Segregation

Segregation is defined as separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform.

Causes of segregation:

1. differences in the size of particles and in the specific gravity of the mix constituents that are the primary causes of segregation.
2. method of placing and handling of concrete: if the concrete does not have far to travel and is transferred directly from the wheelbarrow to the final position in the form, the danger of segregation is small.
3. Dropping concrete from a considerable height, passing along a chute, particularly with changes of direction, all theses encourage segregation so that under such circumstances a particularly cohesive mix should be used.
4. Excessive vibration: segregation may occur due to improper use of vibrator. This is particularly so when vibration is allowed to continue too long.
   with many mixes separation of coarse aggregate toward the bottom of the form and of the cement paste toward the top may result.
   such concrete would obviously be weak, and this surface would be too rich and too wet and result with a tendency to dusting.

Types of segregation:

1. In the first type the coarse particles tend to separate out since they tend to travel further along a slope or settle more than finer particles.
2. The second form of segregation, occurring particularly in wet mixes, is manifested by the separation of grout (cement plus water) from the mix.

With some grading when a lean mix is used, this type may occur if the mix is too dry, the addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second type of segregation would take place.

How to decrease occurring of segregation:

1. The choice of suitable grading: using coarse aggregate whose specific gravity differs appreciably from that of the fine aggregate would lead to increase segregation.
2. Segregation can be greatly reduced by using correct method of handling, transporting and placing.
3. Concrete should be placed direct in the position in which it is to remain and must not be allowed to flow or to be worked along the form.
4. Using entrained air reduces segregation.

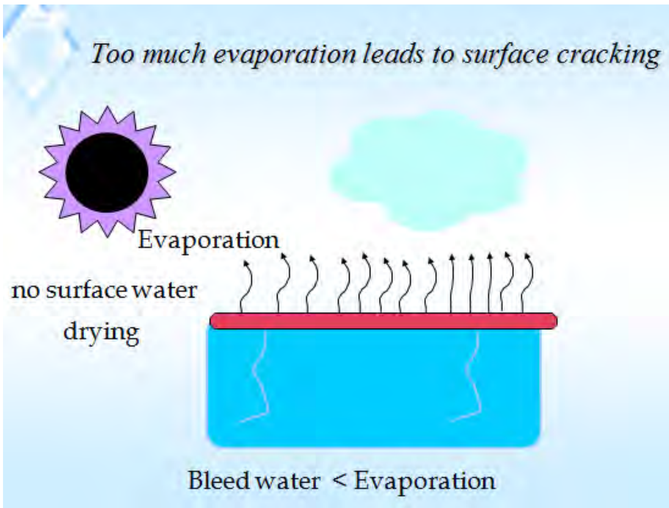
A good picture of cohesion of the mix is obtained by the flow test.

Bleeding:

Bleeding is a form of segregation in which some of the water in the mix tends to rise to the surface of freshly placed concrete.

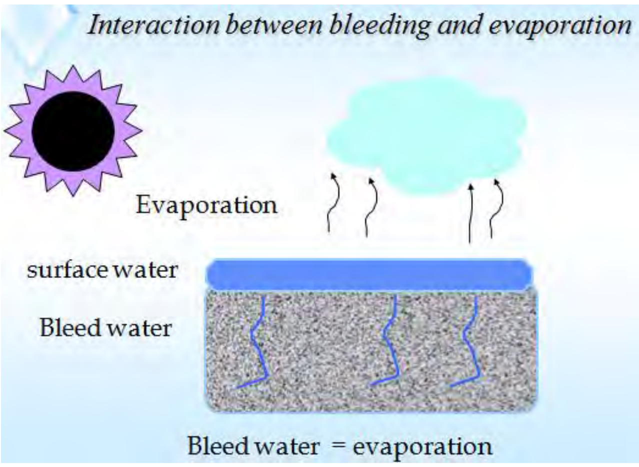
Effect of bleeding on concrete:

1. As a result of bleeding the top of the concrete becomes very wet (w\c is high) and if the water is trapped by superimposed concrete, porous, weak and non-durable concrete will result.
2. If evaporation of water from the surface of the concrete is faster than the bleeding rate, plastic shrinkage cracking may result. This is took place in hot weather as the rate of evaporation is higher than movement of water to the top and cause cracking in plastic state. in some cases aluminum powder is used as it causes expansion of cement paste to avoid the effect of shrinkage due to bleeding.



3. During bleeding, some of the rising water becomes trapped on the underside of the coarse aggregate particles or of reinforcement, thus creating zones of poor bond. This water leaves behind capillaries, and since all the voids are oriented in the same direction, the permeability of the concrete in a horizontal plane may be increased. This also might lower the durability of the concrete.
4. If the rising water carries with it a considerable amount of finer cement particles, a layer of laitance will be formed; laitance should always be removed by washing and brushing.

Bleeding is not necessarily harmful. If the water evaporates, the effective water to cement ratio may be lowered with a resulting increase in strength.



Factors affecting bleeding :

1. Physical properties for cement and fine agg., bleeding decreases with increase cement fineness and fine agg. content.
2. Chemical properties, bleeding decreases when:
   a) High alkali content
   b) High C_3A content
   c) Using accelerators ($CaCl_2$) which causes accelerating setting, hence, preventing water from rising up and sedimentation of mix constituents.

3. Mixes rich with cement content had less tendency to bleed than poor mixes because water move from agg. to cement in order to react.
4. Adding pozzolanic materials and air entraining agents decreases bleeding.

Mixing of concrete:

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; this uniformity must not be disturbed by the process of discharging from the mixer.

Types of mixing:

1. hand mixing: require work and efforts in order to obtain a homogeneous mix (the mix less homogeneous and lower strength)
2. mechanical mixing : in this type several types of mixers are used :
   a) Tilting mixer: used with dry mixes that contain large aggregate size.
   b) Pan mixers: used in labs for stiff and cohesive mixes, or in large concrete projects.
   c) Dual drums mixers: used in road construction and has high productivity.

Mixing time:

It is necessary to know the minimum mixing time required for obtaining homogeneous mix with suitable strength. Mixing time depends on:

a) Type of mixer.
b) Size and volume of mixer.
read in book relationship between compressive strength and mixing time.
when mixing concrete for less than 1.25 min. the mix will be with unstable homogeneous. with increasing mixing time rate of compressive strength will increase and the increase has no effect after 2 min., because the mix will be homogeneous therefore, mixing time do not affect strength after 2 min.

Compaction of concrete

- The process of compaction consists essentially of elimination of entrapped air.
- With elimination of entrapped air, optimum density with maximum strength would be obtained.
- With increasing voids ratio, density is reduced and hence, the strength decreased. The presence of (5%) voids decreases compressive strength by (30%).
- Compaction of concrete for a long time causes segregation which lead to weakening concrete and formation of laitance on the surface of the concrete.

Compaction of concrete is used for:

1. Expelled air voids in the mix
2. Increasing cohesion of concrete constituent, i.e., between cement and aggregates, and between concrete itself and reinforcement.
3. Increasing density of concrete
4. Decreasing water absorption and increasing resistance of cement for climate and weathering conditions.

Methods of compaction:

1.Ramming: using steel road. This method is not useful for dry mixes (compacting factor below 0.75). It is usually used for wet mixes (mixes with wet consistency) and high workability.

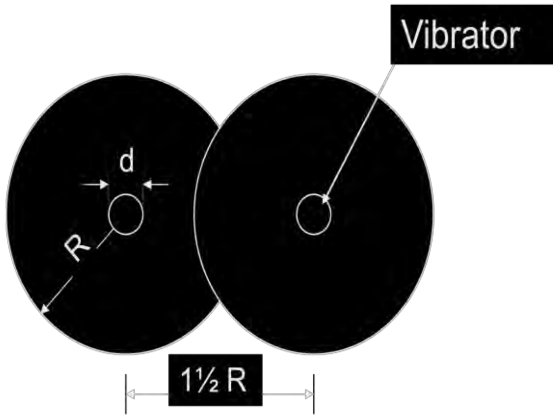
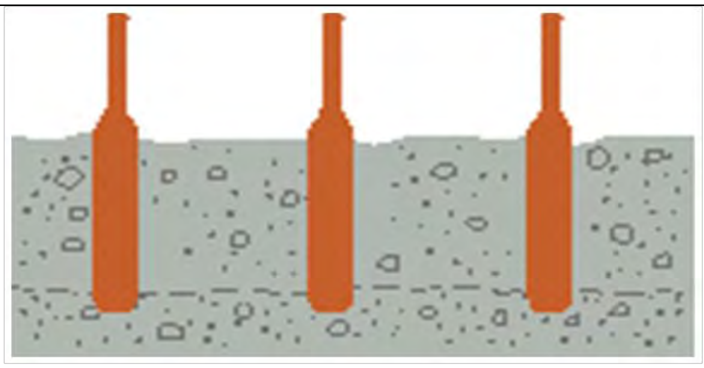
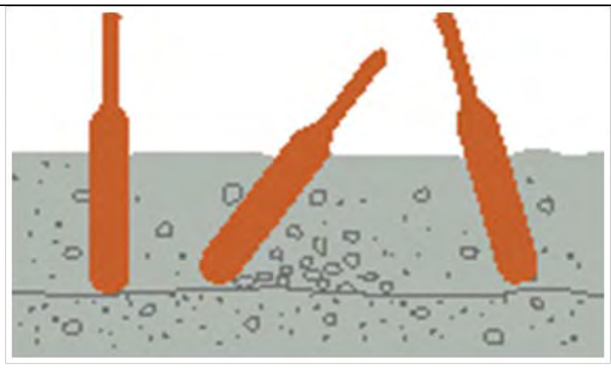
2.Mechanical method suitable for dry mixes by using vibrator.
The advantages of using mechanical vibration almost same as those for compaction:

1. Increasing strength in term of compression and flexure
2. Increasing density of concrete
3. Decreasing water absorption
4. Increasing resistance of concrete for weathering effects, increasing cohesion and bond between concrete and reinforcement
5. Decreasing volumetric changes

Mechanical method do not used for wet mixes as they cause segregation.

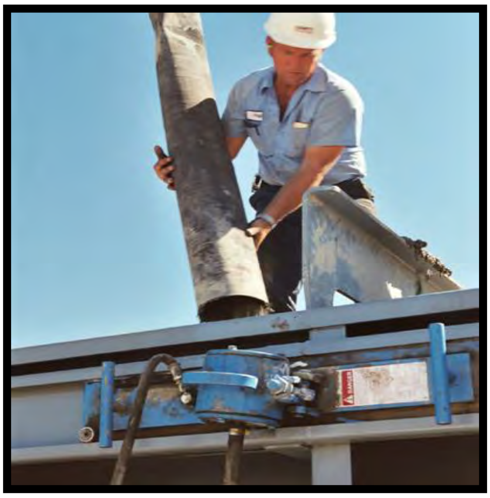
Types of vibrators:

1. **Internal vibrators:** the process of compaction is conducted for each (0.5 – 1.0 m3) for (5 – 30 Sec) according to concrete consistency or workability. The real finishing for

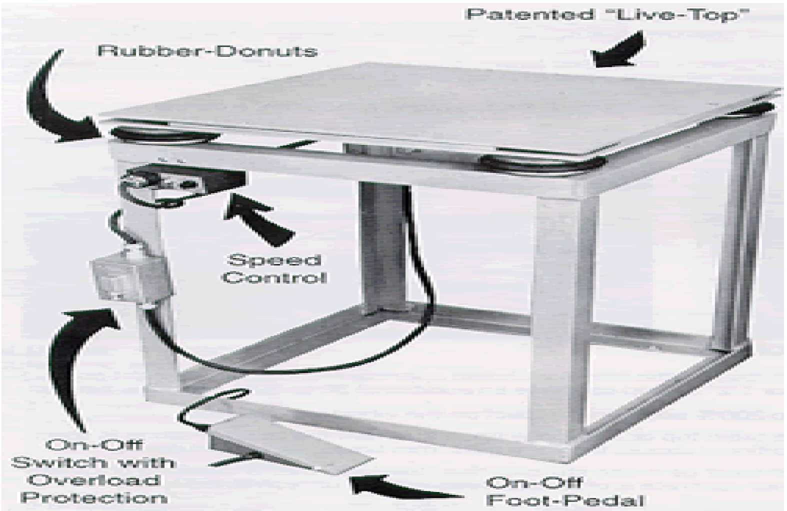
	
 CORRECT Vertical penetration a few inches into previous lift (which should not yet be rigid) of systematic regular intervals will give adequate consolidation 	 INCORRECT Haphazard random penetration of the vibrator at all angles and spacings without sufficient depth will not assure intimate combination of the two layers

compaction process depends on the appearance of concrete surface which should be clear of gaps or cavities and do not contain extra mortar because it causes cracking on the surface. This type of vibrators are considered the best as they affect directly on concrete and can be used in concrete sections with heavy reinforcement.

2.**External vibrators:** the vibrator is rigidly clamped to the formwork. Used for compacting precast or prestressed units or when it is difficult to use internal vibrators



3.**Vibrating tables:** this is a case of formwork clamped to the vibrator. Used for precast concrete.



4.**Other vibrators:** like surface vibrators which is used for compacting mass concrete in dams

Concreting in hot weather:

The problems related to concreting in hot weather include:

1.High rate of water evaporation

2.Rise of temperature in concrete itself

High evaporation occurs due to rise in temperature and decreasing in relative humidity.

The effect of temperature rise on concrete:

1- Effect on fresh concrete

a- Increasing amount of water required for suitable workability

b-Increasing loss in workability due to rise in temp. Which fastening chemical reactions and hydration process.

c- Increasing plastic shrinkage due to increasing evaporation rate which is higher than bleeding.

d-Difficulty in controlling air entraining agents specially in dams and roads works.

e- Increasing setting which cause difficulty in transporting, handling and finishing of concrete.

f- Formation Possibility of cold joints, which means when pouring layer of concrete it will harden quickly and when pouring another layer, there will be a joint between them which forms weak area in concrete.

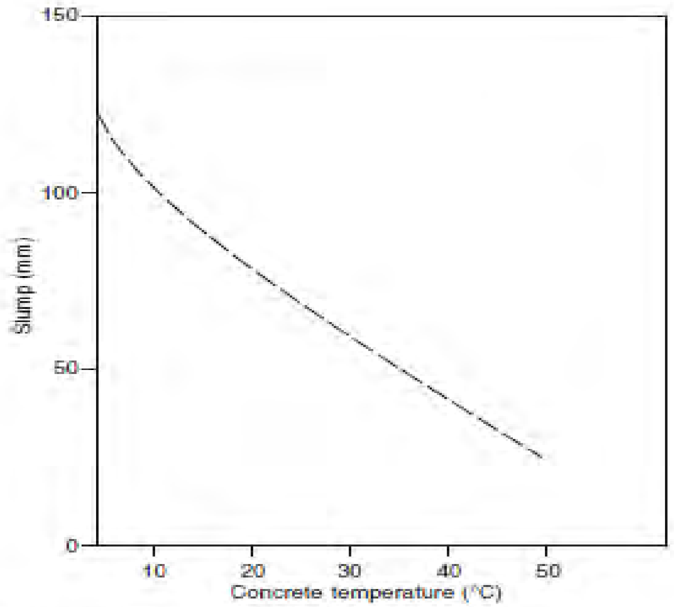


Figure 5.1 Effect of temperature on slump (after ACI 305).

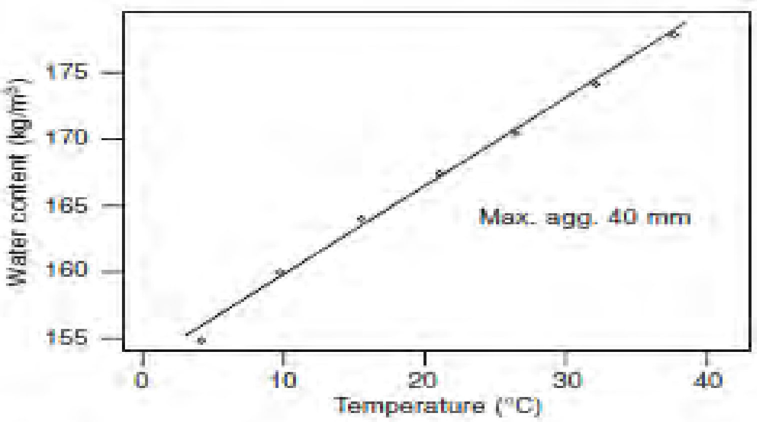


Figure 5.2 Effect of concrete temperature on the amount of water required to produce concrete with 75 mm slump (after ACI 305).

2- **Effect on hardened concrete:**

1.Decreasing strength of hardened concrete after 7 days as the early strength became high and the final is low because of :

a-Rising in temperature during pouring and setting of concrete increases early strength but, it affects inversely on strength after 7 days. This is due to increasing initial hydration which lead to formation of hydration products with weak physical structure and high porosity (gel/space ratio is low) therefore, the final strength is low.

b-Reducing the time required to arrange the distribution of hydration products inside capillary porous, hence they will be in some places more than others and (gel/ space ration) will be reduced and cause decreasing final strength.

2.High temperature causes reducing concrete durability

3.High temperature causes reducing bond between concrete and reinforcement.

4.As the setting and hardening happen quickly, there will be no time for good finishing of concrete surface.

5. Increasing creep of concrete

6. Increasing permeability which leads to corrosion of reinforcement.

Remedial measures

To reduce problems related to concreting in hot weather:

1.Reducing cement content in the mix as possible in order to reduce heat of hydration, using low heat cement, using sulphate resistance cement because it has slow hydration, or using additives like pozzolana or blast furnace slag. The reason for this use is that their cement had low heat of hydration.

2.Reducing temperature of fresh concrete by precooling of one or more of its ingredients. For example cooling water using ice instead of some of the mixing water. But it is important that the ice should be completely melted before finishing mixing time.

The temperature T of freshly mixed concrete can be easily calculated from that of the ingredient, using the equation below:

$$T = \frac{0.2\ (Ta.Wa + Tc.Wc) + Tw.Ww}{0.2\ (Wa + Wc) + Ww}$$

where:

T: temp. of freshly mixed concrete in F or ˚C

W: weight of ingredient per unit volume of concrete

a,c,w,: referred to aggregate, cement and water.

0.2: is the approximate value of specific heat of the dry ingredient.

The actual temperature of the concrete will be higher than that calculated by the equation above due to work done in mixing, and will further rise because of development of the heat of wetting and hydration in cement.

3.Using water reducers and retarders as they increase the workability with same w/c ration. The effect of plasticizers is little when the temperature is high as we need large amount and the cost will be high.

Strength of Concrete

The "strength" of hardened concrete is its ability to resist strain or rupture induced by external forces. The resistance of concrete to compressive, tensile and bending stresses is known as compressive strength, tensile strength, and bending (or flexural) strength, respectively. The resistance of concrete to repeated stresses is called its fatigue strength. Strength is expressed in terms of MPa.

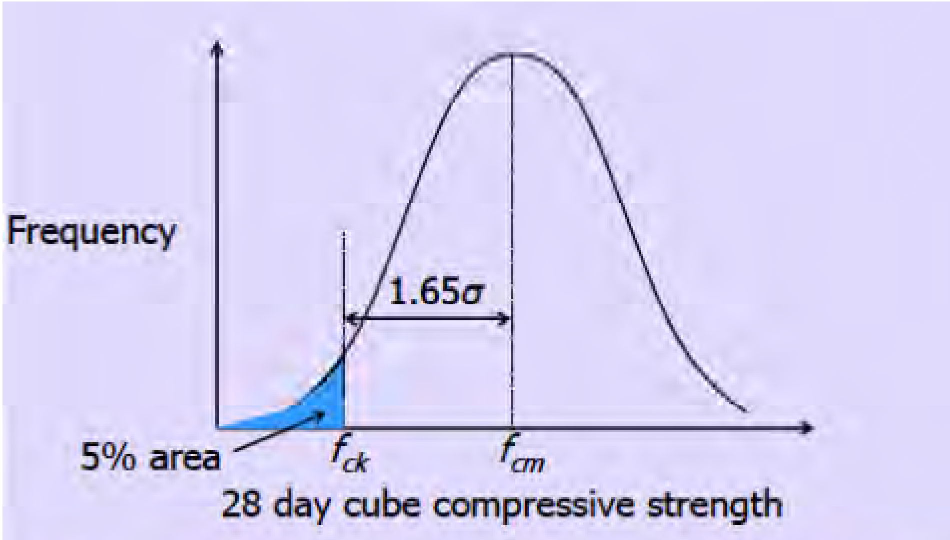
The strength of concrete is required to calculate the strength of the members. For pre-stressed concrete applications, high strength concrete is required for the following reasons:
1) To sustain the high stresses at anchorage regions.
2) To have higher resistance in compression, tension, shear and bond.
3) To have higher stiffness for reduced deflection.
4) To have reduced shrinkage cracks.

Types of strength of concrete:

1. Compressive strength
2. Tensile strength
3. Flexural strength
4. Shear strength
5. Fatigue strength

1. Compressive Strength

The compressive strength of concrete is given in terms of the characteristic compressive strength of 150 mm size cubes tested at 28 days (fck). The characteristic strength is defined as the strength of the concrete below which not more than 5% of the test results are expected to fall. This concept assumes a normal distribution of the strengths of the samples of concrete.
The following sketch shows an idealized distribution of the values of compressive strength for a sizeable number of test cubes. The horizontal axis represents the values of compressive strength. The vertical axis represents the number of test samples for a particular compressive strength. This is also termed as frequency. The average of the values of compressive strength (mean strength) is represented as fcm. The characteristic strength (f_{ck}) is the value in the x-axis below which 5% of the total area under the curve falls. The value of f_{ck} is lower than fcm by 1.65σ, where σ is the standard deviation of the normal distribution.



1-5.2 Idealised normal distribution of concrete strength

- The compressive strength of concrete is usually determined at an age of 28 days of the specimen. The 28-day compressive strength is the strength value used in concrete designs.
- Sometimes, the compressive strength at 7 days is also determined. The 7-day compressive strength is approximately 65-70% of its 28-day strength.
- At least three specimens should be tested; the average of their compressive strengths is found for determining the compressive strength of a concrete sample on a particular testing day.
- The compressive strength values obtained for cylinder specimens and cube specimens prepared from the same concrete sample are not the same:

$$\mathbf{f_{cylinder} = 0.85\ f_{cube}}$$

Factors affecting the compressive strength, fc:

1. Effect of materials and mix proportions
2. Curing conditions (Time, Temperature, Relative Humidity)
3. Testing Parameters

1. Effect of materials and mix proportions

1) Water / cement ratio:

- At w/c < 0.3, disproportionately high increase in f'c can be achieved for very small reduction in w/c. This phenomena is mainly attributed to a significant improvement to the strength of the transition zone (TZ).
- Reason: The size of the calcium hydroxide crystals become smaller with decreasing w/c ratio.

2) Air Entrainment

- Air voids are formed due to inadequate compaction.
- They have an effect in increasing porosity and decreasing the strength of the system.
- At a given w/c ratio, high-strength concretes (containing high cement content) suffer considerable strength loss with increasing amounts of entrained air, whereas low strength concretes (containing a low cement content) tend to suffer a little strength loss or may actually gain some strength as a result of air entraining.
- Entrainment of air increases workability without increasing w/c ratio.

3) Cement Type

- Type III cement hydrates more rapidly than Type I, therefore at early ages, Type III cement will have lower porosity and have higher strength matrix.
- Degree of hydration at 90 days and above is usually similar. Therefore: the influence of cement composition on porosity of matrix and strength of concrete is limited to early ages.

4) Maximum Size Aggregate (MSA)

- Economy mandates that you should use maximum size of aggregate possible.
- Concrete mixtures containing larger aggregate particles require less mixing water.
- Larger aggregates tend to form weaker transition zone (TZ), containing more microcracks.

5) Influence of Mineralogy

Differences in the mineralogical composition of aggregates affect concrete strength.

6) Mixing Water

- Drinking water is most appropriate for use in concrete.
- Oily, acidic, salty, and sea water should not be used in concrete mix.

- If drinking water is not available, compare samples made with available water to samples made with distilled water. If strength is not hurt more than 10%, it can be used in the concrete mix.

2. Curing of Concrete

Procedures developed to promote cement hydration, consisting of control of time, temperature, and humidity conditions immediately after the placement of a concrete mixture into formwork.

- **Curing Temperature** is much more important than casting temperature.
- **TIME:** At a given w/c ratio, the longer the moist curing period, the higher the strength.
- **HUMIDITY:** Concrete increases in strength with age if drying is prevented. When the concrete is permitted to dry, the chemical reactions slow down or stop.
- Concrete should be kept moist as long as possible.
- A minimum period of 7-day moist curing is generally recommended for concrete containing normal Portland cement.
- For pozzolanic concretes; longer periods are recommended, for pozzolanic reaction.

Moist curing is provided by:

- Spraying
- Ponding
- Covering the concrete surface with wet sand, sawdust, or cotton mats.

Curing temperature is much more important than casting temperature. Ordinary concrete placed in cold weather must be maintained above a certain minimum temperature for a sufficient length of time.

3. Testing Parameters

Factors Influencing Cube Compressive Strength

- Rate of loading
- Size of the specimen
- Moisture content
- Age of the specimen
- stress type

Specimen Size:

- In the U.S., the standard specimen for testing the compressive strength of concrete is a cylinder. (height/diameter = h/D =2), • The larger the diameter, the lower the strength.

Reason:

- Variation in strength with varying specimen size are due to the increasing degree of statistical homogeneity in large specimens

Moisture condition:

- Standard: Specimen must be in moist condition at the time of testing.
- Air-dried specimens show 20 to 25% higher strength than corresponding saturated specimen.

Reason: Due to existence of disjoining pressure within the cement paste.

Loading Condition:

- The compressive strength of concrete is measured by a uniaxial compression test. i.e., load is progressively increased to fail the specimen within 2 to 3 minutes.

Rate of Loading

- The more rapid the rate of loading, the higher the observed strength value.
- ASTM C 469 says that in a uniaxial compression test, the load should be progressively increased to fail the specimen within 2 to 3 minutes.
- The usual rate of loading is 35±5 psi/second.

Critical Stress

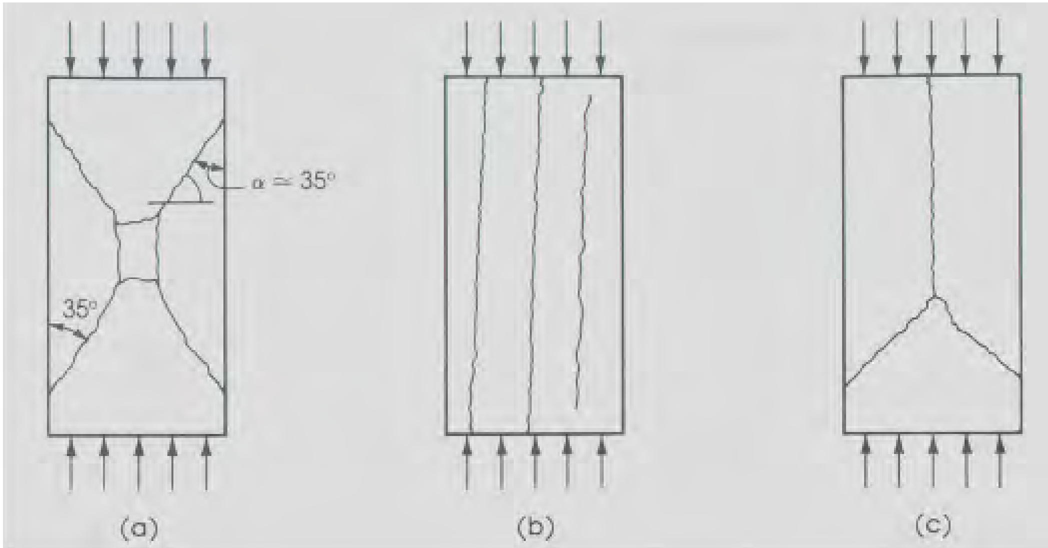
- Critical stress corresponds to the max value of volumetric strain.

The initial change in volume is almost linear up to about 0.75 f ' c. At this point the direction of the volume change is reversed, resulting in volumetric expansion near or at f ' c.

Types of compression failure

There are three modes of failure:

a) Under axial compression concrete fails in shear.
b) The separation of the specimen into columnar pieces by what is known as splitting or columnar fracture.
c) Combination of shear and splitting failure.



Tensile Strength
The tensile strength of concrete can be expressed as follows.
1) Flexural tensile strength: It is measured by testing beams under 2 point loading (also called 4 point loading including the reactions).
2) Splitting tensile strength: It is measured by testing cylinders under diametral compression.
3) Direct tensile strength: It is measured by testing rectangular specimens under direct tension.

1. Flexural strength

Tensile strength ~ 8% to 15% of f'_c , Modulus of Rupture, f_r , for deflection calculations, use:

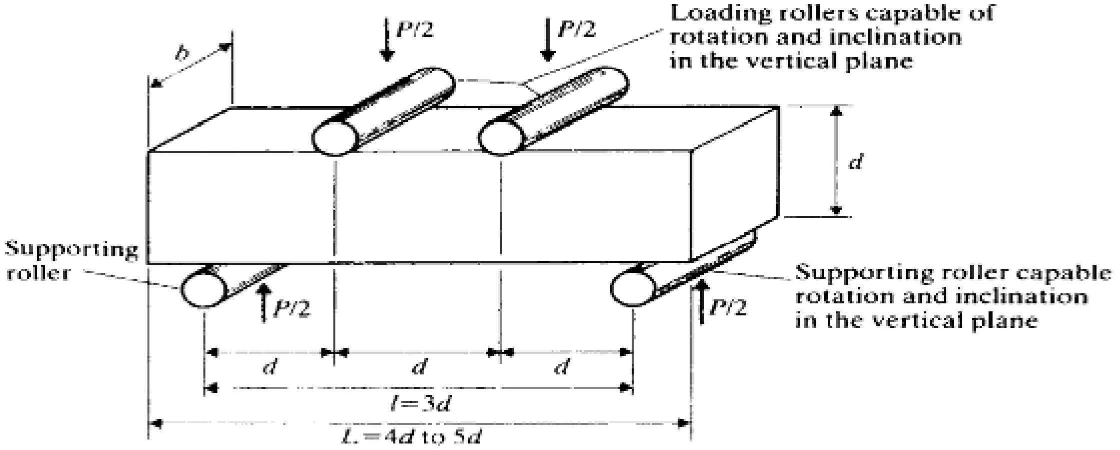


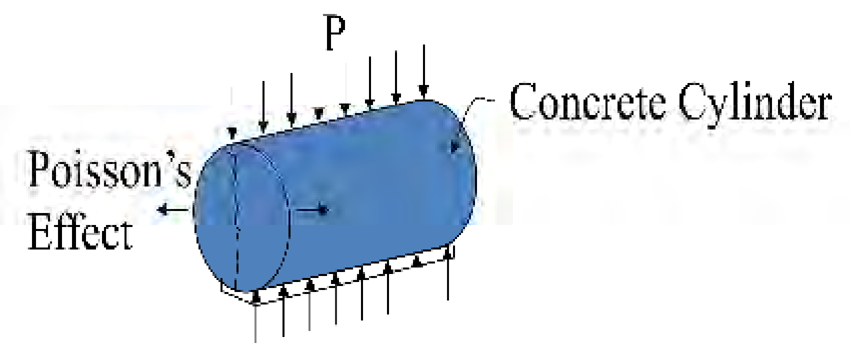
Fig. 16.4: Arrangement for the modulus of rupture test

$$f_{bt} = \frac{Pl}{bd^2}$$

where P = maximum total load,
l = span,
d = depth of the beam, and
b = width of the beam.

2. Tensile Strength

Splitting Tensile Strength, f_{ct}, Split Cylinder Test



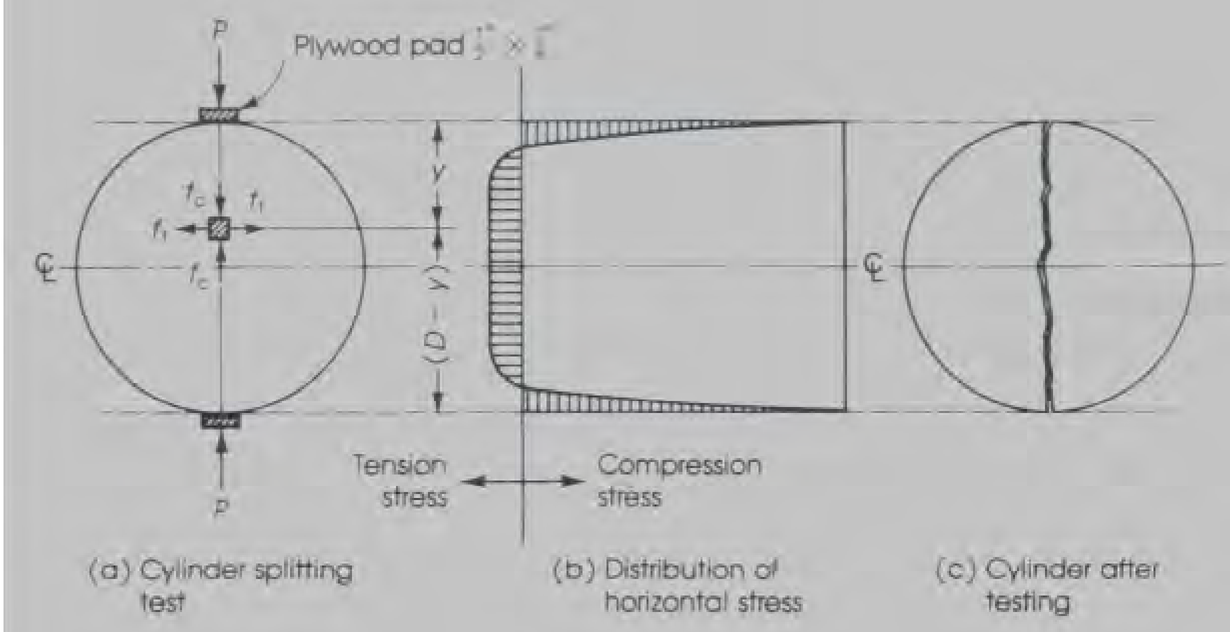


FIGURE 2.6. Cylinder splitting test:[7] (a) configuration of test, (b) distribution of horizontal stress, and (c) cylinder after testing.

$$f_{ct} = \frac{2P}{\pi l d}$$

$$f_{ct} = (5 \ to \ 7)\sqrt{f'_c \,(psi)}$$

Volume Changes in Concrete

Concrete is subjected to changes in volume either autogenous or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete. Volume changes in concrete can be:

1. Shrinkage 2.Creep Swelling

Shrinkage:

- One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage. It is difficult to make concrete which does not shrink and crack; it is only a question of magnitude.
- Now the question is how to reduce the shrinkage and shrinkage cracks in concrete structures. The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.
- Simply, shrinkage occurs due to water loss to atmosphere (volume loss).

Types of Shrinkage in Concrete

To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage

(b) Drying Shrinkage

(c) Autogeneous Shrinkage

(d) Carbonation Shrinkage

a. Plastic Shrinkage

Shrinkage of this type occur when the concrete is still wet (soon after the concrete is placed in the forms) while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade, is believed to be the reasons of plastic shrinkage. The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.

In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage. Sometimes even if the concrete is not subjected to severe drying, but poorly made with a high water/cement ratio, large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out, the surface concrete collapses causing cracks.

Plastic concrete is sometimes subjected to unintended vibration or yielding of formwork support which again causes plastic shrinkage cracks as the concrete at this stage has not developed enough strength.

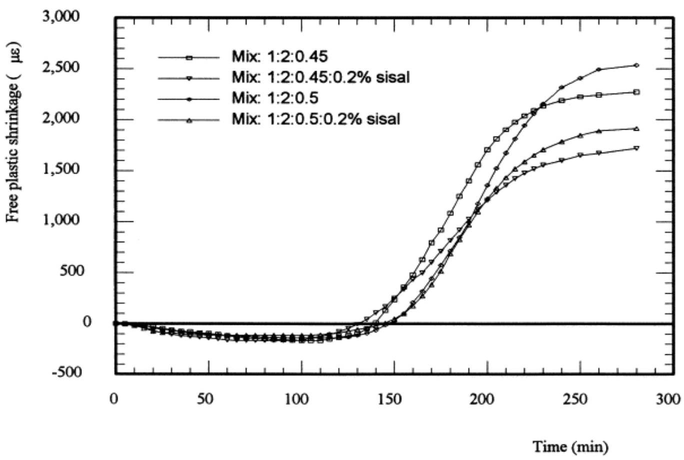
From the above it can be inferred that high water/cement ratio, badly proportioned concrete, rapid drying, greater bleeding, unintended vibration etc., are some of the reasons for plastic shrinkage. It can also be further added that richer concrete undergoes greater plastic shrinkage.

Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by fog spray that keeps the surface moist; or by working at night. Use of small quantity of aluminium powder is also suggested to offset the effect of plastic shrinkage.

Similarly, expansive cement or shrinkage compensating cement also can be used for controlling the shrinkage during the setting of concrete.
Factors affecting plastic shrinkage:

1. Amount of water: increasing amount of water in the mix causes increasing plastic shrinkage.
2. Amount of cement: increasing cement leads to increasing plastic shrinkage.
3. Degree of hydration: shrinkage increases with increasing degree of hydration and early setting and hardening because the reactions increase with increasing temperature and decreasing humidity. Therefore, hydration is fast at hot weather which increases plastic shrinkage. Also, plastic shrinkage increases at the case of high wind.
4. Bleeding: plastic shrinkage decreases with increasing bleeding because it will compensate water evaporated from the surface of concrete which decreases plastic shrinkage.

Occur of shrinkage as we say will be represented by cracking which affects the durability of concrete. With the presence of cracks the permeability increases which causes deterioration of concrete and corrosion of reinforcements and hence, lowering strength of concrete.



Effect of cement content represented by different mixes on plastic shrinkage

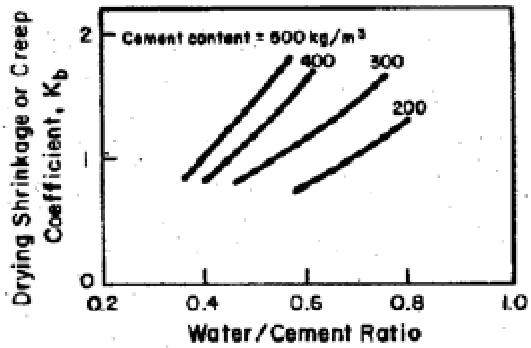
b. Drying Shrinkage

Just as the hydration of cement is an everlasting process, the drying shrinkage is also an everlasting process when concrete is subjected to drying conditions. The drying shrinkage of concrete is similar to the mechanism of drying of timber specimen. The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume. Under drying conditions, the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions. Cement paste shrinks more than mortar and mortar shrinks more than concrete. Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate. The magnitude of drying shrinkage is also a function of the fineness of gel. ***The finer the gel the more is the shrinkage.***

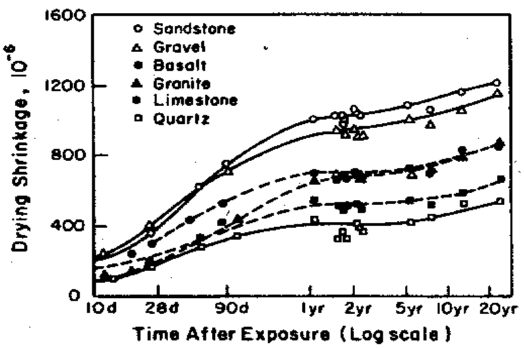
Factors affecting drying shrinkage:

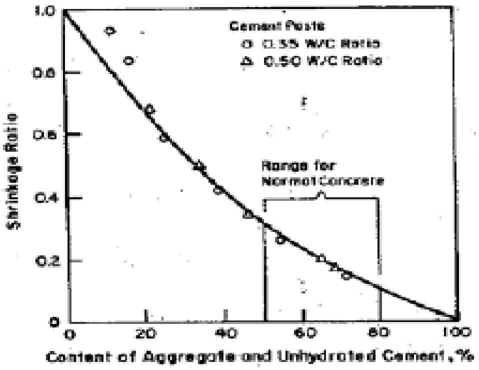
a) Water/cement ratio:

1. For a constant cement content an incremental increase in W/C ratio increases both drying shrinkage and creep.



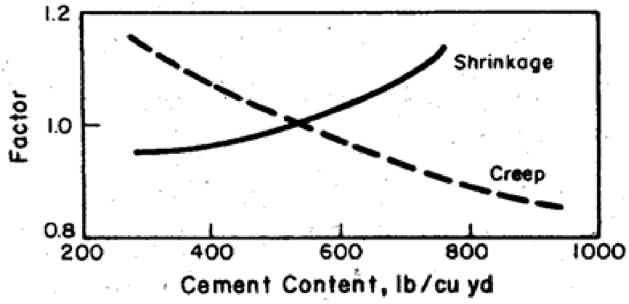
2.**Aggregate type and content:** increasing agg. content and agg. size decreases shrinkage due decreasing the surface area exposed to drying and decreasing the amount of cement that causes shrinkage.





Effect of aggregate type (modulus of elasticity) **Effect of aggregate content**

3. Cement type and content: For a constant W/C ratio an incremental increase in cement content reduces the creep but increases the drying shrinkage. This is the only case in which exists an opposite effect.

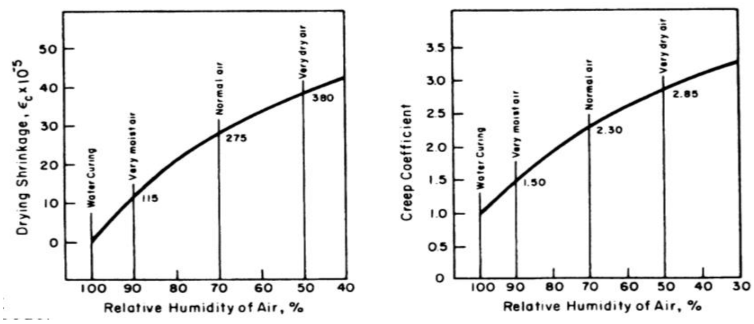


4.Curing

5.Admixtures

6. Relative humidity (largest for relative humidity of 40% or less).

- One of the most important factors for both shrinkage and creep is the relative humidity of the medium surrounding the concrete. For a given concrete, creep is higher the lower the relative humidity.
- An incremental increase on relative humidity of air decreases both the drying shrinkage and creep.



7.Temperature:

Given the same curing history for two specimens, the one that is kept in a higher temperature will have more creep and drying shrinkage than the other one.

c. Autogeneous Shrinkage

This type of shrinkage occur after setting and hardening of concrete and when w/c is less than 0.42. the water will be depleted by the hydration reactions and there is no excess water of curing, this will cause surface tension and then autogeneous shrinkage.

In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage. Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of a concrete dam. factors affecting this type is the same as these affecting plastic shrinkage especially cement type (fineness of cement) and content.

d. Carbonation Shrinkage

Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide [$Ca(OH)_2$] gets converted to calcium carbonate ($CaCO_3$)and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete very slowly.

The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. ***Carbonation is accompanied by an increase in weight of the concrete and by shrinkage (because*** ($CaCO_3$) ***is smaller than*** [$Ca(OH)_2$].

Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place.

Carbonation of concrete also results in increased strength and reduced permeability, possibly because water released by carbonation promotes the process of hydration and also calcium carbonate reduces the voids within the cement paste. As the magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage, this aspect is not of much significance.

Swelling: Occurs when the concrete is continuously in wet conditions. On contrary to shrinkage, swelling sometimes occurs due to consumption of water and the concrete shows a total increase in weight and volume. The water particles work against cohesive forces and push gel particles far from each other which cause volume increase. Also, the entrance of water reduces the surface tension for the gel and lead to sudden expansion.

The property of swelling when placed in wet condition, and shrinking when placed in drying condition is referred as moisture movement in concrete.

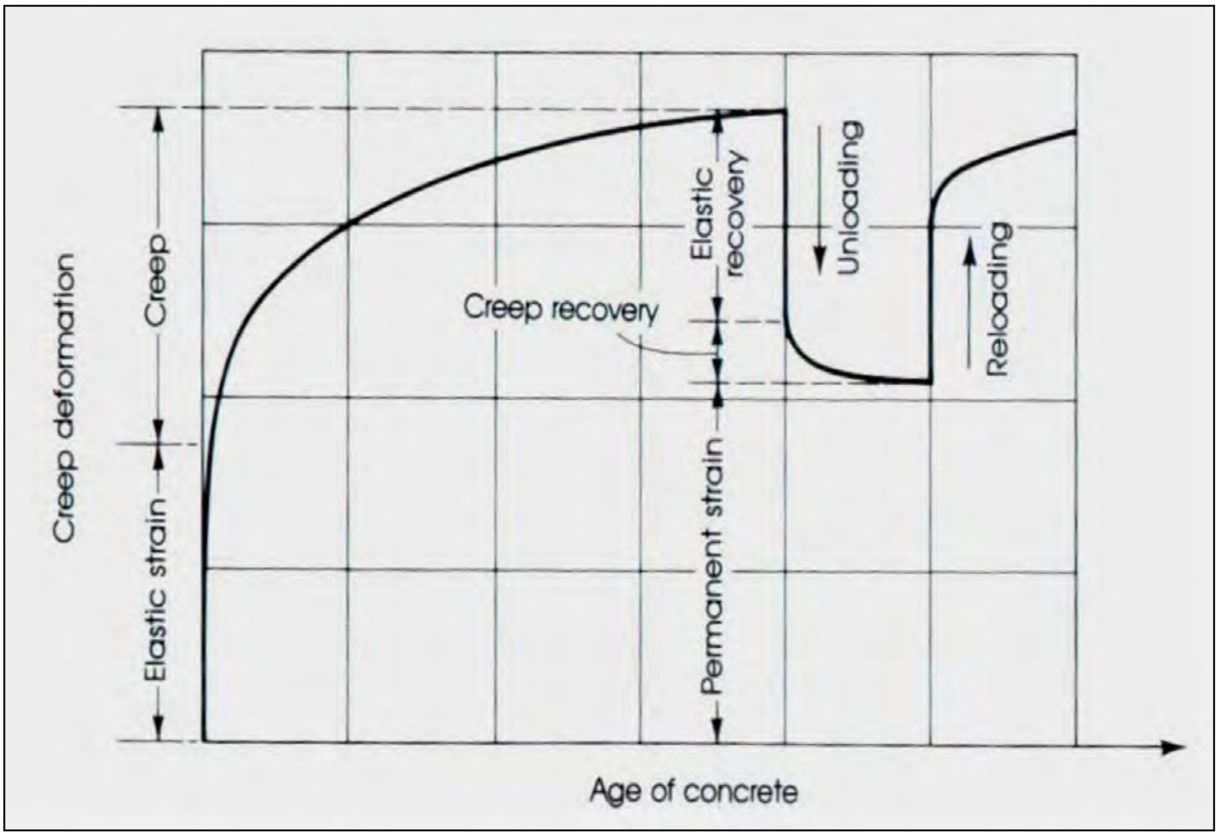
Creep in concrete

Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending.

Creep does not necessarily cause concrete to fail or break apart. Creep is factored in when concrete structures are designed.

Creep strain develops over time…

- Absorbed water layers tend to become thinner between gel particles that are transmitting compressive stresses
- Bonds form between gel particles in their deformed position.



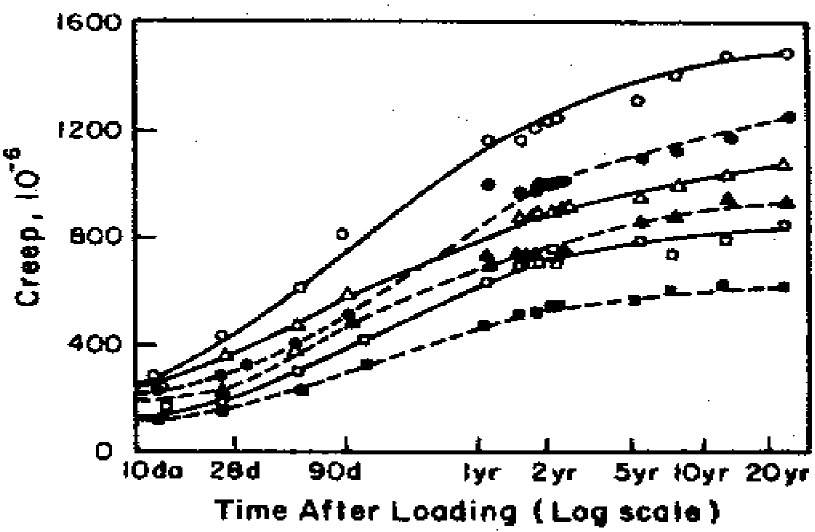
Factors Affecting Creep

1. Aggregate
2. Mix Proportions
3. Age of concrete

1. Influence of Aggregate

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. The modulus of elasticity of aggregate is one of the important factors influencing creep.

It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

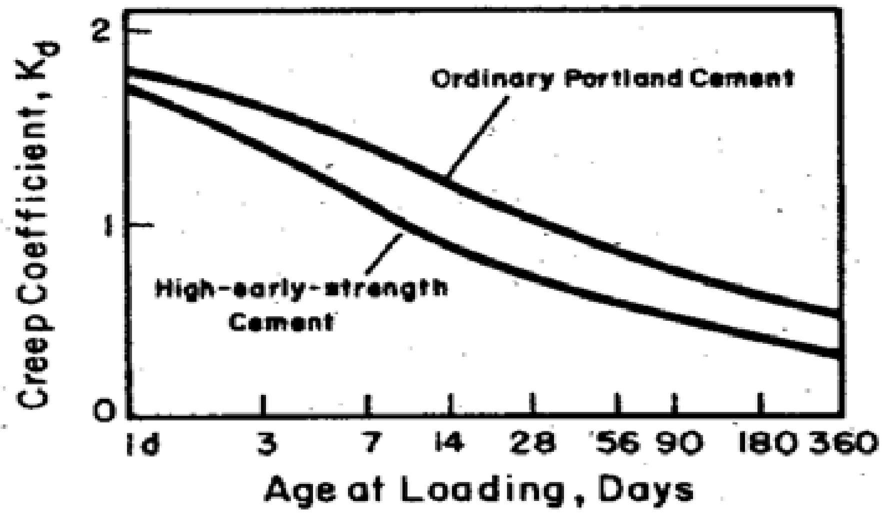


2. Influence of Mix Proportions:

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age:

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.



Effects of Creep on Concrete and Reinforced Concrete

- In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can load to buckling.
- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.

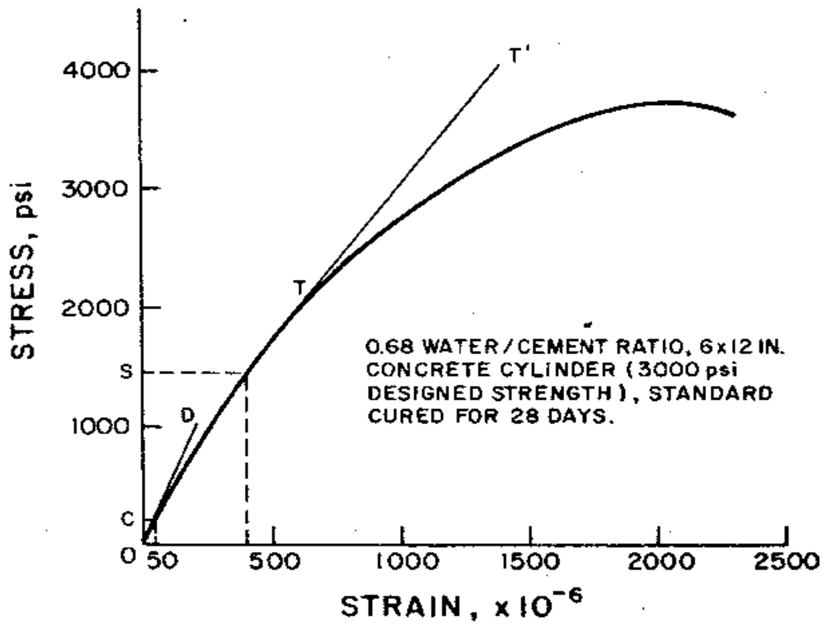
- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.

- Creep of plain concrete does not by itself affect strength, although under very high stresses creep hastens the approach of the limiting strain at which failure takes place.
- Another instance of the adverse effects of creep is its influence on the stability of the structure through increase in deformation and consequent transfer of load to other components.
- Thus, even when creep does not affect the ultimate strength of the component in which it takes place, its effect may be extremely serious as far as the performance of the structure as a whole is concerned.
- The loss of prestress due to creep is well known and accounted for the failure of all early attempts at prestressing. Only with the introduction of high tensile steel did prestressing become a successful operation.
- The effects of creep may thus be harmful. On the whole, however, creep unlike shrinkage is beneficial in relieving stress concentrations and has contributed to the success of concrete as a structural material

Elastic Modulus of Concrete

- Types of Elastic Modulus (***E***) are static and dynamic
- ***E*** is given by the shape of ϵ-σ curve for concrete under uniaxial loading (since the curve for concrete is nonlinear, three methods for computing moduli are used).
- **Tangent Modulus** (slope of a line drawn tangent to the ϵ-σ curve at any point on the curve)
- **Secant Modulus** (slope of the line drawn from the origin to a point on the curve corresponding to a 40% *f'c*)
- **Chord Modulus** (slope of a line drawn between two points on the ϵ-σ curve)

Different types of elastic moduli and the method by which these are determined.



CALCULATING THE ELASTIC MODULI

σ_{ULT} = 3600 psi
40% σ_{ULT} = 1440 psi = SO

Secant Modulus: Slope of the line corresponding to stress SO = 1440/400 × 10^{-6} = 3.6 × 10^6 psi

Chord Modulus: Slope of the line corresponding to stress SC = (1440-200)/(400-50) × 10^{-6} = 3.5 × 10^6 psi

Tangent Modulus: Slope of the line TT' drawn tangent to any point on the σ-ε curve = 2.5 × 10^6 psi

Dynamic Modulus (Initial Tangent Modulus): Slope of the OD from the origin = 1000/200 × 10^{-6} = 5 × 10^6 psi

Elastic Modulus of Concrete

- According to ACI Building Code 318, with a concrete unit weight between 90 and 155 lb/ft3, the modulus of elasticity can be determined from:

$$E = f(w_c, f'_c)$$

$$E_c = W_c^{1.5} \times 33 f_c'^{1/2}$$

Where: ***Ec*** = elastic modulus
Wc = unit weight of concrete (lb/ft3)
f'c = the 28-day compressive strength of standard cylinders

Factors Controlling Elastic Modulus

- In single phase solids (homogeneous materials) a direct relationship exists between density and modulus of elasticity.
- In heterogeneous, multi-phase materials, i.e., concrete, the volume fraction, density, and modulus of elasticity of each phase, and the characteristics of TZ determine the elastic behavior of the composite.

Factors Controlling Elastic Modulus

1. Aggregate:

- Porosity of aggregate (determines stiffness) is the most important factor that affects ***E*** of concrete. Dense aggregates have a high ***E***.

- In general, the larger the amount of coarse aggregate with a high elastic modulus in a concrete mixture, the greater would be the modulus of elasticity of concrete.

Granite	20×10^6 psi
Sandstone (porous)	$3\text{-}7 \times 10^6$ psi
Lightweight expanded shale	$1\text{-}3 \times 10^6$ psi

2. Hydrated Cement Paste (HCP):

- The elastic modulus of the cement paste matrix (***Ep***) is determined by its porosity.
- The factors controlling the porosity of the cement paste are: w/c, air content, mineral admixtures, and degree of cement hydration.

$$E_c = E_a g + E_p (1 - g)$$

Volume fraction of aggregate (g)

Volume of cement paste ($1 - g$)

3. Transition zone (TZ):

- Void space, microcracks, and orientation of CH crystals are more common in TZ than in bulk cement paste; therefore they play a very important role in determining the stress-strain relationship in concrete.

Poisson's ratio

For a material subjected to simple axial load, the ratio of the lateral strain to axial strain **within the elastic range** is called **Poisson's ratio**.
With concrete the values of Poisson's ratio generally vary between 0.15 and 0.20.

$$\text{Poisson's Ratio} = \frac{\text{Lateral Strain}}{\text{Axial Strain}} = \nu$$

Concrete Mix Design

1. Introduction

- The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design.

- The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted.

- The property of workability, therefore, becomes of vital importance. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour.

- The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

- The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job.

- The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

2. Requirements of concrete mix design

The requirements which form the basis of selection and proportioning of mix ingredients are :

a) The minimum compressive strength required from structural consideration
b) The adequate workability necessary for full compaction with the compacting equipment available.
c) Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
d) Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

2.1 Types of Mixes

i. Nominal Mixes

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

ii. Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes. IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

iii. Designed Mixes

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

The various factors affecting the mix design are:

3.1. Compressive strength

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

3.2. Workability

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

3.3. Durability

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

3.4. Maximum nominal size of aggregate

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate.

IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

3.5. Grading and type of aggregate

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive. The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

3.6. Quality Control

The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

4 Mix Proportion designations

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

4.1 Factors to be considered for mix design

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

ACI AND BRITISH (DOE) METHOD OF CONCRETE MIX DESIGN

ACI METHOD OF CONCRETE MIX DESIGN

• **Workability**: The property of the concrete that determines its capacity to be placed and consolidated properly and be finished without harmful segregation.
• **Consistency**: It is the relative mobility of the concrete mixture, and measured in terms of the slump; the greater the slump value the more mobile the mixture.
• **Strength**: The capacity of the concrete to resist compression at the age of 28 days.
• **Water-cement (w/c) or water-cementitious (w/(c+p)) ratio**: Defined as the ratio of weight of water to the weight of cement, or the ratio of weight of water to the weight of cement plus added pozzolan. Either of these ratios is used in mix design and considerably controls concrete strength.
• **Durability**: Concrete must be able to endure severe weather conditions such as freezing and thawing, wetting and drying, heating and cooling, chemicals, deicing agents, and the like. An increase of concrete durability will enhance concrete resistance to severe weather conditions.
• **Density**: For certain applications concrete may be used primarily for its weight characteristics. Examples are counterweights, weights for sinking pipelines under water, shielding from radiation, and insulation from sound.

DESIGN PARAMETERS

ACI 211.1-91, Reapproved 2002, states: "The procedure for selection of mix proportions given below is applicable to normal weight concrete. Estimating the required batch weights for the concrete involves a sequence of logical straightforward steps. Some or all of the following specifications are required; maximum water-cement or water-cementitious material ratio, minimum cement content, air content, slump, maximum size of aggregate, strength, and admixtures."

ACI METHOD OF PROPORTIONING CONCRETE MIXES

The ACI Standard 211.1 is a "*Recommended Practice for Selecting Proportions for Concrete*". The procedure is as follows:

Step 1. Choice of slump

Step 2. Choice of maximum size of aggregate

Step 3. Estimation of mixing water and air content

Step 4. Selection of water/cement ratio

Step 5. Calculation of cement content

Step 6. Estimation of coarse aggregate content

Step 7. calculation of Fine Aggregate Content

Step 8. Adjustments for Aggregate Moisture

Step 9. Trial Batch Adjustments

Step 1. Choice of slump

If slump is not specified, a value appropriate for the work can be selected from the below Table which is reproduced from the text book below*, (note that the table numbers are given from the text book rather than the ACI standard).

Table 1

Type of Construction	Slump	
	(mm)	(inches)
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3
Mass concrete	25 - 50	1 - 2

Step 2. Choice of maximum size of aggregate.

Large maximum sizes of aggregates produce less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete, and of coarse it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the **MAXIMUM SIZE OF AGGREGATE SHOULD BE THE LARGEST AVAILABLE SO LONG IT IS CONSISTENT WITH THE DIMENSIONS OF THE STRUCTURE.**

In practice the dimensions of the forms or the spacing of the rebars controls the maximum CA size.

ACI 211.1 states that the maximum CA size should not exceed:

- one-fifth of the narrowest dimension between sides of forms,
- one-third the depth of slabs,
- 3/4-ths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.

Step 3. Estimation of mixing water and air content.

The ACI Method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump.

In general the quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum CA size, the shape and grading of both CA and FA, as well as the amount of entrained air.

The approximate amount of water required for average aggregates is given in Table.2.

Table: 2: Approximate Mixing Water and Air Content Requirements for Different Slumps and Maximum Aggregate Sizes.

	Mixing Water Quantity in kg/m^3 (lb/yd^3) for the listed Nominal Maximum Aggregate Size							
Slump	9.5 mm 0.375 in	12.5 mm 0.5 in	19 mm 0.75 in	25 mm 1 in	37.5 mm 1.5 in	50 mm 2 in	75 mm 3 in	100 mm 4 in
Non-Air-Entrained								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
Recommended Air Content (percent)								
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Step 4. Selection of water/cement ratio.

The required water/cement ratio is determined by strength, durability and finishability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table.3 and/or Table.4.

Table.3: Water-Cement Ratio and Compressive Strength Relationship

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

Table.4: Water-Cement Ratio

Maximum permissible water-cement or water-cementitious materials ratios for concrete in severe exposure		
Type of Structure	Structure wet continuously and exposed to frequent freezing and thawing	Structure exposed to sea water or sulfates
Thin section (railings, curbs, sills, ledges, ornamental work) and sections with less than 25 mm cover over steel	0.45	0.40
All other structures	0.50	0.45

Step 5. Calculation of cement content.

The amount of cement is fixed by the determinations made in Steps 3 and 4 above.

$$\text{weight of cement} = \frac{\text{weight of water}}{w/c}$$

Step 6. Estimation of coarse aggregate content.

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Table. 5: Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus			
	2.40	**2.60**	**2.80**	**3.00**
9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

Notes:

1. These values can be increased by up to about 10 percent for pavement applications.
2. Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29.

The ACI method is based on large numbers of experiments which have shown that for properly graded materials, the finer the sand and the larger the size of the particles in the CA, the more volume of CA can be used to produce a concrete of satisfactory workability.

Step 7. Estimation of Fine Aggregate Content.

At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate. Then once the volumes are know the weights of each ingredient can be calculated from the specific gravities.

Table. 6: First estimate of concrete weight (kg/m³)

First estimate of concrete weight (kg/m³)	
Nominal maximum size of aggregate	**Non-air-entrained concrete**
9.5	2280
12.5	2310
19	2345
25	2380
37.5	2410
50	2445
75	2490
150	2530

Step 8. Adjustments for Aggregate Moisture.

Aggregate weights. Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

Amount of mixing water. If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Step 9. Trial Batch Adjustments.

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishability, unit weight, air content and strength.

Example

We require a mix with a mean 28-day compressive strength (measured on standard cylinders) of 35 MPa and a slump of 50 mm, ordinary Portland cement being used. The maximum size of well-shaped, angular aggregate is 20 mm, its bulk density is 1600 kg/m3, and its specific gravity is 2.64. The available fine aggregate has a fineness modulus of 2.60 and a specific gravity of 2.58. No air entrainment is required. For the sake of completeness, all steps, even when obvious, will be given.

Solution:

Step 1: A slump of 50 mm is specified (or from **Table:1**).

Step 2: The maximum size of aggregate of 20 mm is specified (or from **ACI 211.1**).

Step 3: From Table 14.5 for a slump of 50 mm and a maximum size of aggregate of 20 mm (or 19 mm), the water requirement is approximately 190 kg per cubic metre of concrete (or from **Table :2**).

Step 4: From **Table:3** (past experience comparing with **Table:4**), a water/cement ratio of 0.48 is expected to result in concrete with a compressive strength, measured on cylinders, of 35 MPa. There are no special durability requirements.

Step 5: The cement content is 190/0.48 = 395 kg/m3.

Step 6: From **Table:5**, when used with a fine aggregate having a fineness modulus of 2.60, the bulk volume of oven-dry rodded coarse aggregate with a maximum size of 20 mm is 0.64. Given that the bulk density of the coarse aggregate is 1600 kg/m3, the mass of coarse aggregate is 0.64 × 1600 = 1020 kg/m3.

Step 7: To calculate the mass of fine aggregate, we need first to calculate the volume of all the other ingredients. The required values are as follows.

Volume of water is 190/1000 = 0.19 m^3
Solid volume of cement (SG=3.15)= 395/(3.15*1000) = 0.126 m^3
Solid volume of coarse Agg is 1020/(2.64*1000) = 0.386 m^3
Volume of entrped air (Table:2) is 0.02 = 0.02 m^3
Hence, total volume of all ingredients except fine agg is = 0.722 m^3
The required volume of fine agg is 1.0 – 0.722 = 0.278 m^3
The mass of fine agg is 0.278 * 2.58 * 1000 = 717 kg/ m^3

From the various steps, we can list the estimated mass of each of the ingredients in kilograms per Cubic meter of concrete as follows:

Water=190 kg/m^3, Cement=395 kg/m^3, C.Agg=1020 kg/m^3, F.Agg=717 kg/m^3 ,
Final density= the sum of all the above=2322 kg/m^3.

Step 8: To adjust calculation for moisture content is 2% and 5%for coarse and fine aggregate respectively, the water absorption was is 0.5% and 0.3%for coarse and fine aggregate respectively:

Adjusted weight of coarse agg = 1 + moisture content * calc. weight
= (1+0.05) * 1020 = 1071 kg/m^3

Adjusted weight of fine agg = 1 + moisture content * calc. weight
= (1+0.02) * 717 = 731 kg/m^3

Step 9: Trail batch adjustment for mixing water added

Water rate added by coarse agg = moistur –absorption = 2-0.5 =1.5 %

Water rate added by fine agg = moistur –absorption = 5-0.3 =4.7 %

Total water added = coarse agg weight * rate + Fine agg weight * rate

= 1020 *0.015 + 717 * 0.047 = 49.6 kg/m^3

Adjusted water required = 190 -49.6 = 140.4 kg/m^3

Adjusted cement content = 140.4/0.48= 292.5 kg/m^3

Adjusted batch is as following:

Coarse aggregate weight is = 1071 kg/m^3

Fine aggregate weight is = 731 kg/m^3

Water for the mix is = 140.4 kg/m^3

Cement content weight is = 292.5 kg/m^3

Adjusted density = 1071+731 + 140.4+292.5+1071+731 = 2235 kg/m^3

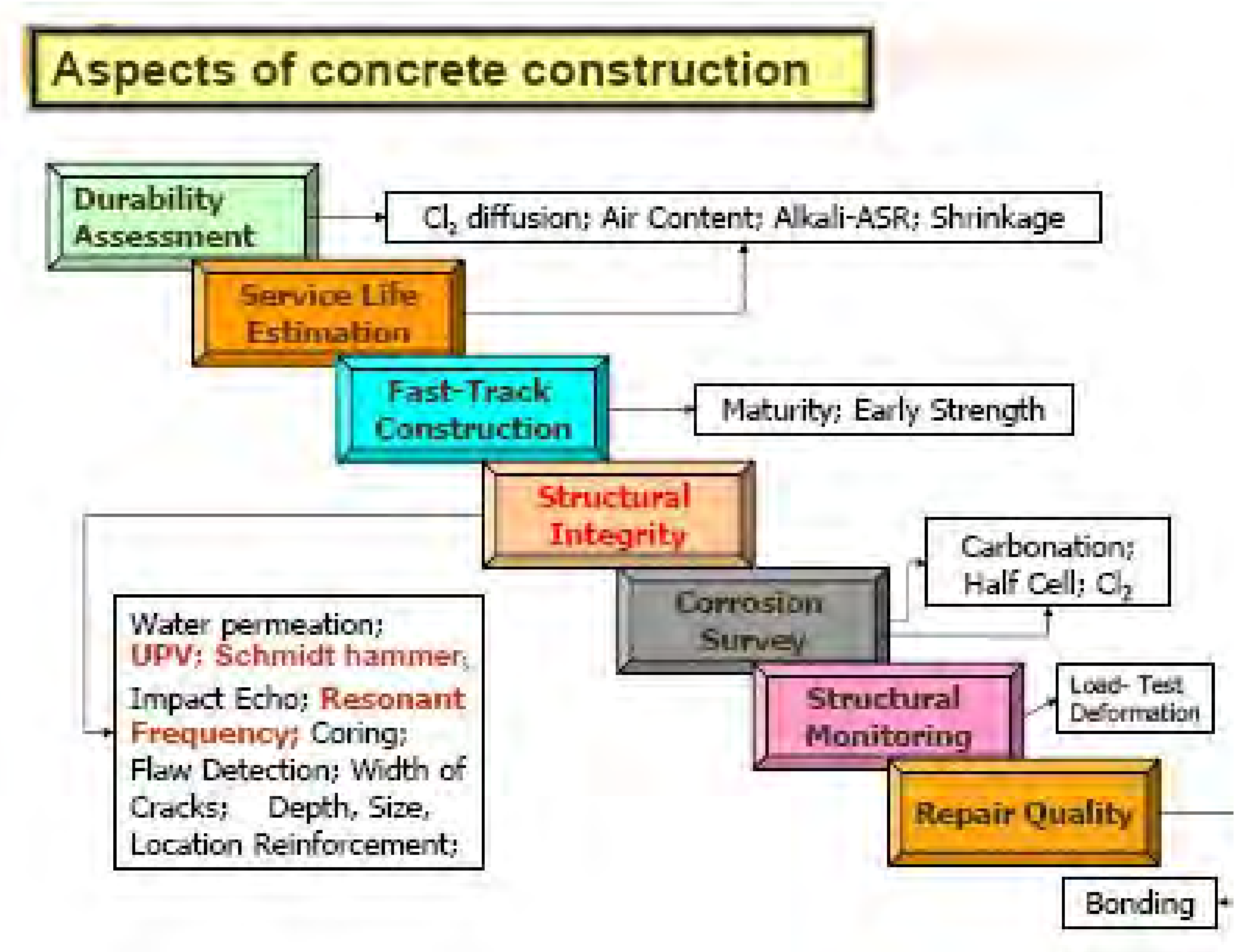
Non Destructive Testing in Concrete

Concrete Testing

Destructive tests

Concrete tests

Non-destructi


Aspects of concrete construction
Durability Assessment
Cl2 diffusion; Air Content; Alkali-ASR; Shrinkage
Service Life Estimation
Fast-Track Construction
Maturity; Early Strength
Structural Integrity
Carbonation; Half Cell; Cl2
Corrosion Survey
Water permeation; UPV; Schmidt hammer; Impact Echo; Resonant Frequency; Coring; Flaw Detection; Width of Cracks; Depth, Size, Location Reinforcement;
Structural Monitoring
Load- Test Deformation
Repair Quality
Bonding

ortance

Whether concrete is hardened pro gained its designed strength ?

NDT is for both old and New Struct

Exercise this without damaging the Structure…….

Here NDT play important rule...

Deliverables of NDT

- Elastic Modulus
- Density
- strength
- Cracks and Voids Determination
- Reinforcement Location
- Quality of Workmanship
- Surface Hardness
- Surface Absorption

Cost Effectiveness

- Destructive testing
  - Huge Cost initially has to put in for taking sample and then to test it.
- NDT
  - Its very easy and simple process and a lot many tests can be performed on concrete less than single amount require for sampling of concrete

Where to use NDT

- Quality control of Construction , in situ
- Confirming Workmanship
- Determining position of reinforcement
- Location of Cracks/Joints/Honeycombing

BASIC METHODS

- VISUAL TESTING
- SCHMIDTS REBOUND HAMMER TEST
- ULTRASONIC PULSE VELOCITY TEST
- PERMEABILITY TEST
- HALF CELL ELECTRIC POTENCIAL METHOD
- PENETRATION RESISTANCE or WINDSOR PROBE TEST
- COVERMETER TESTING

Cont…

- RADIO GRAPHIC TESTING
- SONIC METHOD
- CARBONATION DEPTH MEASUREMENT
- TOMOGRAPHIC MODELLING
- IMPACT ECO-TESTING
- GROUND PENETRATION RADAR TESTING
- INFRARED THERMOLOGY

Qualification/Certifica

- A person / Organization should hav
Certification From

ISO - 97

IS codes

- IS 1311
  - Non Destructive Testing
- IS 13311 (PART 1) : 1992
  - Ultrasonic Pulse Velocity
- IS 13311 (PART 2) : 1992
  - Rebound Hammer Test

VISUAL INSPECTION

Experience and well trained Eye

Signs of Distress

- Cracks
- Pop-outs
- Spalling
- Dis-integration
- Color change
- Weathering
- Staining
- Surface blemishes
- Lack of Uniformity

Tools/ Equipment's

- Measuring Tape
- Ruler
- Marker
- Thermometer
- Anemometers
  - In case access to site is not possible
    - Binoculars
    - Telescopes
    - Bore scopes
    - Endoscopes
    - fiberscopes

Methodology

Defects Observed

- Cracks
- Surface pitting and Spalling
- Surface Staining
- Differential movements and Displacements
- Variation in algal and vegetable growth
- Surface voids
- Honeycombing
- Bleed Marks
- Constructional and Lift Joints

Radioactive Methods

- Use of X-rays and Gamma rays in NDT is new concept
- X and gamma rays are the component of high energy region on the electromagnetic spectrum, it penetrates concrete but undergo attenuation in the process
- The degree of attenuation is measured
- The intensity of X/Gamma rays passing through the specimen is measured
- By using these two values density of concrete is calculated

- Gamma rays transmission mission has been used to measure the thickness of concrete slabs of known density
- Gamma radiation of Known intensity is made to pass and penetrate through concrete and the intensity at other face is measured and from this the thickness of member is calculated

Nuclear Methods

- There are two basic methods which are used to find out some properties of concrete
  - Neutron scattering Methods ; moisture content
  - Neutron Activation analysis ; cement content

Magnetic Methods

- Battery operated magnetic devices that are used to measure Depth of reinforcement cover in concrete
- Detect the position of reinforcement bars
- Apparatus is known as COVERMETER

Electrical Methods

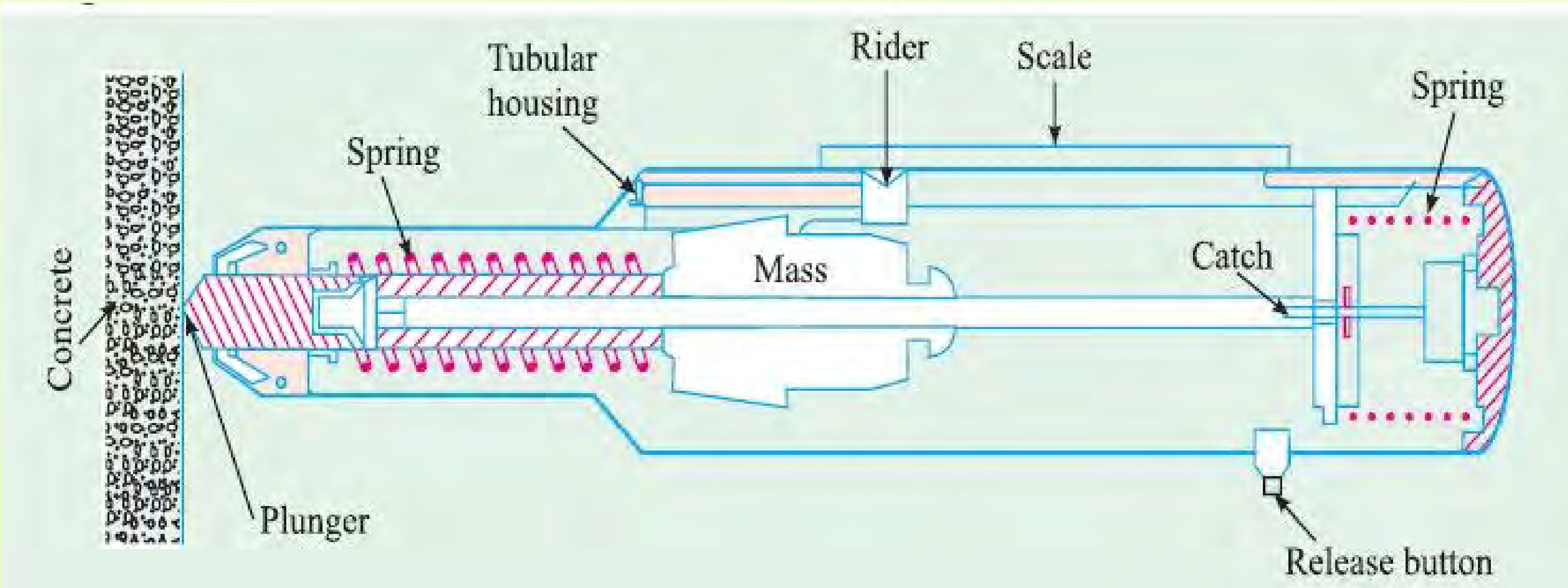
- To find out moisture content of Hardened Concrete
- Tracing of Moisture permeation through concrete
- Determination of thickness of Concrete pavements

REBOUND HAMMER TEST

Rebound Hammer Test

- Surface hardness test
- Rebound of elastic mass depends on hardness of surface
- Relation between rebound number and strength of surface

Components of Hammer



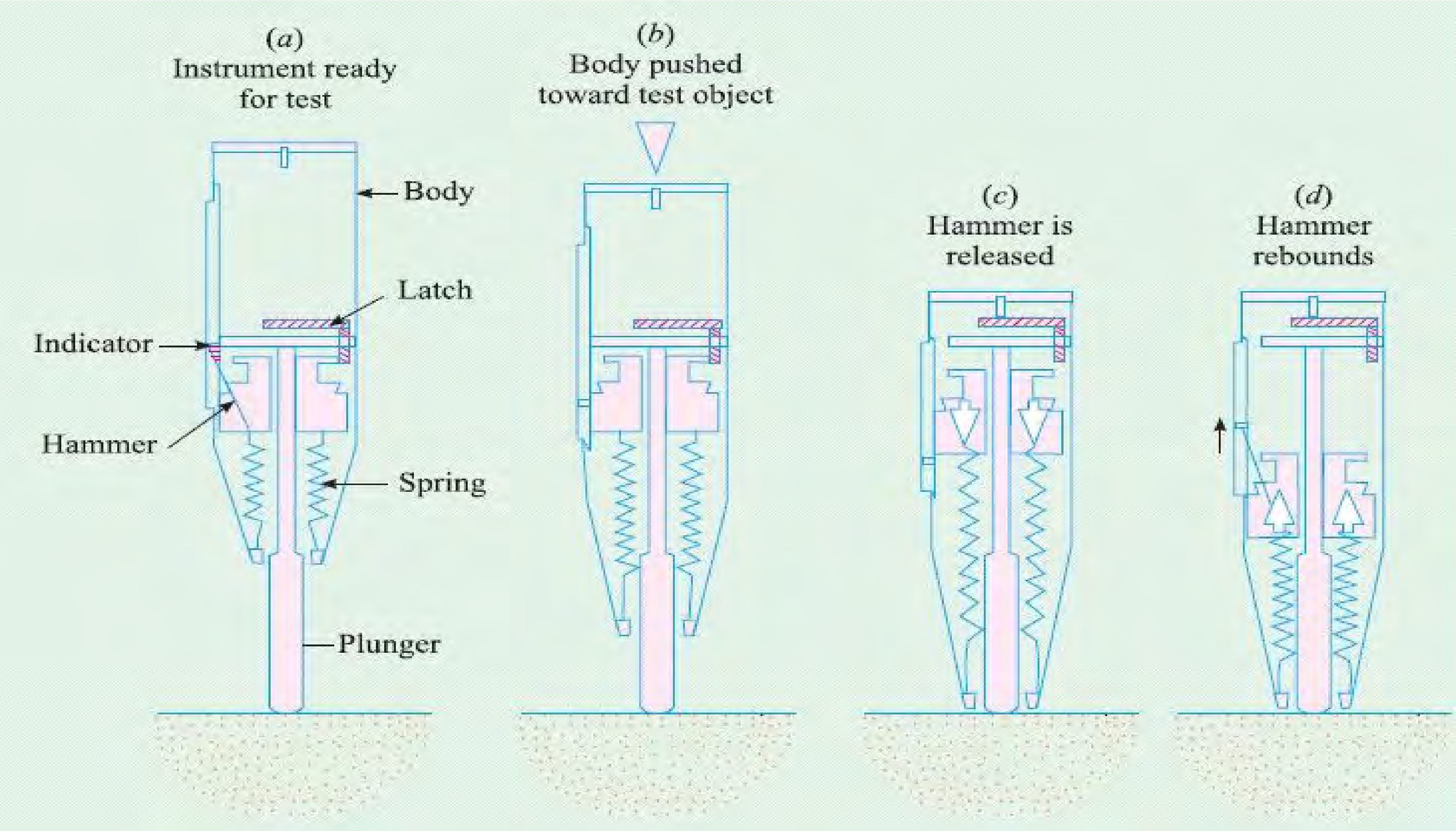
- HAMMER :

Device	Measuring Direction	Applications	Weight
Original Schmidt Hammer	Impact direction perpendicular to the surface	Used for the non-destructive measurement of the concrete/mortar compressive strength characteristics	900 g
Silver Schmidt Hammer	independent of impact direction	Suitable for testing a wide variety of concrete, mortar and rock	600 g

Limitation

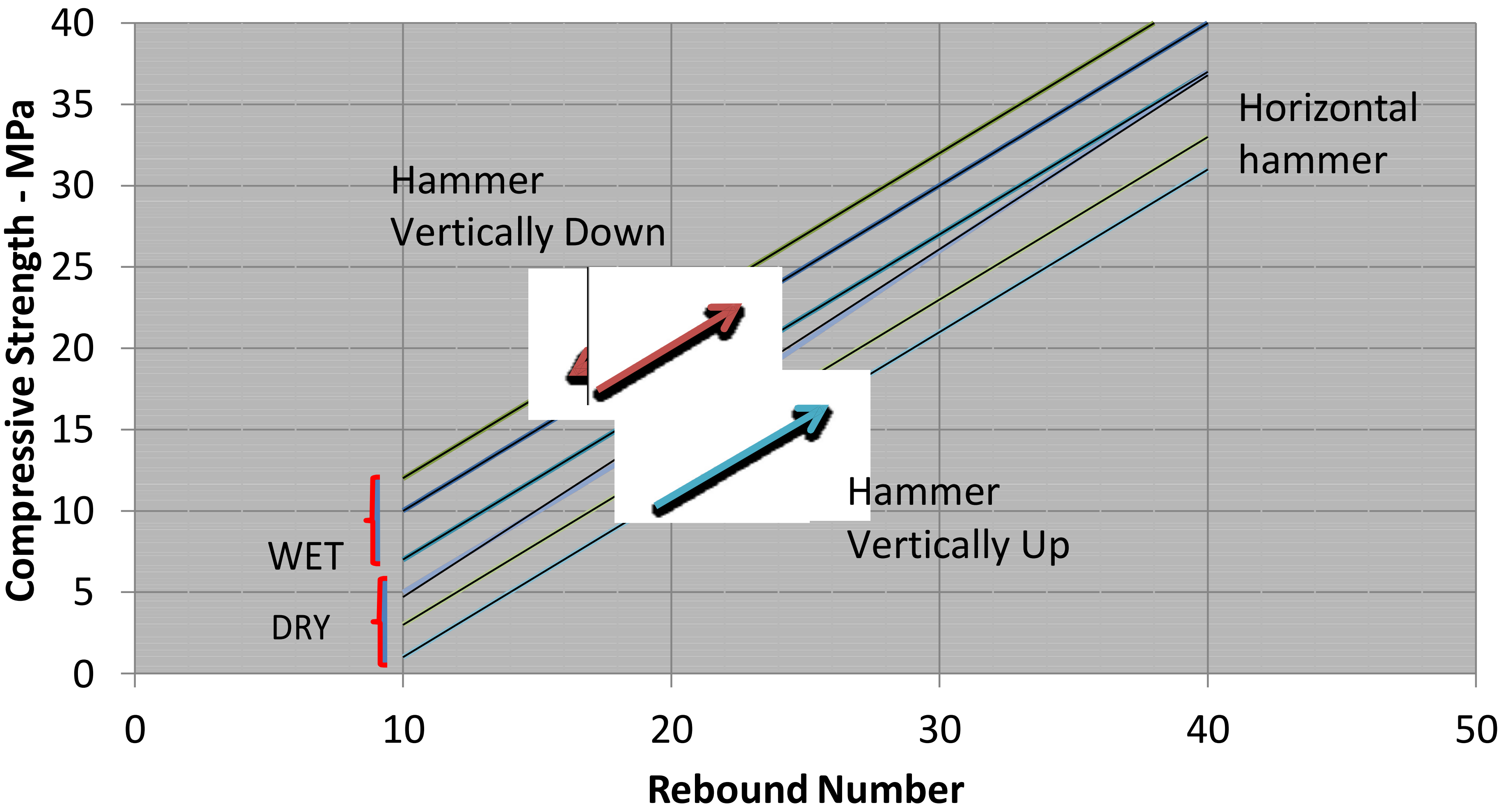
a) Smoothness of surface under test
b) Size , shape and rigidity of the specimen
c) Age of specimen
d) Surface and internal moisture condition of the concrete
e) Type of coarse aggregate
f) Type of cement
g) Type of mould
h) Carbonation of concrete surface

Procedure

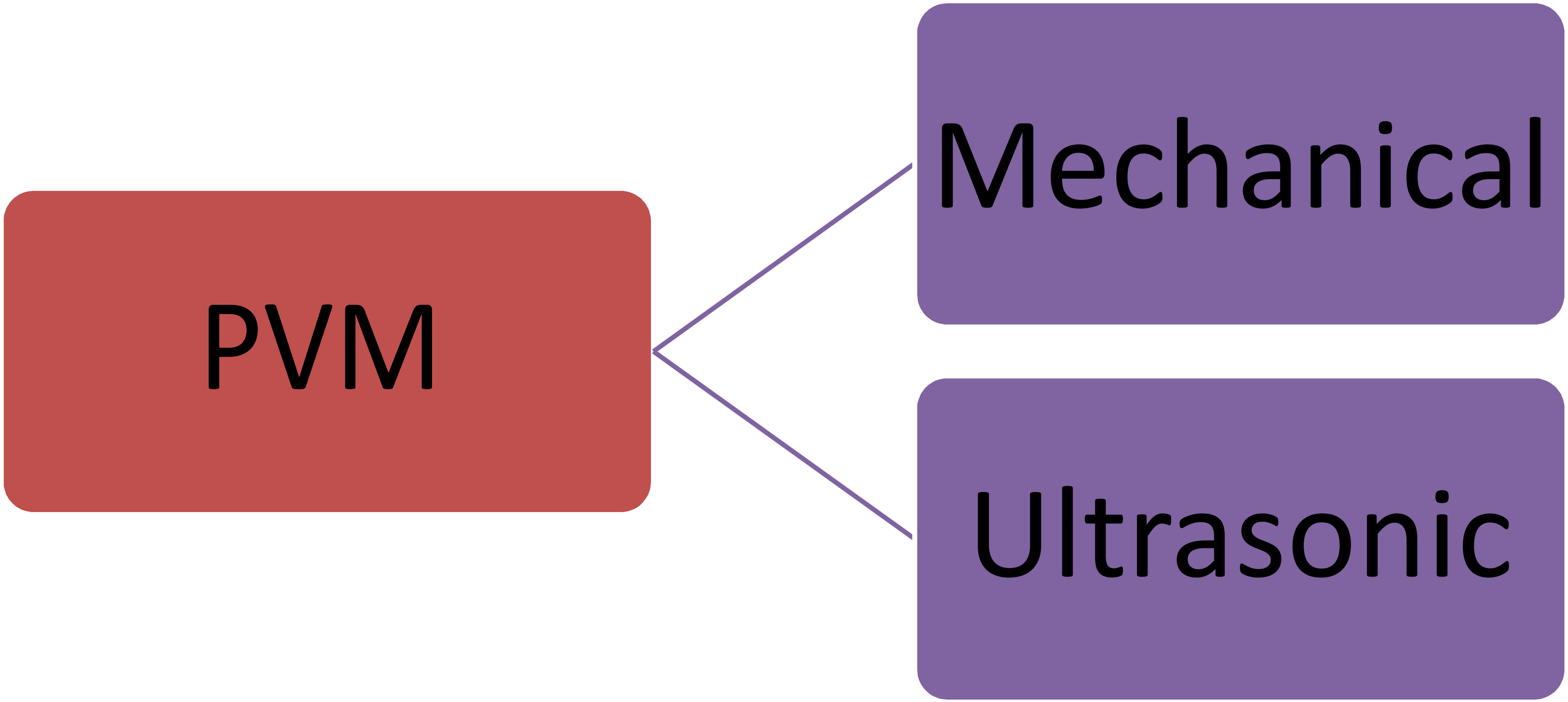


(a)
Instrument ready for test
Body
Latch
Indicator
Hammer
Spring
Plunger
(b)
Body pushed toward test object
(c)
Hammer is released
(d)
Hammer rebounds

Rebound Hammer & strength of Concrete



Pulse Velocity Method



objective

- Homogeneity of the concrete
- Presence of cracks, voids and other imperfections
- Changes in the structure of the concrete with time
- Quality of concrete related to standard requirement
- Quality of one element of concrete in relation with another
- Values of dynamic elastic modulus of the concrete

Principle

- Electro acoustical Transducer
- Waves
  - Longitudinal
  - Shear
  - Surface

Apparatus

a) Electrical pulse generator
b) Transducer
c) Amplifier
d) Electronic timing device

Techniques measuring for pulse Velocity Test

- Direct transmission
- Indirect transmission
- Surface transmission

Factors affecting

1. Smoothness of contact surface under test
2. Influence of path length on pulse velocity
3. Temperature of concrete
4. Moisture condition of concrete
5. Presence of reinforcing steel

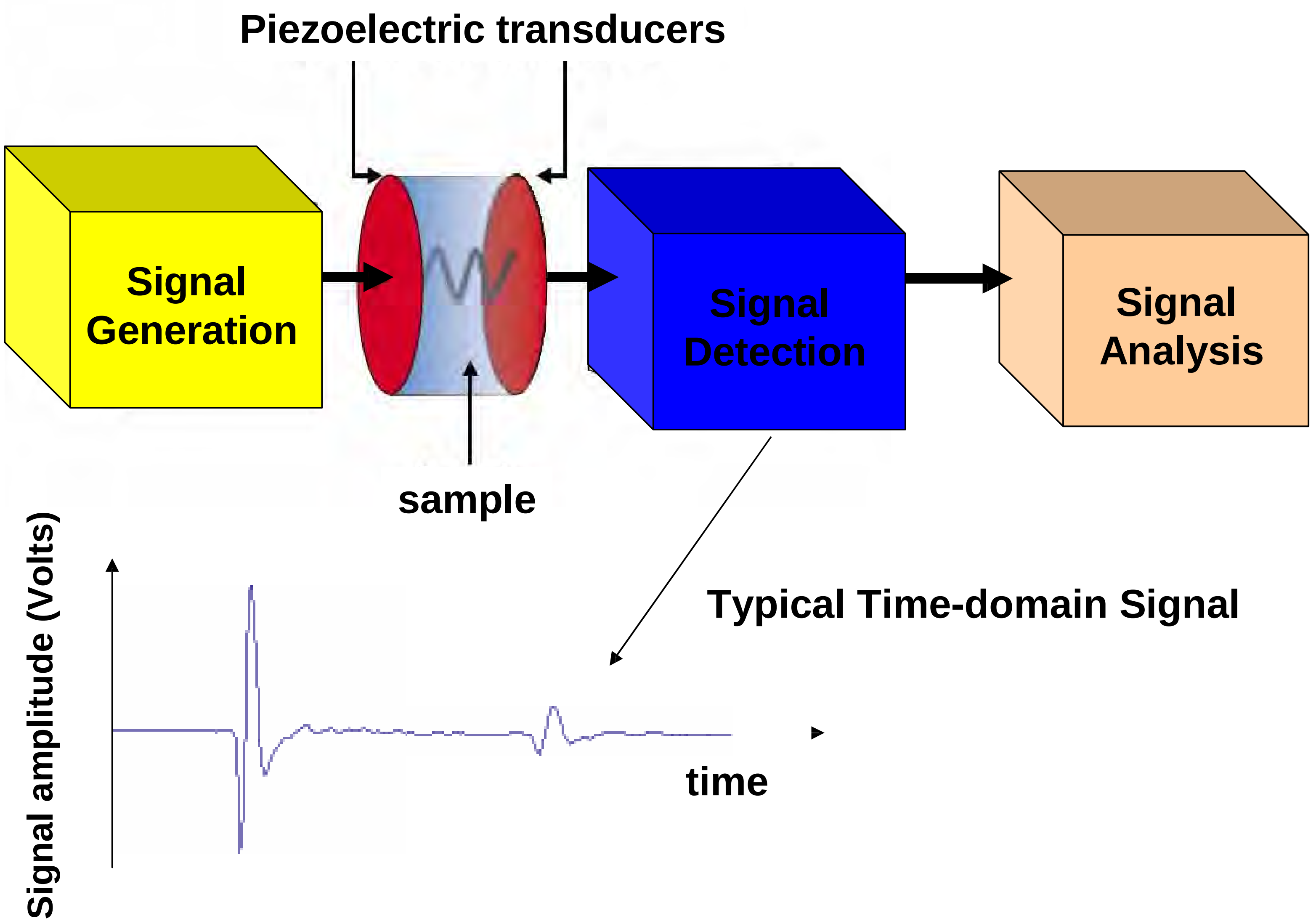
Applications

- Establishing uniformity of concrete
- Establishing acceptance criteria
- Determination of pulse modulus of Elasticity
- Estimation of strength of concrete
- Determination of setting characteristics of concrete
- Studies on durability of concrete
- Pulse velocity techniques
- Measurement of deterioration of concrete due to fire exposure

Why do we need to measure Ultrasonic Pulse Velocity (UPV) ?

- Evaluating the uniformity within a member.
- Locating internal voids and cracks.
- Estimating severity of deterioration.
- Estimating depth of fire damage.
- Evaluating effectiveness of crack repairs.
- Identifying anomalous regions in drilled cores.
- Estimate early-age strength (with correlation).

Ultrasonic Measurement Principles



How do we measure UPV ?

- PUNDIT- Portable Ultrasonic Nondestructive Digital Indicating Tester.
- ASTM C 597, BS 1881-203

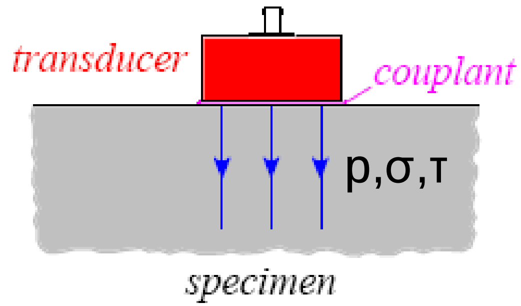
Couplant

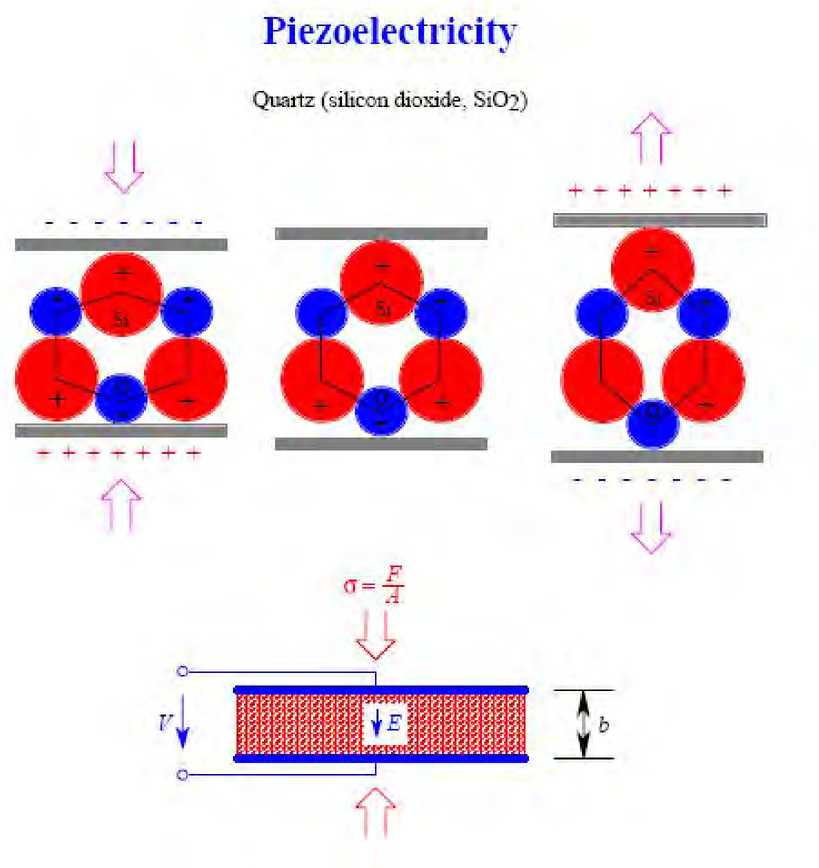
Measuring Unit

Calibration Bar

Transducers (24 kHz-1MHz)

Transducers

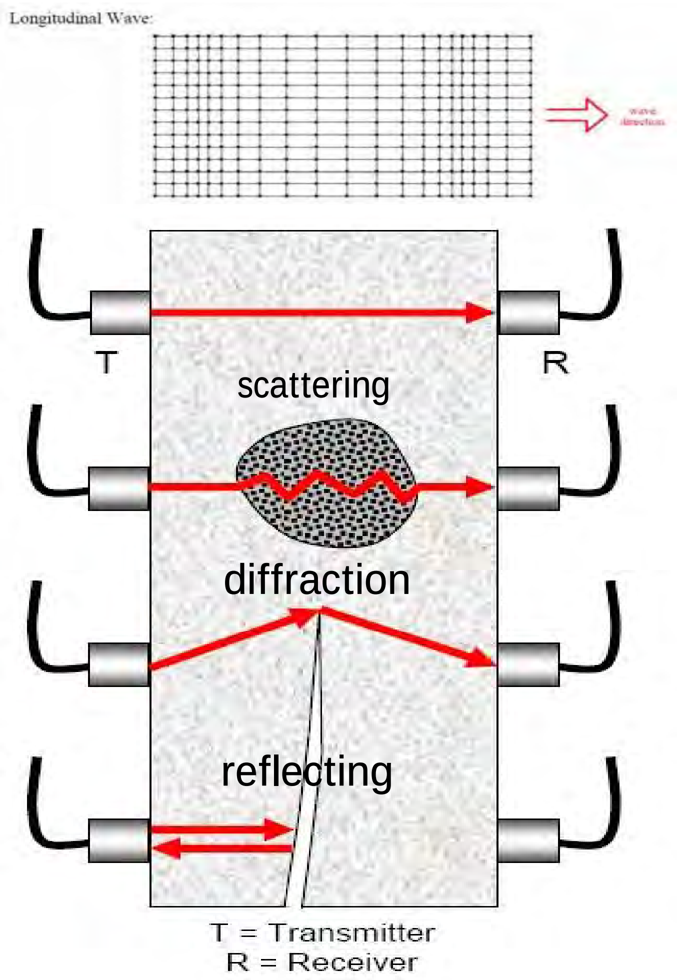




Materials	Frequency (kHz)
Concrete	24 - 150
Timber	150 - 220
Ceramics	24 - 220
Graphite	200 - 1
Cast iron	1

General Guidelines: Use lower frequencies for large, dense, and heterogeneous test objects and higher frequencies for smaller, less dense and more homogeneous test objects.

PUNDIT Measuring Principle



- Set reference (using a reference bar)
- Range selection – 0.1µsec (0 to 400 mm)
- The pulse is introduced into a member and is received.
- The transit time is determined by the instrument.
- The pulse velocity (Cd)

  = distance (L) / transit time (T).

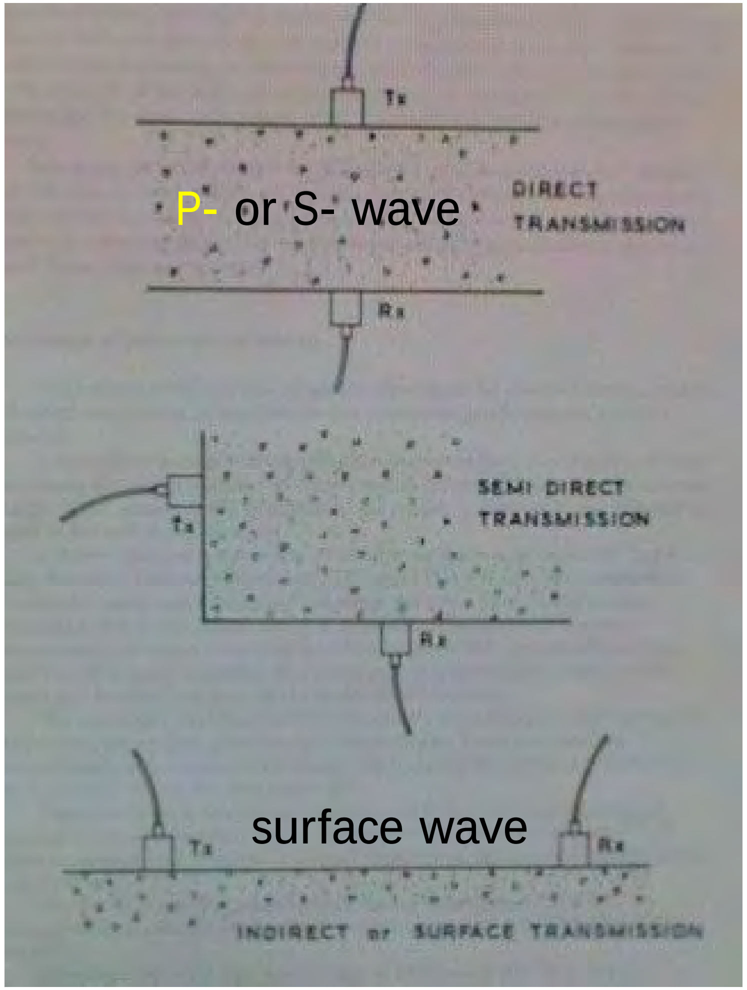
Longitudinal UPV-dynamic elastic modulus

$$c_d = \sqrt{\frac{E(1-\nu)}{(1+\nu)(1-2\nu)\rho}}$$

Methods of Propagating Pulses

Through transmission
(direct)

Most satisfactory
(Max Energy, V_D)



Diffuse or Scattering
(indirect)

Some satisfactory
(1-2% energy)
$V_D = 1.05V_L$

Influence of test conditions

- Path length.

  negligible if not less than 100 mm when 20 mm size aggregate is used.

  negligible if not less than 150 mm when 40 mm size aggregate is used.
- Lateral dimensions of the tested specimen.
- Moisture content of concrete.
- Presence of reinforcing steel.

Effect of specimen dimensions on pulse transmission			
Transducer frequency	Pulse velocity in concrete (in km/s)		
	C^d=3.5	C^d=4.0	C^d=4.5
	Minimum permissible lateral specimen dimension		
kHz	mm	mm	mm
24	146	167	188
54	65	74	83
82	43	49	55
150	23	27	30

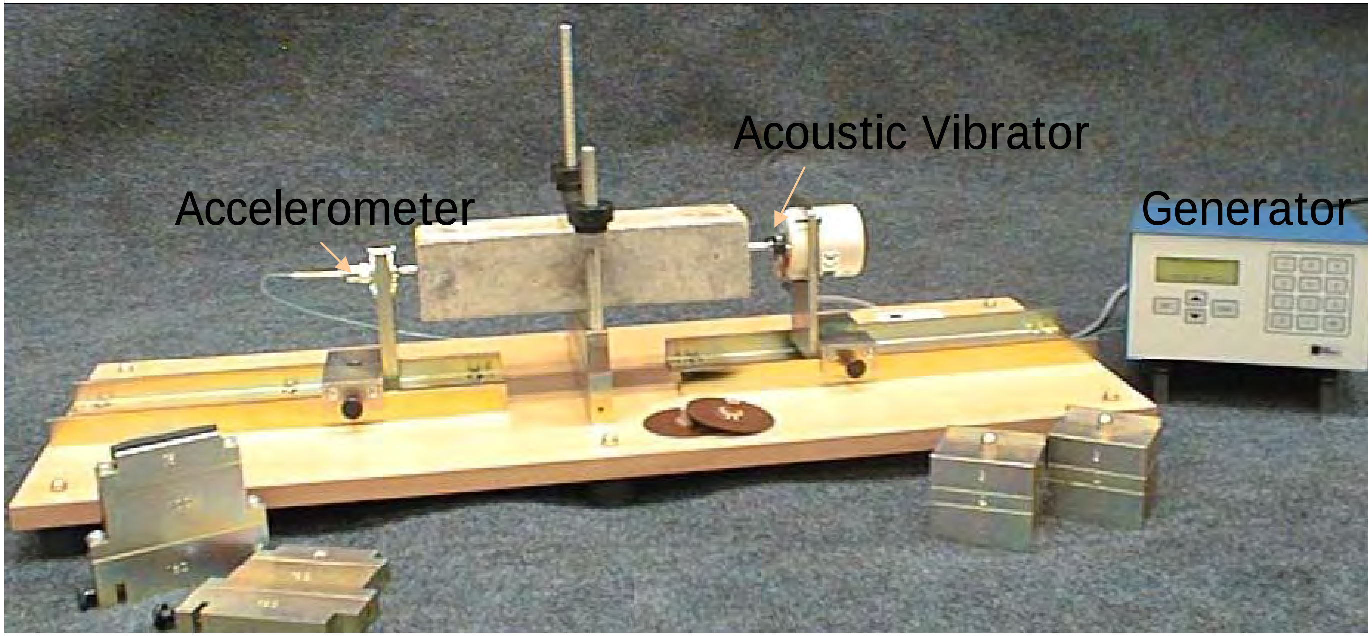
Effect of temperature on pulse transmission		
Temperature	Correction to the measured UPV	
	Type of Concrete	
	Air-dried	Water-saturated
^oC	%	%
60	+5	+4
40	+2	+1.7
20	0	0
0	-0.5	-1
-4	-1.5	-7.5

Resonant Frequency Test

Why do we need to perform Resonant Frequency Test ?

- To determine the dynamic elastic properties (modulus of elasticity, poisson ratio, shear modulus of elasticity).
- To monitoring damage as a result of exposure to accelerated weather.
- Quality Control of manufactured products.

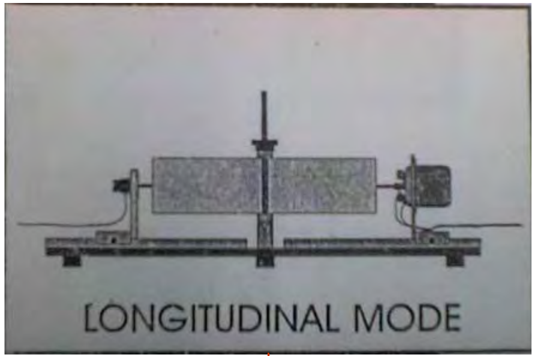
ERUDITE

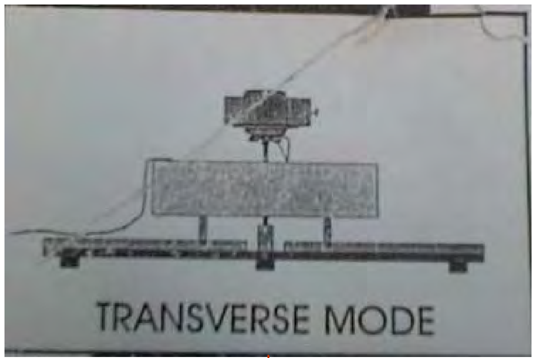


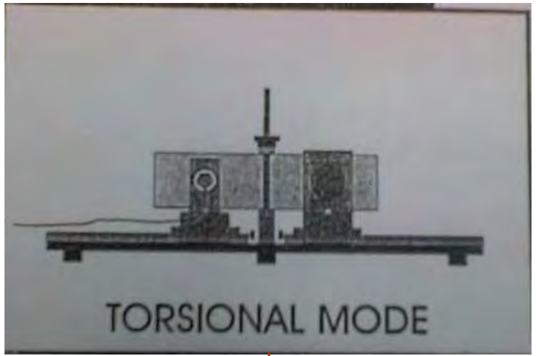
ERUDITE determines the resonant frequency of prismatic or cylindrical specimens (ASTM C 215, Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant frequencies of Concrete Specimens).

“The frequency of the acoustic vibrator is varied continuously and the corresponding amplitude of specimen vibration is monitored. When the specimen is driven at its resonant frequency the amplitude of specimen vibration is at its maximum”.

ERUDITE Measuring Principle







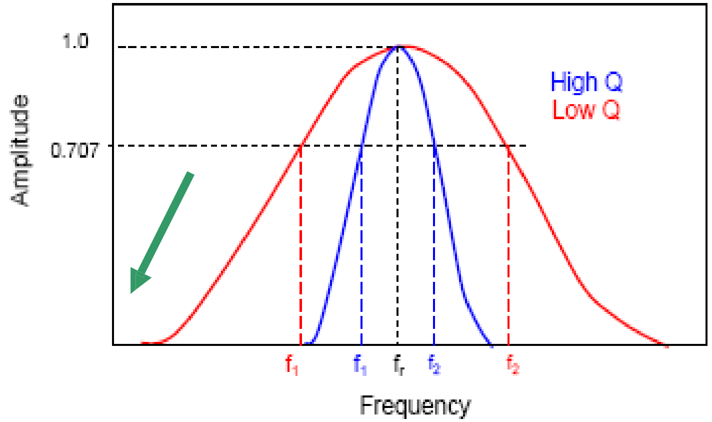
Modulus of Elasticity, E_D

modulus of rigidity, G_D

1. An acoustic vibrator is positioned on one side of the specimen.
2. An accelerometer is mounted on another side.
3. A generator drives the acoustic vibrator at a given frequency
4. The vibration of the specimen is measured by the accelerometer.
5. The frequency of the acoustic vibrator is varied continuously.
6. The corresponding amplitude of specimen vibration is monitored.
7. When the specimen is driven at its resonant frequency f_r - the amplitude of specimen vibration is at its maximum.

Measurement of Resonant frequency (f_r) Inverse of Damping Coefficient (Q)

Resonant frequency (f_r)



When the specimen is driven at f_r the vibration amplitude is at maximum.

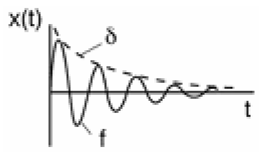
Inverse of Damping Coefficient (Q)

(Damage or imperfection Factor)

$$Q = \frac{f_r}{f_2 - f_1}$$

Where f_r = the resonant frequency (mode dependent)

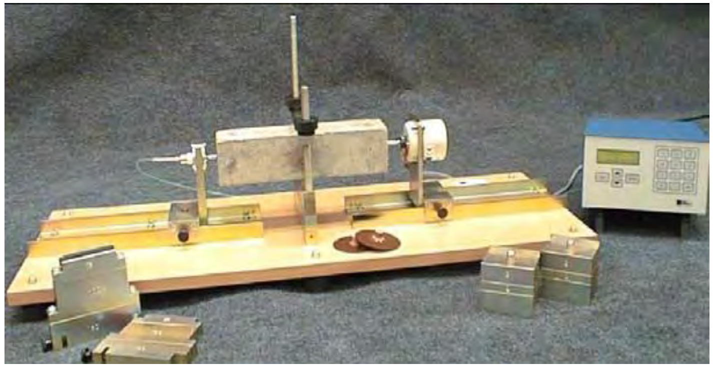
f_1, f_2 = frequencies at either side of f_r at which the amplitude drops to 0.707 f_r (the 3 dB frequencies).

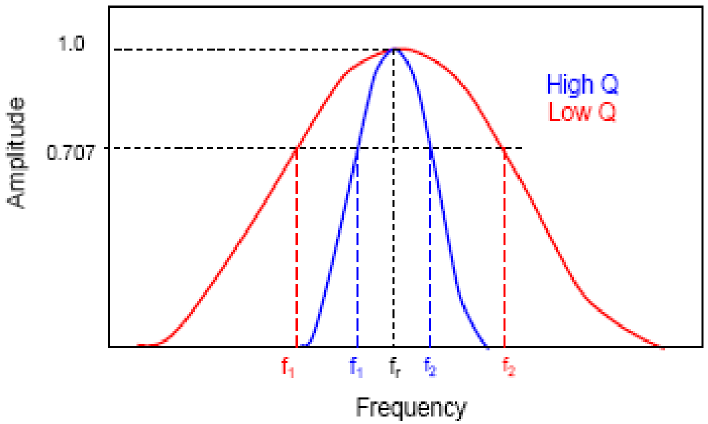


Damping Coefficient – Energy Dissipated Per Cycle

1. A material with high damping (good for seismic applications) has a low Q-factor.
2. The resonant frequency and Q-value will decrease as the specimen is damaged.

Calculation: the Dynamic modulus of elasticity, E_D





- For longitudinal mode in kg/cm^2

$$E_D = DW(fL_r)^2$$

Where

W = weight of specimen (kg)
fL_r = fund. longitudinal frequency (Hz)
$D^{cylinder}$ = $519.4 \times 10^{-5}\ L/d^2\ (sec^2/cm^2)$
D^{prism} = $408 \times 10^{-5}\ L/bt\ (sec^2/cm^2)$
L = length of specimen in cm
d = diameter of specimen in cm
t,b = dimensions of cross section of prism in cm

More equations for calculating the dynamic moduli of rigidity, density, and the dynamic Poisson's ratio should be found in ASTM C 215

Measuring Procedure

Manual Mode

- Setting up an experiment on an oscilloscope.
- Determine the range of frequencies for a certain type of specimen.
- Measuring f_r and Q manually.

Automatic Mode

- Measuring f_r and Q automatically by sweeping through the range of frequencies up to 3 different bands.

Approximate Range of Frequency Selection (Hz) for Concrete

Size of specimen (mm)	Longitudinal	Flexural	Torsional
150x150x750	1700-3000	550-1050	1150-1050
150x150x700	2000-3200	600-1150	1200-1150
100x100x750	1700-3000	400-750	1150-1800
100x100x500	3000-4500	900-1500	1800-2700
100x100x300	5000-7000	2500-4500	3000-4200
150x300 cylinders	5000-7000	2500-4500	3000-4200

Estimation of f_r from UPV measurement

- This is just one of many guidelines for

- specimens of unusual materials.

- specimens with non standard length and cross section dimensions.

$$f^L_r = \frac{10^6}{2 \times \text{PUNDIT Reading}} \text{ Hz}$$

Using longitudinal mode

True when $\frac{d}{\lambda_p} < 1$

Where: d = least lateral dimension,

λ_p=wavelength of ultrasonic pulse vibrations