cent.**

Compaction Methods:

The compaction of the concrete can be achieved in four ways: (i) hand rodding, (ii) mechanical vibrations, (iii) centrifugation or spinning, and (iv) high pressure and shock.

Mechanical Vibrations

- **Vibration is the commonly used method of compaction of concrete, which reduces the internal friction between the different particles of concrete by imparting oscillations to the particles and thus consolidates the concrete into a dense and compact mass.**
- **The mechanical vibrations can be impacted by means of vibrators which are operated with the help of an electric motor or diesel engine or pneumatic pressure.**
- **The various types of vibrators utilized used are the following :**

1. **Immersion or needle vibrators**
2. **External or Shutter Vibrators**
3. **Surface Vibrators**
4. **Vibrating Table**

CURING OF CONCRETE

- **For complete and proper strength development, the loss of water in concrete from evaporation should be prevented, and the water consumed in hydration should be replenished.**
- **This process of creation of an environment during a relatively short period immediately after the placing and compaction of the concrete, favorable to the setting and the hardening of concrete, is termed *curing.***
- **The curing increases compressive strength, improves durability, impermeability and abrasion resistance.**
- **In addition, the length of curing is also important. The first three days are most critical in the life of Portland cement concrete. In this period the hardening concrete is susceptible to permanent damage.**
- **Moist curing for the first 7 to 14 days may result in a compressive strength of 70 to 85 per cent of that of 28 days moist curing.**

Methods of Curing Concrete:

There are various methods available for curing. The actual procedures widely depending on the conditions on the site, and on the size, shape and of the member. The methods are the following:

a) **Ponding of water over the concrete surface after it has set**
b) **Covering the concrete with wet straw or damp earth**
c) **Covering the concrete with wet burlap**
d) **Sprinkling of water**
e) **Covering the surface with waterproof paper**
f) **Leaving the shuttering or formwork on**
g) **Membrane curing of the concrete**
h) **Chemical curing**

FORMWORK

- **The formwork or shuttering may be defined as molds of timber or some other material into which the freshly mixed concrete is poured at the site and which hold the concrete till it sets.**
- **Concrete construction practices directly affect formwork requirements. It is more than simply making forms of right size. A good formwork should be strong, stiff, smooth and leak proof.**

Requirements of Formwork

Quality: The formwork is designed and built accurately so that the desired shape, size, position and finish of cast concrete is obtained, and thus

1. all lines in the formwork should be true and the surface be plane, so that the cost of finishing the surface of concrete on removal of shuttering is the least, and
2. the formwork should be leak proof.

Safety: The formwork is built substantially so that it is strong enough to support the dead and live loads during construction without collapse or danger to workmen or the structure. The joints in the formwork should be rigid to minimize the bulging, twisting or sagging due to dead and live loads. Excessive deformations may disfigure the surface of the concrete.

Economy: The formwork should be built efficiently to save time and money for the contractor and owner alike. After the concrete has set, the formwork should be easily strippable without damage so that it can be used repeatedly.

Types of Formwork

The material used in the formwork largely depends upon the availability and cost. Usually, the timber scantlings consisting of softwood planks and joists are very suitable.

Timber Formwork:

- **The timber used for formwork should be cheap, easily available and easy to work manually and on machines.**
- **A good timber for formwork should be light for easy handling and lifting, stiff for not giving excessive deflections, usually free from knots, knot holes, bad flaws, etc., which may cause failure.**
- **In practice, it would be economical to standardize the size of timber used in formwork so that their repeated use is possible.**
- **It is better to use clamps and screws, rather than nails, in the formwork to facilitate its stripping and reuse.**

Plywood Formwork:

- **Plywood sheets bound with synthetic resin adhesive are being widely used nowadays.**
- **The thickness of ply varies from 3 to 18 mm. Sizes less than 6 mm thick are used for lining the timber formwork to get neat and smooth surface finish and as a formwork for curved surfaces.**
- **The common sizes are 1200x 1200 mm to 3000 x 3000 mm.**
- **The main advantage is that large panel surfaces are available. The fixing of forms is rapid and economical. It does not warp, swell and shrink during the setting of concrete. Moreover, it has high impact resistance.**

Steel Formwork:

- **Steel formworks are commonly employed for big projects where the forms are to be repeatedly used.**
- **The steel forms can be easily fabricated and do not require many adjustments as the units are standardized. They give smooth surfaces needing very little finishing.**

- **These prove to be economical and are best suited for circular columns and flat slab construction.**
- **Square steel plates of 500 mm size are generally used. Light steel sheet panels of 500 mm size and stiffened with angles are also available.**

Stripping of Form

- **The removal of forms after the concrete has set is termed *stripping of forms*.**
- **The stripping or striking of forms should proceed in a definite order. The formwork should be so designed and constructed as to allow them to be stripped in the desired order.**
- **The period up to which the forms must be left in place before they are stripped is called *stripping time*.**
- **The factors affecting the stripping time are the position of the forms, the loads coming on the elements immediately after stripping, temperature of the atmosphere, the subsequent loads coming on the element, etc.**
- **Using *ordinary portland cement* with temperatures above 20°C, the stripping times normally required are given in Table 11.5.**

- **For *rapid hardening Portland cement*, the stripping period can be reduced to three-sevenths of that given in Table 11.5 except for the vertical sides of slabs, beams and columns where the forms are to be retained for 24 hours.**

Table 11.5 Stripping time for different condition

Element and supporting conditions	Stripping time, Days
Walls, columns, vertical sides of beams	1 to 2
Slabs with props left in position	3
Beam soffits with props left in position	7
Slabs: removal of props	
(a) Span up to 4.5 m	7
(b) Span over 4.5 m	14
Beam and arches: removal of props (supports)	
(a) Span up to 6 m	14
(b) Span over 6 m	21

end

CHAPTER:-08-Inspection and Quality Control of Concrete-

8.1-Quality control of Concrete

- **Quality control is a corporate, dynamic programme to assure that all aspects of materials, equipment and workmanship are well looked after.**
- **The effective quality control is to cheek what is done in totality to confirm to the specification.**

Factors causing the variations in the quality of concrete

The main factors causing variation in concrete are as follows:-

1. Personnel:-

The basic requirement for the successive of any quality control plan is:-

- **Availability of experience**
- **Knowledge and trained personnel at all level**
- **Everything in quality control cannot be specified and much depends on the attitude and orientation of people involved.**

2. Materials, Equipment and Workmanship:-

- **For uniform quality of concrete, the ingredients should be used from a single source.**
- **When ingredients from different sources are used, the strength and other characteristics of the materials are changed.**
- **Therefore, they should be used after proper evaluation and testing.**
- **The cement should be tested initially once from each source of supply and subsequently once in every two months.**
- **Grading, size, shape and moisture content of the aggregate are the major sources of variability.**
- **The aggregate sizes should be so selected that one size fits into the void left by next higher size.**
- **The aggregate should be free from impurities and deleterious materials.**
- **The aggregate should be tested daily at the late for grading and moisture content.**
- **The water used for batching, mixing and vibration should be of the right capacity.**
- **The fresh concrete should be handled, transported and placed in such a manner that it does not get segregated.**

- The time interval between mixing and placing the concrete should be reduced to the minimum possible.
- Adequate curing is essential for handling and development of strength of concrete.

8.2-MIXING

- The object of mixing is to coat the surface of all aggregate particles with cement paste, and to blend all the ingredients of concrete into a uniform mass.
- The mixing action of concrete thus involves two operations:
  - (i) a general blending of different particle sizes of the ingredients to be uniformly distributed throughout the concrete mass, and
  - (ii) a vigorous rubbing action of cement paste on to the surface of the inert aggregate particles.
- Concrete mixing is normally done by mechanical means called mixer, but sometimes the mixing of concrete is done by hand.
- Machine mixing is more efficient and economical compared to hand mixing.
- In the mixing process, the cement paste is formed first with simultaneous absorption of water in the aggregates.

- **In the second stage, the cement paste coats the aggregate particles.**
- **The mixing process should be continued till a thoroughly and properly mixed concrete is obtained.**
- **At the end of this stage the concrete appears to be of uniform colour and grading.**
- **The uniformity must be maintained while discharging the concrete from the mixer.**
- **As a matter of fact the classification of the mixers is based on the technique of discharging the mixed concrete as follows:**
  1. **Tilting type mixer**
  2. **Non-tilting type**
  3. **Pan or stirring mixer**

TRANSPORTATION OF CONCRETE

- **Concrete from the mixer should be transported to the point where it has to be placed as rapidly as possible by a method which prevents segregation or loss of ingredients.**
- **The concrete has to be placed before setting has commenced. Attempts have been made to limit the time lapse between mixing and compaction within the forms.**

- **The specifications, however, permit a maximum of two hours between the introduction of mixing water to the cement and aggregates, and the discharge, if the concrete is transported in a truck mixer or agitator.**
- **In the absence of an agitator, this figure is reduced to one hour only.**
- **The temperature of concrete, when deposited, is not less than 5 °C or more than 32 °C.**

The requirements to be fulfilled during transportation are:

1. No segregation or separation of materials in the concrete.

2. Concrete delivered at the point of placing should be uniform and of proper consistency.

PLACING OF CONCRETE

- **The methods used in placing concrete in its final position have an important effect on its homogeneity, density and behavior in service.**
- **The same care which has been used to secure homogeneity in mixing and the avoidance of segregation in transporting must be exercised to preserve homogeneity in placing.**

- **The forms must be examined for correct alignment and adequate rigidity to withstand the weight of concrete, impact loads during construction without undue deformation.**
- **The forms must also be checked for tightness to avoid any loss of mortar which may result in honeycombing.**
- **Before placing the concrete, the inside of the forms are cleaned and treated with a release agent to facilitate their removal when concrete is set.**
- **While concreting in walls, footings and other thin sections of appreciable height, the concrete should be placed in horizontal layers not less than 150 mm in depth, unless some other thickness is specified. The concreting should start at the ends or corners of forms and continue towards the center.**
- **In large openings, concrete should be placed first around the perimeter.**
- **On a slope, concreting should begin at the lower end of slope to avoid cracking due to settlement.**
- **While concreting a slab, the batches of concrete should be placed against or towards preceding ones, not away from them.**

CURING OF CONCRETE

- **For complete and proper strength development, the loss of water in concrete from evaporation should be prevented, and the water consumed in hydration should be replenished.**
- **This process of creation of an environment during a relatively short period immediately after the placing and compaction of the concrete, favorable to the setting and the hardening of concrete, is termed *curing.***
- **The curing increases compressive strength, improves durability, impermeability and abrasion resistance.**
- **In addition, the length of curing is also important. The first three days are most critical in the life of Portland cement concrete. In this period the hardening concrete is susceptible to permanent damage.**
- **Moist curing for the first 7 to 14 days may result in a compressive strength of 70 to 85 per cent of that of 28 days moist curing.**

Methods of Curing Concrete:

There are various methods available for curing. The actual procedures widely depending on the conditions on the site, and on the size, shape and of the member. The methods are the following:

a) **Ponding of water over the concrete surface after it has set**
b) **Covering the concrete with wet straw or damp earth**

c) Covering the concrete with wet burlap
d) Sprinkling of water
e) Covering the surface with waterproof paper
f) Leaving the shuttering or formwork on
g) Membrane curing of the concrete
h) Chemical curing

8.3-Inspection and Testing

Inspection

- To ensure that the construction complies with the design an inspection procedure should be set up covering materials, records, workmanship and construction.
- 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.

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) there are clear instructions on permissible deviations;

d) elements critical to workmanship, structural performance, durability and appearance are identified; and

e) there is a system to verify that the quality is satisfactory in individual parts of the structure, especially the critical ones.

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

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 may be carried out.

8.4-Durability

- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.
- Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

Durability requirements of Concrete

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.

end

CHAPTER:-09-Special Concrete-

9.1-Introduction to ready mix concrete-

- **Special Concrete means the concrete used or made for special cases.**
- **Concrete may be used for some special purpose for which special properties are more important than those commonly considered. Sometimes it may be of great importance to enhance one of the ordinary properties.**

HIGH PERFORMANCE CONCRETE

- **A performance enhanced concrete or high-performance concrete (HPC) is a specialized series of concrete designed to provide several benefits in the construction of concrete structures that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices.**
- **It has low water-cement ratio**
- **It provides high durability, strength, low water-cement ratio and longer life span of the structure.**

- **Special ingredients such as plasticizer, optimum aggregate size and fibre steel reinforcement are used to make this type of concrete admixture.**
- **This concrete is used in special and complex structure such as bridges and tunnels.**

Advantages

- **It reduces the size of the member resulting in increase in plinth area and direct savings in the concrete volume.**
- **It reduces the self weight and super imposed dead load with the accompanying saving due to smaller foundation.**
- **It reduces the formwork area and the cast accompanied with it.**
- **Construction of high rise buildings with the accompanying savings in real estate costs in congested areas.**

Disadvantages

- **It is costlier than conventional concrete.**
- **It requires high quality control related to various material selections.**
- **Less fine resistance.**

SILICA FUME CONCRETE

- Silica fume is an artificial pozzolona having high pozzolonic activity.
- It is a by-product from an electric arc furnace used in manufacture of silicon metal or silicon alloy.
- It has high silica content of more than 80%.
- It is an excellent for use as a Portland cement supplement.

Physical characteristics

- It should be in premium white and standard grey colors.
- The specific gravity of the silica fume concrete is 2.2.
- Its specific surface area is to be 20,000 sq.meters / kg.
- Particle size is less than 1 micron with average diameter of 0.1 micron.
- The shape of the particle is spherical.
- It should be in Amorphous in nature.

Silica-fume in concrete can be used for the following purposes:

1. To conserve cement
2. To produce ultra high strength concrete

3. To control alkali-silica reaction

4. To reduce chloride associated corrosion and sulfate attack

5. To increase early age strength of fly ash/slag concrete

SHOTCRETE OR GUNITING

- Shotcrete is mortar or very fine concrete deposited by jetting it with high velocity (pneumatically projected or sprayed) on to a prepared surface.
- Shotcrete offers advantages over conventional concrete in a variety of new construction and repair works.
- Shotcrete is frequently more economical than conventional concrete because of less formwork requirements, requiring only a small portable plant for manufacture and placement.
- Shotcrete has wide applications in different constructions, such as thin over-head vertical or horizontal surfaces, particularly the curved or folded sections; canal, reservoir and tunnel lining; swimming pools and other water-retaining structures and prestressed tanks.

- **Shotcrete is very useful for the restoration and repair of concrete structures, fire damaged structures and waterproofing of walls.**

Types of Shotcreting

There are two basic types of shotcreting processes

1. **Dry process**
2. **Wet process**

1. Dry process:

- **Cement and sand are thoroughly mixed.**
- **The cement/sand mixture is fed into a special air-pressurized mechanical feeder termed as 'gun'.**
- **The mixture is metered into the delivery hose by a feed wheel or distributor within the gun.**
- **This material is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet.**

- The wet mortar is jetted from the nozzle at high velocity onto the surface to be gunited.

Advantages of Dry process

- Easy start up, shutdown and clean up.
- Control of materials is on site.
- Nozzle man can be up to 300m to 500m horizontally or 45 to 100m vertically from the gun.
- Widely used in mining

2. Wet process:

Step1: All ingredients, including water, are thoroughly mixed and introduced into the shotcrete equipment.

Step 2: Wet material is pumped to the nozzle where compressed air is introduced to provide high velocity for placement and consolidation of the material onto the receiving surface.

Step 3: Mostly wet-process shotcreting is done with premixed mortar or small aggregate concrete.

Advantages of Wet process

- Little or no formwork is required.
- Cost effective method for placing concrete.
- Ideal for irregular surface applications.
- Allows for easier material handling in areas with difficult access.

Benefits Of Shotcrete Technology

- Lowers cost due to quick speed of construction
- Easier to construct complex forms or shapes
- Can use recycled materials such as fly ash and rebar in the mix
- Bonds well with most surfaces
- No forming needed, therefore lower costs

Disadvantages Of Shotcrete Technology

- Strong wind will separate the material between the nozzle and the point of deposit, reducing the strength.
- It requires skilled and experienced labours.
- A greater degree of geotechnical knowledge is required.

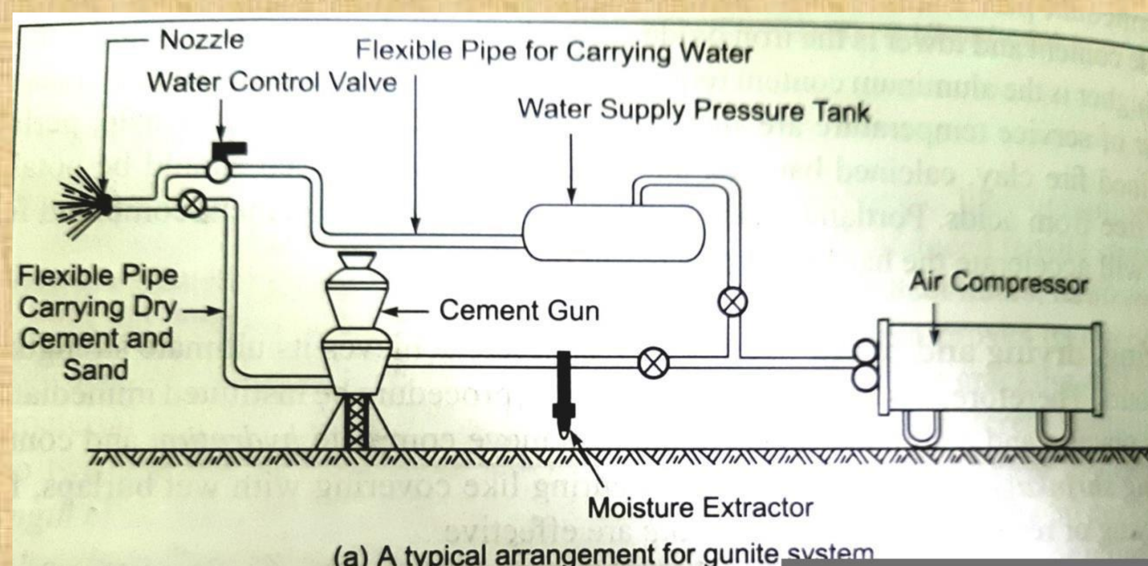
- **Improperly applied shotcrete may create conditions much worse than the untreated condition**
- **The production cost is very high.**
- **So many wastages of concrete.**

SHOTCRETE MACHINES

- **Shotcrete machines are available which control the complete process and make it very fast and easy.**
- **Manual and mechanical methods are used for the wet spraying process but wet sprayed concrete is traditionally applied by machine.**

Guniting

- **Gunite also known as a dry process shotcrete, uses air pressure to convey dry material from machine through hose to nozzle where water is added.**



(a) A typical arrangement for gunite system

- **The technique of depositing very thin layers of mortar in each pass of the nozzle than that available with the shotcrete, is termed *guniting.***
- **Guniting requires careful and skilful handling of nozzle for high quality finished work.**
- **The surface to be gunited should be cleaned thoroughly of grease or oil or any other loose or defective material by applying either air blast or high pressure water jet.**
- **The surfaces likely to absorb water should be kept wet up to six hours before guniting.**
- **The mix generally used for guniting is 1:3 to 1:4.5 with a water-cement ratio of about 0.30.**
- **The guniting can effectively be used for the repair of dams, spillways, bridge piers, sewerage pipes and water mains, and for protection of canal banks.**
- **It has been extensively used for the protection of steel girders from corrosion, etc., and waterproofing of reservoirs and tunnels.**

*****end*****

CHAPTER:-10-Deterioration of concrete and its prevention

Definition

- **Deterioration of concrete is caused not only by acids in the form of water solutions or acidic gases which form acids on dissolving in water, but by salt solutions and even by alkalies.**
- **A large number of other substances, such as fertilizers, insecticides and certain organic compounds are harmful to concrete.**

10.1-Types of Deterioration

Alkali-Silica Reaction:

- **Alkali-silica reaction (ASR) takes place when free lime (alkali) in concrete interacts with reactive silica present in many types of aggregates.**
- **The reaction forms a gel that absorbs moisture, and expands and creates tensile stresses that can crack concrete.**

- **Some chemical compounds can prevent ASR by consuming the free lime essential for ASR to occur and by reducing penetration of the moisture necessary for ASR.**

Leaching:

- **This type of deterioration may be caused by the dissolution of the ingredients of hardened cement by the aqueous solution, i.e., by the leaching process.**
- **Since calcium hydroxide is a readily soluble ingredient of hardened cement, the destruction of concrete by the leaching action is also called lime leaching.**
- **It is greatly dependent upon the permeability of the concrete. When the free lime of concrete is leached out, hydrolysis of calcium silicates and aluminates takes place to release more lime for further leaching action.**
- **When the concentration of lime inside the concrete is reduced on account of leaching action, more of it will dissociate to produce additional amount of lime.**
- **Increased solubility of lime accelerates the destruction of concrete and after a 10 per cent loss in lime in terms of initial cement, concrete starts rapidly losing its strength.**

- **When the leached out lime reacts with atmospheric carbon dioxide gas, the concrete surface gets covered with white residue of calcium carbonate. This is called the white death of concrete due to the leaching action.**

Chemical Interaction:

- **Deterioration may be caused by the chemical reaction between the hardened cement constituents of concrete and the chemicals of a solution.**
- **The reaction products formed may be either water soluble and may get removed from the internal structure of concrete by a diffusion process, or the reaction products if insoluble in water may get deposited on the surface of concrete as an amorphous mass having no binding properties, with the result that it can be easily washed out from the concrete surface.**

- **Acids first react with free lime of concrete forming calcium salts and later on attack the hydro silicates and hydro aluminates forming the corresponding calcium salts, whose solubility will govern the extent of deterioration caused to the concrete.**

Crystallization:

- Concrete may get deteriorated by the accumulation or crystallization of salts in its pores, which leads to the development of internal stresses and formation of cracks.
- These salts in the pores of concrete may be either formed as a result of chemical reaction between the corrosive media and the constituents of hardened cement or may be brought from outside by the penetration of salt solution and released there on the evaporation of water.
- Alkaline solutions of low concentration are less harmful to concrete; however, the concrete gets deteriorated on exposure to concentrated solutions of alkalies, as they combine with atmospheric carbon dioxide producing crystallizable carbonates.

Prevention of Concrete Deterioration

- A durable structural concrete requires the satisfaction of two criteria, namely that of a suitable binding agent of adequate chemical resistance and that of thorough compaction to a high density.
- From the considerations of permeability the water-cement ratio is usually limited to 0.45 to 0.55 except in mild environment.

- In the concrete for marine environment or in sea water applications, a minimum cement content of 350 kg/m³ or more is required.
- The concrete in sea water or exposed directly should be at least of M20 grade in case of plain concrete and M25 in case of reinforced concrete.
- As the addition of hydraulic additives reduces the rate of leaching considerably, their addition will also be helpful in the prevention of deterioration of concrete.
- Deterioration of concrete can also be prevented by treating concrete with solutions of salts or even acids in minor concentration to attain on the surface of hardened cement a layer of calcium salts less soluble than calcium hydroxide.

CORROSION OF REINFORCEMENT

- Concrete normally provides a high degree of protection against corrosion to embedded steel reinforcement. This is because concrete inherently provides a highly alkaline environment for the steel which protects and passivates the steel against corrosion.
- Corrosion of steel and accompanying distress can result if the concrete is not of

suitable quality, the structure is not properly designed for the anticipated environment or the actual environment or other factors were not as anticipated or changed during the life of the structure.

- The first evidence of distress is the brown staining of concrete around the embedded steel. This brown staining resulting from rusting or corrosion of the steel permeating to the concrete surface without cracking of the concrete but usually is accompanied by cracking.

Effects of Corrosion

- In most cases, the corrosion rate is extremely slow and the normal life span of a structure is not largely affected.
- The external and internal conditions are such that a corrosive environment exists, a destructive action may take place at an increased rate and create serious problems.
- The distress due to corrosive action may be in the form of deep pitting and a severe loss of cross section of the reinforcement.
- This is particularly serious if the reinforcement is subjected to high stresses as in the case of structures carrying heavy loads.
- A combination of high stress and intense corrosion will produce stress concentrations that may result in rupture of the reinforcement.

Prevention of Corrosion

1. **For the reinforced-concrete members totally immersed in sea water, the cover should be increased by 40 mm beyond that specified for normal conditions.**
2. **The additional cover thickness ranging from 15 to 50 mm beyond the values for normal conditions may be provided when the surfaces of the concrete members are exposed to the action of harmful chemicals, saline atmosphere, acid vapors, sulfurous smoke, etc.**
3. **To reduce the corrosion of reinforcement, the chloride ions in the concrete should be limited to its threshold or critical value.**
4. **In the case of an excessively aggressive environment, or where for practical reasons it is not possible to meet the requirements of cover and quality of concrete recommended above, special protection systems should be considered. Waterproof membranes are also being extensively used.**

End

CHAPTER:-11-Repair technology for concrete structures-

11.1-symptom,causes, prevention and remedy

Symptom	Cause	Prevention	Remedy
-Cracks in horizontal surface, as concrete stiffens or very soon thereafter.	-Plastic shrinkage: rapid drying of surface.	-Shelter during placing. Cover as early as possible. Use air entrainment.	-Seal by brushing in cement or low viscosity polymer.
-Cracks form above ties, reinforcement, etc., or at arrisses, especially in deep lifts.	-Plastic settlement: concrete continues to settle after starting to stiffen.	-Change mix design. Use air entrainment.	-Recompact upper part of concrete while still plastic. Seal cracks after concrete has hardened.
-Cracks in thick sections, occurring as concrete cools.	-Restrained thermal contraction.	-Minimize restraint to contraction. Delay cooling until concrete has gained strength.	-Seal cracks.
-Blowholes in form face of concrete.	-Air or water trapped against formwork: Inadequate compaction. Unsuitable mix design. Unsuitable release agent.	-Improve vibration. Change mix design. Use appropriate release agent. Use absorbent formwork.	-Fill with polymer modified fine mortar.

-Voids in concrete.	-Honeycombing: In-adequate compaction. Grout loss.	-Improve compaction. Reduce maximum size of aggregate. Prevent leakage of grout.	-Cut out and make good. Inject resin.
-Erosion of vertical surfaces, in vertical streaky pattern.	-Scouring: Water moving upwards against form face.	-Change mix design, to make more cohesive or reduce water content.	-Rub in polymer modified fine mortar.
-Color variations.	-Variations in mix proportions, curing conditions, materials, characteristics of form face, vibration, release agent. Leakage of water from formwork.	-Ensure uniformity of all relevant factors. Prevent leakage from formwork.	-Apply surface coating.
-Powdery formed surface.	-Surface retardation, caused by sugars in certain timbers.	-Change form material. Seal surface of form work. Apply lime wash to form face before first few uses.	-Generally, none required.
-Rust strains.	-Pyrites in aggregates. Rain streaking from unprotected steel. Rubbish in form work.	-Avoid contaminated aggregates. Protect exposed steel. Clean forms thoroughly. Turn ends of	-Clean with dilute acid or sodium citrate/sodium dithionite. Apply

	Ends of wire ties turned out.	ties inwards.	surface coating.
-Plucked surface.	-Insufficient release agent. Careless removal of formwork.	-More care in applications of release agent and removal of formwork.	-Rub in fine mortar, or patch as for spalled concrete.
-Lack of cover to reinforcement.	-Reinforcement moved during placing of concrete, or badly fixed. Inadequate tolerances in detailing.	-Provide better support for reinforcement. More accurate steel fixing. Greater tolerances in detailing.	-Apply polymer modified cement and sand rendering. Apply protective coating.

Cracking of concrete due to different reasons

Cracking due to Chemical Reactions

The concrete may crack, as a result of expansive reactions between aggregate containing active silica and alkalies derived from cement hydration, admixture or external sources (e.g., curing water, ground water, alkaline solutions stored).

Cracking due to Weathering

The environmental factors that can cause cracking include (i) freezing and thawing, (ii) wetting and drying, and (iii) heating and cooling.

Cracking due to Corrosion of Reinforcement

The corrosion of steel produces iron oxides and hydroxides, which have a volume much greater than the volume of the original metallic iron. This increase in volume causes high radial bursting stresses around reinforcing bars and results in local radial cracks.

Cracking due to Construction Overloads

The loads induced during construction can be far more severe than those experienced in service. These conditions may occur at the early ages when the concrete is most susceptible to damage and often result in permanent cracks.

Cracking due to Errors in Design and Detailing

The design and detailing errors that may result in unacceptable cracking include use of poorly detailed re-entrant corners in walls, precast members and slabs; improper selection and/or detailing of reinforcement; restraint of members subjected to volume changes caused by variations in temperature and moisture; lack of adequate contraction joints, and improper design of foundations resulting in differential settlement within the structure.

Cracks due to Externally Applied Loads

Load induced tensile stresses may result in cracks in concrete elements.

Repair Techniques

1. Preparation of surface

- The cracked and deteriorated areas are cut or chipped out to the solid concrete.

- **The unsound concrete is removed with percussive tools.**
- **All the loose material should be cleaned and the surface should preferably be washed off before actual patching work is started.**
- **To obtain a good bond, it is generally recommended that the surface of concrete be coated with a thin layer of cement grout before placing the patching material.**

2. Selection of materials

- **The repair system should be so selected that the mechanical properties of the repair material are similar to those of the structure being repaired.**
- **Cement-based repairs can provide fire resistance while resins soften at relatively low temperature.**
- **For conventional repairs, the cement-based materials to be used for patchwork may either be mortar or concrete depending upon the extent of repair.**

3. Application of material

- **The methods generally used for filling the material are: (a) drypacking, (b)concrete replacement, (c) mortar replacement, (d) grouting, (e) large volume prepacking of concrete, and (f) shotcreting or guniting.**

4. Curing of repair work

- **The curing of patch material requires much more care than that required for a complete structure.**

- There is a tendency of old concrete absorbing moisture from the replacement material.

Polymer-based Repairs

Polymer Impregnated Concrete (PIC): This is a Portland cement concrete impregnated by a monomer system which is subsequently polymerized by radiation or heat, and the use of a catalyst.

Polymer Cement Concrete (PCC): This is a concrete in which the monomer is added during the mixing of Portland cement, water and aggregate, followed by polymerization or curing of the replaced material after its placement.

Polymer Concrete (PC): This is a composite material obtained by adding a polymer or its precursor to the aggregate and polymerizing or curing the material after its placement.

1. Polymer impregnation:

- The technique consists of flooding the cleaned, dried cracked concrete surface with a monomer which is then polymerized in place, thus filling and structurally repairing the crack.
- It can also be used to improve the abrasive resistance of industrial concrete floor slabs.
- Polymer impregnation has not been used successfully to repair fine cracks.

2. Drilling and plugging

- The method is only applicable for the cracks running in reasonably straight lines and accessible at one end. It consists in drilling a hole down the length of crack and grouting it to form a key. A hole 50 to 60 mm in diameter should be drilled, centered on and following the crack.
- The hole must be large enough to intersect the crack along its full length and provide sufficient repair material to structurally take the loads exerted on the key.
- The drilled hole is then cleaned and filled with grout.

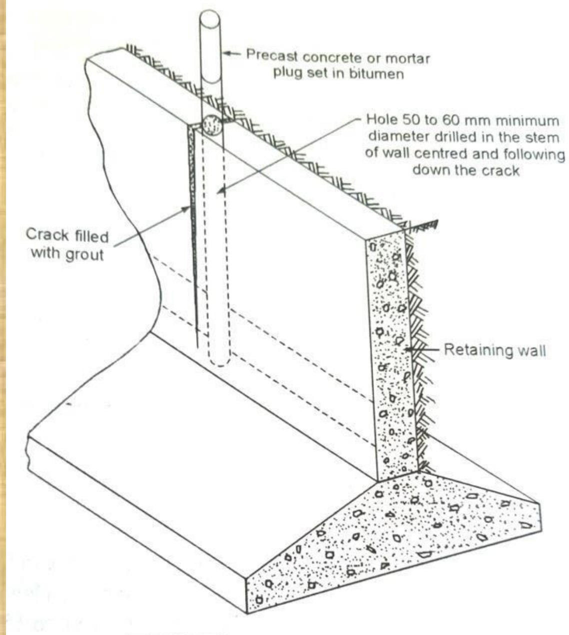


Fig. 17.7 Repair by drilling and plugging

COMMON TYPES OF REPAIRS

1. Sealing of Cracks

- The crack or joint sealers are very important in concrete structures as every concrete structure has cracks or joints.
- The crack sealers should ensure the structural integrity and serviceability. In addition they provide protection from the ingress of harmful liquids and gases.
- The function of the sealant is to prevent water from reaching the reinforcement, hydrostatic pressure from developing within the joint, staining the concrete surface, or causing moisture problems on the far side of the member.

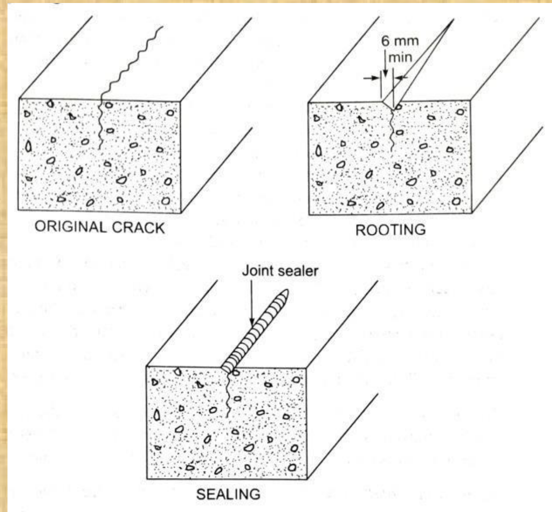


Fig. 17.8 Crack repair by routing and sealing

2. Flexible Sealing

- For repairing an active crack, it is necessary to provide for its continuing movement. One way to achieve this is to rout or chase the crack along its length.
- The prepared routed crack is filled with a suitable field molded flexible sealant with strain capacity being at least as large as the one to be accommodated.

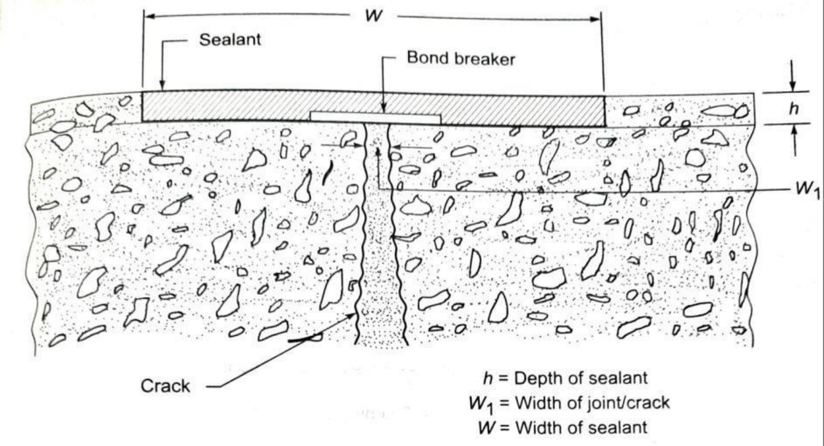


Fig. 17.9 *Repair of an active crack by flexible sealing*

3. Providing Additional Steel

- The cracked reinforced elements (usually bridge decks) can be successfully repaired using epoxy injection and reinforcing bars.
- The technique consists of sealing the crack, drilling holes of 20 mm diameter at 45° to the element surface and crossing the crack plane at approximately 90°.
- The epoxy bonds the bar to the sides of the hole, fills the crack plane and brings the cracked concrete surface back to the monolithic form.

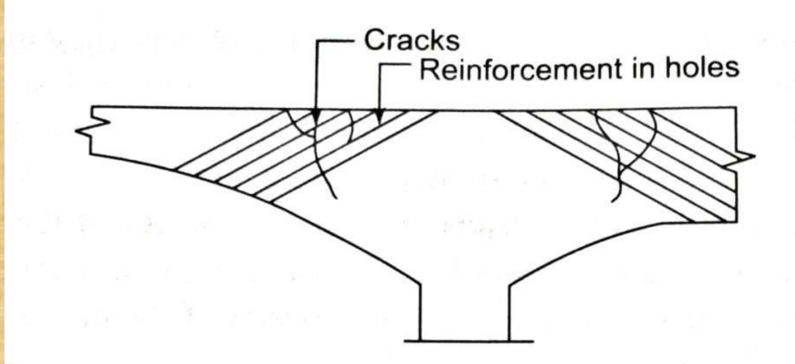


Fig. 17.10 *Repair by providing additional steel*

4. Stitching of Cracks

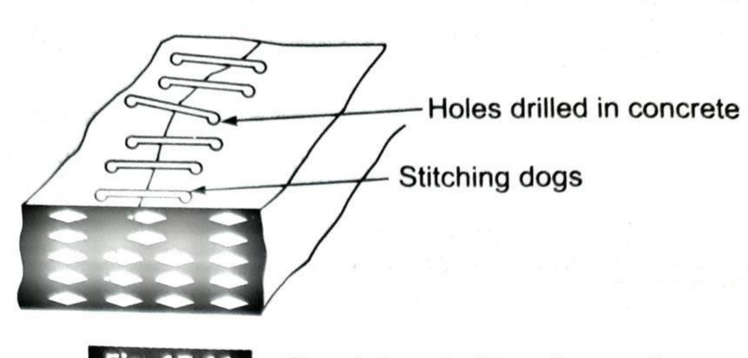


Fig. 17.11 *Repair by stitching the cracks*

- The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the stitching dogs that span the crack, with either a non-shrink grout or an epoxy resin-based bonding system.
- The remedial measures for repairing the structural cracking of a slab, and a beam.

5. Repair by Jacketing

- Jacketing is a process of fastening a durable material, e.g., fiber glass over the existing concrete and filling the gap with a grout that provides the needed performance characteristics.
- The method is particularly useful for the compression members like columns and piles.

6. Autogenous Heeling

- The natural process of crack repair known as autogenous heeling has a practical application in closing dormant cracks in a moist environment.
- Such a case may be found in mass concrete structures.

- **Heeling occurs through the carbonation of calcium hydroxide in cement paste by carbon dioxide, which is present in surrounding air and water.**
- **During the process of heeling it is essential for development of substantial any strength, that the crack and adjacent concrete be saturated with water.**
- **Heeling should commence as soon as possible after the crack appears.**

*****End*****