UNIT-IV

FRESH AND HARDENED PROPERTIES OF CONCRETE

1. Define workability.
   Workability is the property of concrete which determines the amount of internal work necessary to produce full compaction. It is a measure with which concrete can be handled from the mixer stage to its final fully compacted stage.

2. List out the requirements of fresh concrete.
   a. Mixability
   b. Stability
   c. Mobility
   d. Compactability
   e. Finishability

3. List out the Factors affecting Workability?
   a. Water content
   b. Mix proportion
   c. Size of aggregate
   d. Shape of aggregate
   e. Surface texture
   f. Grading
   g. Admixture

4. Mention the methods to measure the workability?
   a. Slump Test
   b. Compaction Factor
   c. Vee-Bee Consistometer
   d. Kelly Ball Penetration test
   e. Flow table Test
   f. Vibrating table

5. Mention the values of different type of slump.

- True slump - up to 125mm from top
- Shear slump - up to 150 mm from top
- Collapse slump -150-225mm

6. List out the usage of slump values

- slump 0 – 25 mm are used in road making
- 10 – 40 mm are used for foundations with light reinforcement

- 50 - 90 for normal reinforced concrete placed with vibration

7. Define compaction factor?
   Compaction Factor is the ratio of the weight of partially compacted concrete to the weight of the concrete when fully compacted in the same mould.

8. Define Vee bee consistometer
   Consistometer is based on consistency test which is a mechanical variation of the simple slump test which includes determination of the workability of concrete.Measures consistency of concrete in terms of time required to transform by vibration a frustum of fresh concrete sample into a cylinder. This time is called VB time.

9. What is the use of Kelly Ball Penetration test
   Kelly Ball Penetration method is used to determine the penetration of a hemispherical metal weight into freshly mixed concrete, which is related to the workability of the concrete.

10. What is the use of flow table method
    Flow table indicates consistency and proneness to segregation. It is used for aggregate of size <40mm. The flow is determined by = {D-250/250}*100.
11. What is batching.
    Batching is the correct measurement of various materials used in the concrete mix. It can be either volume or by weight.

12. How is weight batching is obtained
    Weight batching is more accurate and hence preferred weighing can be done by
    a. Simple spring balance
    b. Platform weighing machines
    c. Automatic weighing machines

13. How is mixing operation is done in concrete
    a. Hand
    b. Machine
       a) Tilting type
       1. Charging by hand
       2. Charging by machine
       b)Non tilting type
       1. Continuous mixer
       2. Pan mixer
       3. Truck mixer

14. What is the purpose of compaction?
    Compaction is done to eliminate air voids in concrete.

15. What is hardened concrete and mention the factors influence its strength

Hardened concrete gives an overall idea about the quality of concrete. It depends on

a. Water cement ratio
b. Degree of compaction
c. Age of concrete
d. Richness of mix
e. Curing of concrete
f. Temperature of concrete.

16. Define curing
    a. Curing is done to keep the concrete saturated until the water filled space in concrete is filled up by the product of hydration.
    b. Curing is done to prevent the loss of water by evaporation and to maintain the process of hydration.

17. Define shrinkage

    Volume change due to loss of moisture affects durability and strength, causes cracks in concrete at different stage due to alkali aggregate reaction, sulphate action, settlement of fresh concrete is shrinkage.

18. Define creep.

    When a concrete member is loaded it deforms to a certain extent as soon as the load is applied. When the load is kept constant, the deformation increases with time. This increase in strain under sustained stress is called creep of concrete.

19. Mention the test conducted to test the properties of hardened concrete.
    a. Compression Testing Machine
    b. Flexure Strength Testing Machine
    c. Lateral Extensometer
    d. Split Tensile Test
    e. Shear strength
    f. Bond strength

20. List out the factors affecting the results of strength test.
    a. Size and shape of aggregate
    b. Condition of casting
    c. Moisture condition
    d. Bearing condition
    e. Rate of loading

1. Explain the following tests:

a. Flow test

b. Compaction factor test

Compacting Factor Test

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test. The diagram of the apparatus.. The essential dimensions of the hoppers and mould and the distance between them .The compacting factor test has been developed at the Road Research Laboratory U.K. and it is claimed that it is one of the most efficient tests for measuring the workability of concrete. This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. The degree of compaction, called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to density of same concrete fully compacted. The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. In the case of a dry-mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion. The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades supplied with the apparatus. The outside of the cylinder is wiped clean. The concrete is filled up exactly upto the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as “Weight of partially compacted concrete”. The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5 cm deep. The layers are heavily rammed or preferably vibrated so as to obtain full compaction. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10 gm. This weight is known as “Weight of fully compacted concrete”.

The Compacting Factor = Weight of partially compacted concrete/Weight of fully compacted concrete

The weight of fully compacted concrete can also be calculated by knowing the oportion of materials, their respective specific gravities, and the volume of the cylinderseen from experience, that it makes very little difference in compacting factor value, whether the weight of fully compacted concrete is calculated theoretically or found out actually after 100 per cent compaction. It can be realised that the compacting factor test measures the inherent characteristics of the concrete which relates very close to the workability requirements of concrsuch it is one of the good tests to depict the workability of concrete.

Flow Test

This is a laboratory test, which gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. In this test, a standard mass of concrete is subjected to jolting. The spread or the flow of the concrete is measured and this flow is related to workability.It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked. A mould made from smooth metal casting in the form of a frustum of a cone is used with the following internal dimensions. The base is 25 cm. in diameter, upper surface 17 cm. in diameter, and height of the cone is 12 cm. The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould

Flow, per cent = Spread diameter in cm – 25/25 X 100

The value could range anything from 0 to 150 per cent. A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

2. **Write a short note on:**
   a. **Compression test**
   b. **Tension test**

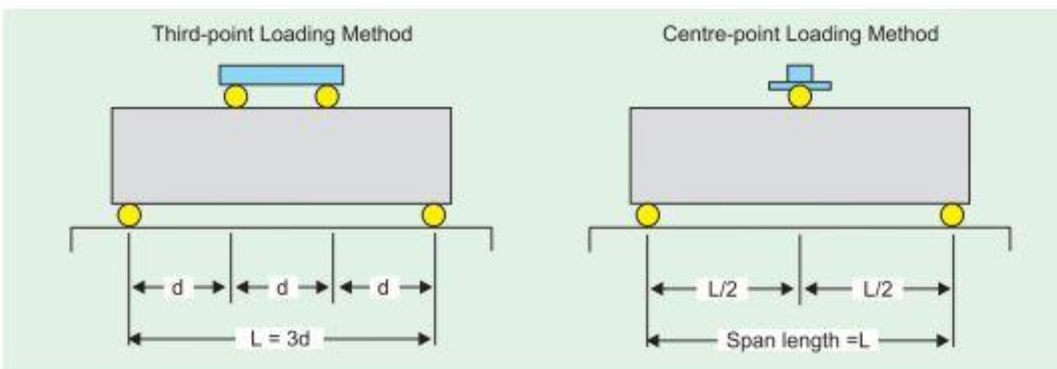
Compression Test

Compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. The compression test is carried out on specimens cubical or cylindrical in shape. Prism is also sometimes used, but it is not common in our country. Sometimes, the compression strength of concrete is determined using parts of a beam tested in flexure. The end parts ofbeam are left intact after failure in flexure and, because the beam is usually of square cross section, this part of the beam could be used to find out the compressive strength. The cube specimen is of the size 15 x 15 x 15 cm. If the largest nominal size of the aggregate does not exceed 20 mm, 10 cm size cubes may also be used as an alternative. Cylindrical test specimens have a length equal to twice the diameter. They are 15 cm in diameter and 30 cm long. Smaller test specimens may be used but a ratio of the diameter of the specimen to maximum size of aggregate, not less than 3 to 1 is maintained. Compression test develops a rather more complex system of stresses. Due to compression load, the cube or cylinder undergoes lateral expansion owing to the Poisson's ratio effect. The steel platens do not undergo lateral expansion to the some extent that of concrete, with the result that steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel platens of the testing machine. It has been found that the lateral strain in the steel platens is only 0.4 of the lateral strain in the concrete. Due to ths the platen restrains the lateral expansion of the concrete in the parts of the specimen near its end. The degree of restraint exercised depends on the friction actually developed. When the friction is eliminated by applying grease, graphite or paraffin wax to the bearing surfaces the specimen exhibits a larger lateral expansion and eventually splits along its full length. With friction acting i.e., under normal conditions of test, the elements within the specimen is subjected to a shearing stress as well as compression. The magnitude of the shear stress decreases and the lateral expansion increases in distance from the platen. As a result of the restraint, in a specimen tested to destruction there is a relatively undamaged cone of height equal to d (where d is the lateral dimension of the specimen).But if the specimen is longer than about 1.7 d, a part it of will be free from the restraining effect of the platen. Specimens whose length is less than 1.5 d, show a considerably higher strength than those with a greater length.

The Flexural Strength of Concrete

Concrete as we know is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature

gradients and many other reasons.Therefore, the knowledge of tensile strength of concrete is of importance. A concrete road slab is called upon to resist tensile stresses from two principal sources– wheel loads and volume change in the concrete. Wheel loads may cause high tensile stresses due to bending, when there is an inadequate subgrade support. Volume changes, resulting from changes in temperature and moisture, may produce tensile stresses, due to warping and due to the movement of the slab along the subgrade. Stresses due to volume changes alone may be high. The longitudinal tensile stress in the bottom of the pavement, caused by restraint and temperature warping, frequently amounts to as much as 2.5 MPa at certain periods of the year and the corresponding stress in the transverse direction is approximately 0.9 MPa. These stresses are additive to those produced by wheel loads on unsupported portions of the slab. Direct measurement of tensile strength of concrete is difficult. Neither specimens nor testing apparatus have been designed which assure uniform distribution of the "pull" applied to the concrete. While a number of investigations involving the direct measurement of tensile strength have been made, beam tests are found to be dependable to measure flexural strength property of concrete. The value of the modulus of rupture (extreme fibre stress in bending) depends on the dimension of the beam and manner of loading. The systems of loading used in finding out the flexural tension are central point loading and third point loading. In the central point loading, maximum fibre stress will come below the point of loading where the bending moment is maximum. In case of symmetrical two point loading, the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum. It can be expected that the two point loading will yield a lower value of the modulus of rupture than the centre point loading. Figure shows the modulus of rupture of beams of different sizes subjected to centre point and third point loading. I.S. 516-1959, specifies two point loading. The details of the specimen and
procedure are described in the succeeding paragraphs. The standard size of the specimens are 15 x 15 x 70 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 20 mm, specimens 10 x 10 x 50 cm may be used.



Principles of flexural testing

The flexural strength of the specimen is expressed as the modulus of rupture f which if 'a' equals the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in cm, is calculated to the nearest 0.05 MPa as follows:f = Pl/bd^2

When 'a' is greater than 20.0 cm for 15.0 cm specimen or greater than 13.3 cm for a 10.0 cm specimen, or

$f = 3pa/bd^2$

when ‘a’ is less than 20.0 cm but greater than 17.0 cm for 15.0 specimen, or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen where b = measured width in cm of the specimen.

3.What is meant by workability? What are the factors affecting workability of concrete?

Factors Affecting Workability

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

(a) Water Content
(b) Mix Proportions
(c) Size of Aggregates
(d) Shape of Aggregates
(e) Surface Texture of Aggregate
(f) Grading of Aggregate
(g) Use of Admixtures.

(a) Water Content

Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. At the work site, supervisors who are not well versed with the practice of making good concrete, resort to adding more water for increasing workability. This practice is often resorted to because this is one of the easiest corrective measures that can be taken at site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content. In case, all other steps to improve workability fail, only as last recourse the addition of more water can be considered. More water can be added, provided a correspondingly higher quantity of cementis also added to keep the water/cement ratio constant, so that the strength remains the same.

(b) Mix Proportions

Aggregate/cement ratio is an important factor influencing workability. The higher the aggregate/cement ratio, the leaner is the concrete. In lean concrete, less quantity of paste is available for providing lubrication, per unit surface area of aggregate and hence the mobility of aggregate is restrained. On the other hand, in case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

(c) Size of Aggregates

The bigger the size of the aggregate, the less is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, bigger size of aggregates will give higher workability. The above, of course will be true within certain limits.

(d) Shape of Aggregates

The shape of aggregates influences workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand and gravel provide greater workability to concrete than crushed sand and aggregate. The importance of shape of the aggregate will be of great significance in the case of present day high strength and high performance concrete when we use very low w/c in the order of about 0.25. We have already talked about that in the years to come natural sand will be exhausted or costly. One has to go for manufactured sand. Shape of crushed sand as available today is unsuitable but the modern crushers are designed to yield well shaped and well graded aggregates.

(e) Surface Texture of Aggregate

The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. From the earlier discussions it can be inferred that rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

(f) Grading of Aggregate

This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.

(g) Use of Admixtures.

Of all the factors mentioned above, the most import factor which affects the workability is the use of admixtures. In Chapter 5, it is amply described that the plasticizers and superplasticizers greatly improve the workability many folds. It is to be noted that initial slump of concrete mix or what is called the slump of reference mix should be about 2 to 3 cm to enhance the slump many fold at a minimum doze. One should manupulate other factors to obtain initial slump of 2 to 3 cm in the reference mix. Without initial slump of 2 – 3 cm, the workability can be increased to higher level but it requires higher dosage – hence
uneconomical. Use of air-entraining agent being surface-active, reduces the internal friction between the particles. They also act as artificial fine aggregates of very smooth surface. It can be viewed that air bubbles act as a sort of ball bearing between the particles to slide past each other and give easy mobility to the particles. Similarly, the fine glassy pozzolanic materials, inspite of increasing the surface area, offer better lubricating effects for giving better workability.

4.What is segregation and bleeding ? how can it be prevented?

Segregation

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. Ifa sample of concrete exhibits a tendency for separation of say, coarse aggregate from the rest of the ingredients, then, that sample is said to be showing the tendency for segregation. Such concrete is not only going to be weak; lack of homogeneity is also going to induce all undesirable properties in the hardened concrete.

Segregation may be of three types firstly, the coarse aggregate separating out or settling down from the rest of the matrix, secondly, the paste or matrix separating away from coarse aggregate and thirdly, water separating out from the rest of the material being a material of lowest specific gravity. A well made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of waters makes a cohesive mix. Such concrete will not exhibit any tendency for segregation. The cohesive and fatty characteristics of matrix do not allow the aggregate to fall apart, at the same time, the matrix itself is sufficiently contained by the aggregate. Similarly, water also does not find it easy to move out freely from the rest of the ingredients. The conditions favourable for segregation are, as can be seen from the above para, the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation. Dropping of concrete from heights as in the case of placing concrete in column concreting will result in segregation. When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades, concrete shows a tendency for segregation. Conveyance of concrete by conveyor belts, wheel barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete. it can be gathered that the tendency for segregation can be remedied by correctly proportioning the mix, by proper handling, transporting, placing, compacting and finishing. At any stage, if segregation is observed, remixing for a short time would make the concrete again homogeneous. As mentioned earlier, a cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation. The use of air-entraining agent appreciably reduces segregation.

Segregation is difficult to measure quantitatively, but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test or the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

Bleeding

Bleeding is sometimes referred as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding. Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel and floats, the aggregate goes down and the cement and water come up to the top surface. This formation of cement paste at the surface is known as “Laitance”. In such a case, the top surface of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season. Owing to the fact that the top surface has a higher content of water and is also devoid of aggregate matter; it also develops higher shrinkage cracks. If laitance is formed on a particular lift, a plane of weakness would form and the bond with the next lift would be poor. This could be avoided by removing the laitance fully before the next lift is poured. Water while traversing from bottom to top, makes continuous channels. If the water
cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures. While the mixing water is in the process of coming up, it may be intercepted by
aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste. The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste

or the reinforcement and the paste due to bleeding can be remedied by revibration of concrete. The formation of laitance and the consequent bad effect can be
reduced by delayed finishing operations. Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement. Bleeding is an inherent phenomenon in concrete. All the same, it can be reduced by proper proportioning and uniform and complete mixing. Use of finely divided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse. It has been already discussed that the use of air-entraining agent is very effective in reducing the bleeding. It is also reported that the bleeding can be reduced by the use of finer cement or cement with low alkali content. Rich mixes are less susceptible to bleeding than lean mixes.
The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding. Removal of water, after it had played its role in providing workability, from the body of concrete by way of bleeding will do good to the concrete. Early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition at that stage, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its plasticity, that causesundue harm to the concrete. Controlled revibration may be adopted to overcome the bad effect of bleeding.

5.How does freeze-thaw damage occur?

The lack of durability of concrete on account of freezing and thawing action of frost is not of great importance to Indian conditions. But it is of greatest considerations in most part of the world. However, certain regions in India, experience sub-zero temperatures in winter. The concrete structures particularly, the one which are exposed to atmosphere are subjected to cycles of freezing and thawing and as such suffer from the damaging action of frost. The frost action is one of the most powerful weathering action on the durability of concrete. In the extreme conditions, the life span of concrete can be reduced to just a couple of years. The damage from freezing and thawing is most common and as such it is one of the extensively studied field on weathering of concrete in the United States of America, Russia and Northern European countries. Though the durability of concrete is affected by alternative wetting and drying, heating and cooling, penetration and deposition of salt and other aggressive chemicals, leaching of calcium hydroxide, action of certain acids, alkali-aggregate reaction, mechanical wear and tear, abrasion and cavitation, one of the very important factors affecting the durability of concrete in the cold countries, is the action of frost. Therefore the aspect of frost resistance is of much importance and has been studied for more than 70 years. It is very well known that fresh concrete should not be subjected to freezing temperature. Fresh concrete contains a considerable quantity of free water; if this free water is subjected
to freezing temperature discrete ice lenses are formed. Water expands about 9% in volume during freezing. The formation of ice lenses formed in the body of fresh concrete disrupt the fresh concrete causing nearly permanent damage to concrete. The fresh concrete once subjected to forst action, will not recover the structural integrity, if later on allowed to harden at a temperature higher than the freezing
temperature. Therefore, the fundamental point to note in dealing with cold weather concreting is that the temperature of the fresh concrete should be maintained above 0°C. The hardening concrete also should not be subjected to an extremely low temperature. It has been estimated that the freezing of water in the
hardened concrete may exert a pressure of about 14 MPa. The strength of concrete should be more than the stress to which it is subjected at any point of time to withstand the damaging action. The fully hardened concrete is also vulnerable to forst damage, particularly to the effect of alternate cycles of freezing and thawing. The severest conditions for frost action arise when concrete has more than one face exposed to the weather and is in such a position that it remains

wet for a long period. Examples are road kerbs, parapets, concrete members in hydraulic structures just above water level etc.

When the concrete is young, it contains more water and if such concrete is subjected to a low temperature greater quantity of water gets frozen and the total disruptive force is of a high order; whereas concrete at later ages contains less moisture and the freezing of such concrete will exert less total pressure.The frost damage can be assessed in several ways. Assessment of loss of weight of a sample of concrete subjected to a certain number of cycles of freezing and thawing is one of the methods. Measuring the change in the ultrasonic pulse-velocity or the change in the dynamic modulus of elasticity of specimen is another method. The resistance of the concrete to freezing and thawing is also measured by the durability factor. Blanks defined the durability factor as the "Number of cycles of freezing and thawing to produce failure divided by one hundred". ASTM method of calculating the durability factor is to continue freezing and

thawing for 300 cycles or until the dynamic modulus of elasticity is reduced to 60% of its original value, whichever occurs first.