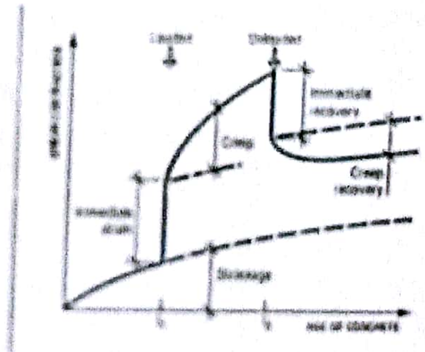
Causes of Distress in Concrete *By Vikas Devarth*

PHYSICAL CAUSES

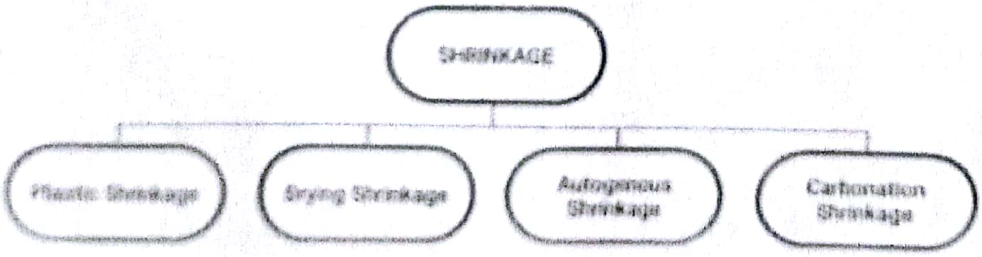
SHRINKAGE IN CONCRETE

Caused by loss of water from concrete. **Loss of water before setting leads to Plastic Shrinkage. Loss of water which occurs after setting leads to Drying Shrinkage.**

Definition of Shrinkage: Shrinkage may be defined as the Volume Change in concrete due to loss of water or moisture due to evaporation or by hydration of cement or by carbonation. Measured as Linear Strain.



Shrinkage strain is time dependent and non-load-induced.



Plastic Shrinkage: *Plastic shrinkage cracks appear in the surface of fresh concrete soon after it is placed and while it is still plastic. These cracks appear mostly on horizontal surfaces. They are usually parallel to each other on the order of 1 to 3 feet apart, relatively shallow, and generally do not intersect the perimeter of the slab. Plastic shrinkage cracking is highly likely to occur when high evaporation rates cause the concrete surface to dry out before it has set*

Plastic shrinkage cracks are unsightly but rarely impair the strength or durability of concrete floors and pavements. The development of these cracks can be minimized if appropriate measures are taken prior to and during placing and finishing concrete.

Plastic shrinkage cracks are caused by a rapid loss of water from the surface of concrete before it has set. The critical condition exists when the rate of evaporation of surface moisture exceeds the rate at which rising bleed water can replace it. Water receding below the concrete surface, forms menisci between the fine particles of cement and aggregate, causing a tensile force to develop in the surface layers. If the concrete surface has started to set and has developed sufficient tensile strength to resist the tensile forces, cracks do not form.

If the surface dries very rapidly, the concrete may still be plastic, and cracks do not develop at that time; but plastic cracks will surely form as soon as the concrete stiffens a little more. Synthetic fiber reinforcement incorporated in the concrete mixture can help resist the tension when concrete is very weak.

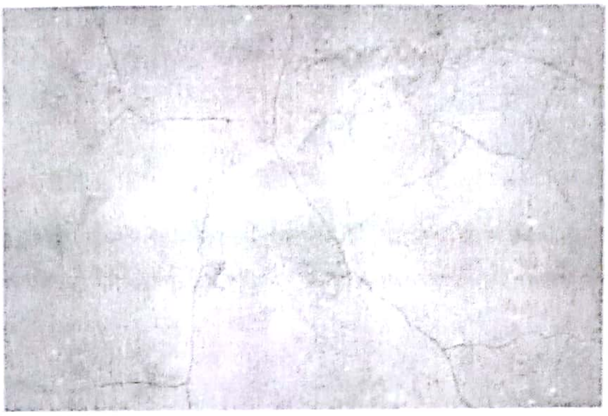
Conditions that cause high evaporation rates from the concrete surface, and thereby increase the possibility of plastic shrinkage cracking, include:

- Wind velocity in excess of 5 mph
- Low relative humidity
- High ambient and/or concrete temperatures.

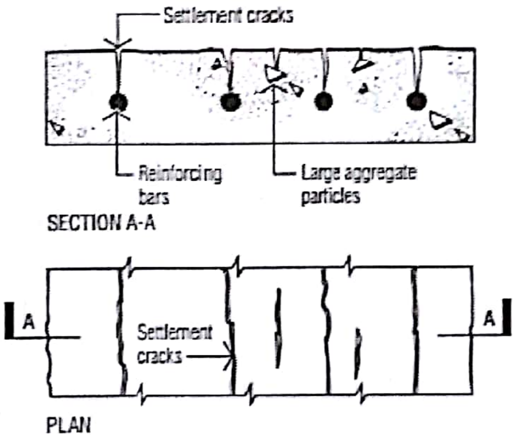
Concrete mixtures with an inherent reduced rate of bleeding or quantity of bleed water are susceptible to plastic shrinkage cracking even when evaporation rates are low.

Factors that reduce the rate or quantity of bleeding include high cementitious materials content, high fines content, reduced water content, entrained air, high concrete temperature, and thinner sections.

Any factor that delay setting increases the possibility of plastic shrinkage cracking. Delayed setting can result from a combination of one or more of the following: cool weather, cool subgrades, high water contents, lower cement contents, retarders, some water reducers, and supplementary cementing materials.



If there is any obstruction to the uniform settlement by way of reinforcement or larger piece of aggregate, then it creates some voids or cracks. This is called **plastic settlement cracks**.



- This happens generally in a deep beam
- These settlement cracks and voids are so severe that it needs grouting operation to seal them off.

In pre-hardened concrete, the most effective repair is to close the cracks shortly after formation by re-vibration and reworking the surface while the concrete is still plastic. Careful timing is essential to ensure the concrete re-liquefies under the action of the vibrator so that the cracks are fully closed. Re-vibrate too soon and cracks may reform; too late and the bond to the reinforcement may be damaged. Mechanical re-trowel ling of the surface may be sufficient to close the cracks and compact the concrete around the reinforcement provided the cover is not too great, but the best result is where this is combined with some form of vibration.

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Caution needs to be exercised in the use of re-trowelling alone since it may just form a skin (which can fracture with subsequent shrinkage, thermal or traffic impacts) over the cracks but not close them. If used it must be done as soon as the cracks become evident.

Drying Shrinkage: When concrete is exposed to its service environment it tends to reach an equilibrium with that environment. If the environment is a dry atmosphere the exposed surface of the concrete loses water by evaporation. The rate of evaporation will depend on the relative humidity, temperature, water-cement ratio and the area of the exposed surface of the concrete. The first water to be lost is that held in the large capillary pores of the hardened concrete. The loss of this water does not cause significant volume change. However, as drying continues, loss of water from small capillary pores and later from gel pores takes place. With the reduction in the vapour pressure in the capillary pores, tensile stress in the residual water increases. Tensile stresses in the capillary water are balanced by compressive stresses in the surrounding concrete and as a result the concrete shrinks. Evaporation of gel water changes the surface energy of the solid phase and causes further shrinkage.

Drying shrinkage makes up a portion of the total **deformation that is observed in a concrete member.**

- ✓ The cracks due to drying shrinkage appear after 7 to 10 days after concreting and around 80% of the drying shrinkage takes place in about a year.
- ✓ Drying shrinkage cracks are generally confined to non-structural members, floor toppings & parapet walls.
- ✓ The total drying shrinkage is made up of irreversible shrinkage & reversible shrinkage. On initial drying out, an appreciable amount of total shrinkage is irreversible but after several cycles of wetting & drying, the shrinkage becomes entirely reversible.

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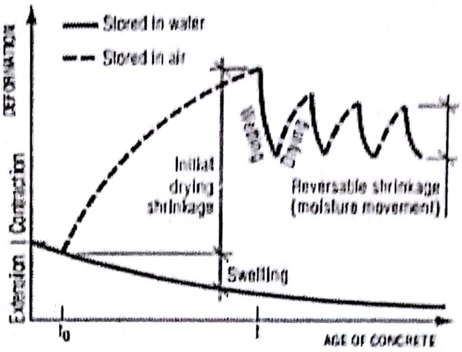

Preventive Measures:

- Use the minimum water content (consistent with placing and finishing requirements).
- Use highest possible volume fraction of good quality aggregate and maximum possible aggregate size.
- Do not use admixtures known to increase drying shrinkage, e.g. those containing calcium chloride.
- Ensure concrete is properly placed, compacted and cured.
- Provide sufficiently closed reinforcement.
- Eliminate the external restraints as much as possible.

Adequate reinforcement

Where cracking occurs, the spacing and width of shrinkage cracks depend upon the percentage of reinforcement in the restrained concrete and the bond characteristics of the reinforcement. The provision and location of adequate reinforcement to distribute the tensile stress caused by drying shrinkage is particularly important in slabs-on ground and similar applications where reinforcement may not be required for structural reasons. The minimum reinforcement resists tensile stresses in restrained concrete and helps prevent the formation of large cracks, it does not completely prevent cracking, and ensures that the cracks, if they occur, are more closely spaced and of a smaller width. In properly designed reinforced concrete, they will be invisible to the naked eye.

Joints

The provision and location of contraction joints permit movement as a result of drying shrinkage. Un-reinforced concrete will tend to develop larger cracks at irregular intervals wherever the tensile strength of the concrete is exceeded by the stresses induced by drying shrinkage. To prevent such cracks, contraction joints should be installed at appropriate intervals.

It may also be more economical to install contraction joints in reinforced concrete than to rely on reinforcement to control shrinkage stresses.

Autogenous Shrinkage:

Autogenous shrinkage of cement paste and concrete is defined as the macroscopic volume change occurring with no moisture transferred to the exterior surrounding environment. It is a result of chemical shrinkage affiliated with the hydration of cement particles.

Autogenous shrinkage does not usually appear in conventional, normal strength concrete, but in high-performance concrete such as high-strength concrete and self-compacting concrete with a low water-cement ratio (W/C), which generally has high durability compared to conventional concrete.

Autogenous shrinkage is an important phenomenon in young concrete. At low water/cement ratios, less than about 0.42, all the water is rapidly drawn into the hydration process and the demand for more water creates very fine capillaries. The surface tension within the capillaries causes autogenous shrinkage (sometimes called chemical shrinkage or self-desiccation) which can lead to cracking. This can be largely avoided by keeping the surface of the concrete continuously wet; conventional curing by sealing the surface to prevent evaporation is not enough and water curing is essential. With wet curing, water is drawn into the capillaries and the shrinkage does not occur.

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. The magnitude of autogeneous shrinkage is in the order of about 100 microns.

Carbonation Shrinkage:

Carbonation shrinkage is a phenomenon very recently recognised. Carbon dioxide present in the atmoshphere reacts in the presence of water with hydrated cement. Calcium hydroxide gets converted to calcium carbonate 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 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. But carbonation reduces the alkalinity of concrete which gives a protective coating to the reinforcement against rusting. If depth of carbonation reaches up to steel reinforcements, the steel becomes liable for corrosion.

FREEZE & THAW ON CONCRETE

Deterioration of concrete from freeze thaw actions may occur when the concrete is critically saturated, which is when approximately 91% of its pores are filled with water. When water freezes to ice it occupies 9% more volume than that of water. If there is no space for this volume expansion in a porous, water containing material like concrete, freezing may cause distress in the concrete. Distress to critically saturated concrete from freezing and thawing will commence with the first freeze-thaw cycle and will continue throughout successive winter seasons resulting in repeated loss of concrete surface.

To protect concrete from freeze/thaw damage, it should be air-entrained by adding a surface active agent to the concrete mixture. This creates a large number of closely spaced, small air bubbles in the hardened concrete. The air bubbles relieve the pressure build-up caused by ice formation by acting as expansion chambers. About 4% air by volume is needed and the air-bubbles should be well distributed and have a distance between each other of less than 0.25 mm in the cement paste.

Concrete with high water content and high water to cement ratio is less frost resistant than concrete with lower water content.

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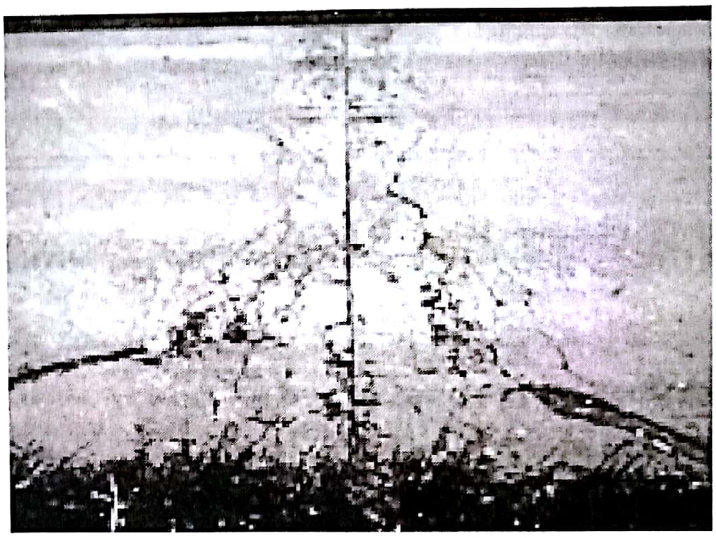
Typical signs of Freeze Thaw are:

- Spalling and scaling of the surface
- Large chunks (cm size) are coming off
- Exposing of aggregate
- Usually exposed aggregate are un-cracked
- Surface parallel cracking
- Gaps around aggregate – in the ideal case

- Freeze & thaw deterioration generally occurs on horizontal surfaces that are exposed to water, or on vertical surfaces that are at the water line in submerged portions of structures.
- **D-Cracking.** Cracking of concrete pavements caused by the freeze-thaw deterioration of the aggregate within concrete is called D-cracking. D-cracks are closely spaced crack formations parallel to transverse and longitudinal joints that later multiply outward from the joints toward the center of the pavement panel. D-cracking is a function of the pore properties of certain types of aggregate particles and the environment in which the pavement is placed. Due to the natural accumulation of water under pavements in the base and subbase layers, the aggregate may eventually become saturated. Then with freezing and thawing cycles, cracking of the concrete starts in the saturated aggregate at the bottom of the slab and progresses upward until it reaches the wearing surface. This problem can be reduced either by selecting aggregates that perform better in freeze-thaw cycles or, where marginal aggregates must be used, by reducing the maximum particle size. Also, installation of effective drainage systems for carrying free water out from under the pavement may be helpful.



✓ **Preventive Measures:**

a) Use of lowest practical W/C ratio and total water content
b) Adequate air entrainment
c) Use of durable aggregate
d) Designing structure to minimize the exposure to moisture, by providing positive drainage rather than flat surfaces whenever possible.

CRAZING ON CONCRETE

Crazing is the development of fine random cracks on the surface of the concrete caused by shrinkage of the surface layer. These cracks are rarely more than 1/8 inch deep and are more noticeable on steel troweled surfaces. The cracks are shaped like irregular hexagon and are typically no more than 1 1/2 inch across. Generally craze cracks develop at an early age and are apparent the day after placement. The crazing is more prevalent when the surface is wet. Crazing cracks are sometimes referred to as shallow map or pattern cracking. They do not affect the structural integrity of the concrete.

Contributing Factors

- Poor or inadequate curing (see curing).
- Too wet a mix, excessive floating, the use of a any other procedure which depresses the coarse aggregate and produces an excessive concentration of cement paste and fines at the surface.\

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- Finishing while there is bleed water present on the surface or the use of steel trowel at a time when the smooth surface brings up too much water and cement fines.
- Sprinkling cement on the surface to dry up bleeds water. This concentrates fines on the surface.
- Use of highly absorptive aggregates batched in the dry state

How to Prevent Crazing

- ✓ Start curing the concrete as soon as possible. The surface should be kept wet by either flooding with water or covering with wet burlap and keeping moist for a minimum of 3 days.
- ✓ Use of moderate slump (3 to 5 inches), air-entrained concrete. Higher slump (up to 6 or 7 inches) can be used, provided the mixture is designed to produce the required strength without excessive bleeding and segregation. Air entrainment helps to reduce the rate of bleeding of fresh concrete and thereby reduces the chance of crazing.
- ✓ Never sprinkle or trowel dry cement or a mixture of cement and fine sand into the surface of the plastic concrete to absorb bleed water. Remove bleed water by dragging a garden hose across the surface. DO NOT perform any finishing operation while bleed water is present on the surface.
- ✓ Dampen the subgrade prior to concrete placement to prevent it from absorbing too much water from the concrete. If an impervious membrane, such as a polyethylene, is required on the sub grade, cover it with 2 to 3 inches of damp sand to reduce bleeding.

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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.

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.

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.

ABRASION, EROSION & CAVITATION IN CONCRETE

Abrasion: It refers to wearing away of the surface by friction. This is caused by the action of debris rolling and grinding against a concrete surface. In hydraulic structures, the areas most likely to be damaged are spillway aprons, stilling basin slabs etc. The surfaces abraded by waterborne debris are generally smooth & may contain localized depressions. To prevent this kind of erosion, hydraulic model studies should be performed prior to construction, to identify potential causes of erosion damage.

Erosion: It refers to wearing away of the surface by fluids.

Cavitation: Refers to damages due to non-linear flow of water at velocities more than 12 m/sec.

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Concrete that has been damaged by cavitation will be severely pitted & extremely rough. As the damage progresses, the roughness of the damaged area may induce additional cavitations. To prevent this in case of hydraulic structures, use of aeration is utilized.

- ✓ The more the compressive strength, the higher is the resistance to abrasion, erosion and cavitation.
- ✓ The shape & surface texture of the aggregates play an important part in the abrasion resistance of the concrete.
- ✓ Use of steel fibres in concrete matrix improves abrasion resistance of concrete and also polymer based systems when applied to concrete, improves the abrasion resistance.

TEMPERATURE CHANGES IN CONCRETE

- ✓ Caused due to heat of hydration of cement in mass concrete work.
- ✓ Variations in climatic conditions.
- ✓ Fire damage

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CHEMICAL CAUSES

- ✓ Acid Attack
- ✓ Aklali Attack
- ✓ Carbonation
- ✓ Leaching
- ✓ Chloride Attack
- ✓ Salt Attack
- ✓ Sulphate Attack

ACID ATTACK

The acids most commonly encountered by concrete (all found in some natural groundwaters) are carbonic acid, humic acid and sulfuric acid. The first two are only moderately aggressive and will not produce a pH below about 3.5. Sulfuric acid is a highly ionised mineral acid and may result in a pH lower than 2. Other similarly aggressive mineral acids may occasionally be found in ground contaminated by industrial processes. The primary effect of any type of acid attack on concrete is the dissolution of the cement paste matrix. This weakens the affected concrete, but unlike sulfate attack, the degradation does not involve significant expansion. Neither ettringite nor thaumasite are stable in acid solution so that the reaction product from sulfuric acid attack will be primarily gypsum.

In concrete with siliceous gravel, granite or basalt aggregate, the surface attack will produce an 'exposed aggregate' appearance. However, in concrete with limestone (calcium carbonate) aggregates, the aggregate may dissolve at a rate similar to that of the cement paste and leave a smoother surface.

The rate of attack depends more on the rate of water movement over the surface and on the quality of the concrete, than on the type of cement or aggregate:

- ❖ Acidic groundwaters that are not mobile appear to have little effect on buried concrete.
- ❖ Mildly acidic (pH above 5.5) mobile water will attack concrete significantly, but the rate of attack will be generally slow, particularly if the acids are primarily organic in origin.

- ❖ Flowing acidic water may cause rapid deterioration of concrete, therefore high quality concrete is needed.
- ❖ In the case of humic acid, reaction products formed on the surface of concrete are mainly insoluble and tend to impede further attack.

Preventive Measures:

- ✓ By increasing cement content and reducing w/c ratio
- ✓ By improving quality of cover concrete
- ✓ By treating the surface with sodium silicate known as water glass
- ✓ By surface treatment with coal tar, bituminous paints, epoxy resins etc

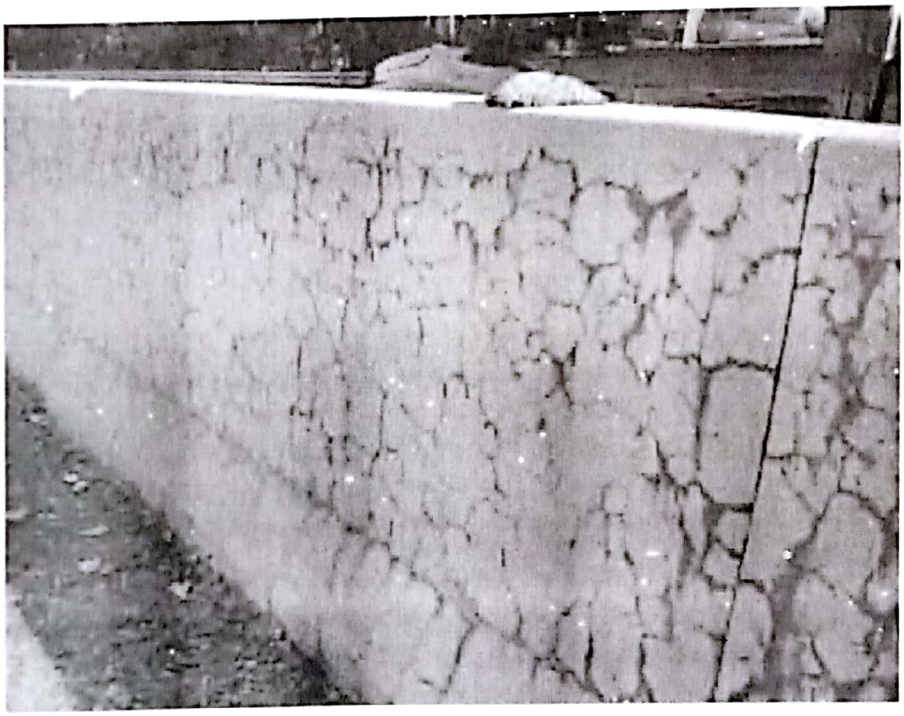
AKALI ATTACK

In most concrete, aggregates are more or less chemically inert. However, some aggregates react with the alkali hydroxides in concrete, causing expansion and cracking over a period of many years. This alkali-aggregate reaction has two forms—alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR).

Alkali-silica reaction (ASR) is of more concern because aggregates containing reactive silica materials are more common. In ASR, aggregates containing certain forms of silica will react with alkali hydroxide in concrete to form a gel that swells as it adsorbs water from the surrounding cement paste or the environment. These gels can swell and induce enough expansive pressure to damage concrete. Typical indicators of ASR are random map cracking and, in advanced cases, closed joints and attendant spalled concrete. Cracking due to ASR usually appears in areas with a frequent supply of moisture, such as close to the waterline in piers, near the ground behind retaining walls, near joints and free edges in pavements, or in piers or columns subject to wicking action.

ASR can be controlled using certain supplementary cementitious materials. In proper proportions, silica fume, fly ash, and ground granulated blast-furnace slag have significantly reduced expansion due to alkali-silica reactivity. In addition, lithium compounds have been used to reduce ASR.

Alkali-carbonate reactions (ACR) are observed with certain dolomitic rocks. Dedolomitization, the breaking down of dolomite, is normally associated with expansion. This reaction and subsequent crystallization of brucite may cause considerable expansion. The deterioration caused by ACR is similar to that caused by ASR; however, ACR is relatively rare because aggregates susceptible to this phenomenon are less common and are usually unsuitable for use in concrete for other reasons.



CHLORIDE ATTACK

Chloride source

- ✓ CEMENT OF THE CONCRETE
- ✓ WATER MIXED IN CONCRETE
- ✓ AGGREGATES OF CONCRETE
- ✓ ADDMIXTURES ADDED TO THE CONCRETE
- ✓ DIFFUSION FROM ATMOSPHERE

Chloride ions originated from sea water or other sources may penetrate through the pore by diffusion or may have direct access through cracks to the interior of the concrete.

Although cement has a natural ability to bind chloride ions, but not all the chloride ions can be bound. There always exist dissolution equilibrium between bound chlorides and free chloride ions in the pore water. Only the free chloride ions are relevant to the corrosion of the reinforcement.

Mechanism of Chloride Ingress in Concrete

Chlorides can enter into concrete by both absorption and diffusion processes.

Absorption: A relatively dry concrete surface will promote chloride to enter into the concrete. Process of capillary absorption is responsible for chlorides in solution to enter into the concrete matrix.

Diffusion: Once the concrete becomes saturated due the capillary absorption, the process of diffusion will then kick in. Due to Fick's law of diffusion, chloride ion will diffuse through the concrete mass as there will be a concentration gradient of chloride ions from outer surface to the inner part of concrete, closer to the reinforcement bars.

Forms of Chlorides

There are following three forms of chloride can be existed in concrete mass:

Free Chlorides

They are the most dangerous forms of chlorides in the concrete as upon entering into concrete free chloride will diffuse through the pore water to attack the reinforcement bar by breaking down its passive oxide layer.

Physically Adsorbed Chlorides

Weakly bonded Chloride ions can be existed in the concrete due to the chemical composition of cement hydrate and type of surface area of hydrate. These forms of physically adsorbed Chlorides have the potential to move toward the reinforcement bar to start corrosion.

Chemically Adsorbed Chlorides

There are strongly chemically bonded chloride ions with the Calcium Aluminium Hydrate to form Friedell's salts. These forms of chlorides are safer as they can not proceed to the reinforcement to induce corrosion.

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Chloride-Induced Corrosion

Chloride threshold level:

Chloride threshold level is a critical chloride content to start off corrosion. It is about 8000 ppm.

Corrosion process:

Chloride-induced corrosion is a very specific type of 'pitting' corrosion. Chloride-induced corrosion is characterised by galvanic action between relatively large areas of passive steel acting as cathodes and very small, local anodic pits connected by means of an electrolyte (pore fluid).

For initiation of corrosion, the passive oxide layer must be broken down and chloride ions must activate the steel surface to form an anode, with the passive surface being the cathode. The important factor here is that chloride ions are regenerated so that the corrosion products do not contain chlorides. This regeneration forms hydrochloric acid which will severely attack the steel, forming localised 'pits', continued corrosion and eventual reduction in the cross-sectional area of steel.

Prevention of Chloride Induced Corrosion:

Chloride-induced corrosion can be minimised by addressing the following requirements:

- Preventing Ingress of Chlorides
- Preventing Ingress of Moisture
- Preventing Ingress of Oxygen

Prevention of Chloride and moisture are more practical means than prevention of oxygen.

Pozzolanic materials especially Microsilica has been proven to be very effective to prevent corrosion induced by the chloride. The main reason is that Microsilica reduces the porosity of concrete matrix and makes the concrete dense watertight matrix, preventing moisture and chloride ion to penetrate and diffuse through the concrete mass. Microsilica also redefine the pore structure by increasing the tortuosity of the pores which further prevent any ingress of moisture and other harmful elements from the environment.

Table 7 Limits of Chloride Content of Concrete
(*Clause* 8.2.5.2)

Sl No.	Type or Use of Concrete	Maximum Total Acid Soluble Chloride Content Expressed as kg/m^3 of Concrete
(1)	(2)	(3)
i)	Concrete containing metal and steam cured at elevated temperature and pre-stressed concrete	0.4
ii)	Reinforced concrete or plain concrete containing embedded metal	0.6
iii)	Concrete not containing embedded metal or any material requiring protection from chloride	3.0

CARBONATION OF CONCRETE

Carbonation is the formation of calcium carbonate (CaCO3) by a chemical reaction in the concrete. The creation of calcium carbonate requires three equally important substances: carbon dioxide (CO_2), calcium phases (Ca), and water (H_2O). Carbon dioxide (CO_2) is present in the surrounding air, calcium phases (mainly $Ca(OH)_2$ and CSH) are present in the concrete, and water (H_2O) is present in the pores of the concrete.

The first reaction is in the pores where carbon dioxide (CO_2) and water (H_2O) react to form carbonic acid (H_2CO_3):

$CO_2 + H_2O \longrightarrow H_2CO_3$

The carbonic acid then reacts with the calcium phases:

$H_2CO_3 + Ca(OH)_2 \longrightarrow CaCO3 + 2 \cdot H2O$

Once the $Ca(OH)_2$ has converted and is missing from the cement paste, hydrated CSH (Calcium Silicate Hydrate - CaO•SiO2•H2O) will liberate CaO which will then also carbonate:

$H_2CO_3 + CaO \longrightarrow CaCO_3 + H_2O$

When these reactions take place the pH value will start falling. The normal pH-value of concrete is above 13 and the pH-value of fully carbonated concrete is below 9.

Once the carbonation process reaches the reinforcement, and the pH-value drops beneath 13 the passive "film" on the re-bars will deteriorate and corrosion will initiate.

The speed of the carbonation process through the concrete mainly depends on two parameters:

- **The porosity of the concrete**
- **The moisture content of the concrete**

The porosity of the concrete

The carbonation process has an ongoing need for carbon dioxide (CO_2) from the atmosphere. For carbonation to spread, fresh carbon dioxide from the surface needs to be supplied continuously deeper and deeper into the concrete. Low porosity and permeability will decrease the ingress speed of carbon dioxide (CO_2) from the atmosphere, thereby delaying the ingress of the carbonation.

Moisture content of the concrete: The moisture content of the concrete is also a very important factor. Carbonation in concrete pores almost only occurs at a relative humidity (RH) between 40% and 90%. When the relative humidity in the pores is higher than 90% carbon dioxide is not able to enter the pore, and when RH is lower than 40% the carbon dioxide can not dissolve in the water.

LEACHING IN CONCRETE

Leaching is the process by which a liquid dissolves and removes the soluble components of a material. The leaching process is when solid compounds in the concrete are dissolved by water and then transported away, either due to concentration gradients (diffusion) or by the flow of water (convection). External or capillary pressures may for example cause water to flow.

Concrete is a solidified mixture of cement and Aggregate. The main components of cement are calcium and silicon. Cement solidification occurs with hydration, which generates calcium compounds. The resulting solidified cement structure is a porous material. Pores in the structure are connected and form a network. The calcium compounds are gradually dissolved in water that invades the pores. Dissolved and ionized calcium migrates into the concrete medium.

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As a result, in environments where the concrete is in contact with water, the solidified cement component of the concrete is gradually dissolved. This cement dissolution increases the porosity of the concrete structure. It is understood that concrete strength is correlated with its porosity. This phenomenon of concrete leaching is currently considered to be the key to the long-term safety of structures .

Leaching effects

When solid material is leached, the porosity will increase and the amount of OH^- ions will decrease in the pore solution and in the pore walls. When the porosity increases, the water permeability will increase and the leaching process will accelerate. When the porosity increases, the strength will also decrease.

SALT ATTACK

When concrete is repeatedly wetted by a salt water solution, with alternate periods of drying during which pure water evaporates, some of the salts dissolved in the salt water solution are left behind in the form of crystals, (mainly sulfates) in the concrete pores and surface of the concrete unit.

These crystals re-hydrate and grow upon subsequent wetting, and thereby exert an expansive force on the surrounding hardened cement paste within the concrete unit when this growth occurs. This expansive force is greatly amplified by the ability of the salt crystal to grow rapidly to many many times its original crystal dimension upon wetting.

This rapid growth causes the concrete paste surrounding the crystal to "burst", exposing the aggregate in the concrete masonry unit. Such progressive surface weathering, commonly known as salt attack, occurs in particular when the ambient temperature is high and isolation is strong so that drying occurs rapidly in the pores of the concrete over some depth from the concrete paving surface.

Thus, intermittently wetted surfaces are vulnerable, as are areas of paving around a salt water swimming pool particularly in the splash zone. Horizontal or inclined paving surfaces are particularly prone to salt attack, and so are surfaces wetted repeatedly but not at short intervals so that thorough drying can take place.

Salt water can also rise by sorption or capillary action. Evaporation of the pure water in this instance will again leave behind salt crystals, which when re-wetted, can and will cause degradation of the surface.

Salt attack can extend to a depth of several millimetres within the paving unit. Hardened cement paste and the embedded fine aggregate particles are removed, leaving behind protruding coarse aggregate particles. With time these particles become loosened, thereby exposing more hardened cement paste which, in turn, becomes liable to salt attack and the process continues until such time as the wetting and drying cycle is stopped.

It should also be noted that, unless the aggregate is dense and has a very low absorption, the aggregate itself is also liable to damage. Because the attack of concrete by salt solutions is physical in nature, the type of cement used is of little importance per se but, to ensure low permeability of the surface zone of concrete, the choice of concrete mix is critical.

Good mix design, utilising high quality material to ensure a very dense cement paste mix is achieved, is paramount in reducing the risk of salt attack. Wet-cast concrete paving units, as produced by UrbanStone, are thus very resistant to salt attack although, as can be seen from the test certificates, there will be an effect on the product when subjected to 'severe salt attack situations' as determined by the current standard.

SULPHATE ATTACK

Sulfates present in soils, groundwater, sea water, decaying organic matter, and industrial effluent surrounding a concrete structure pose a major threat to the long term durability of the concrete exposed to these environments. Sulfate attack of concrete may lead to cracking, spalling, increased permeability, and strength loss.

Thus, resistance of concrete to sulfate attack is integral to ensure satisfactory performance over long periods.

- Sulfate attack is a chemical breakdown mechanism where sulfate ions attack components of the cement paste.
- The compounds responsible for sulfate attack are water-soluble sulfate-containing salts, such as alkali-earth (calcium, magnesium) and alkali (sodium, potassium) sulfates that are capable of chemically reacting with components of concrete.

Sulfate attack might show itself in different forms Depending on :

- ✓ The chemical form of the sulfate
- ✓ The atmospheric environment which the concrete is exposed to

What happens when sulfates get into concrete?

- It combines with the C-S-H, or concrete paste, and begins destroying the paste that holds the concrete together. As sulfate dries, new compounds are formed, often called **ettringite**.
- These new crystals occupy empty space, and as they continue to form, they cause the paste to crack, further damaging the concrete.

Sulfate sources:

1. Internal Sources:

This is rarer but, originates from such concrete-making materials as hydraulic cements, fly ash, aggregate, and admixtures.

- Portland cement might be over-sulfated.
- Presence of natural gypsum in the aggregate.
- Admixtures also can contain small amounts of sulfates.0

2. External Sources:

External sources of sulfate are more common and usually are a result of high-sulfate soils and ground waters, or can be the result of atmospheric or industrial water pollution.

Causes of Distress in Concrete By Vikas Devarth

- Soil may contain excessive amounts of gypsum or other sulfate.
- Ground water is transported to the concrete foundations, retaining walls, and other underground structures.
- Industrial waste waters.

SULFATE ATTACK processes decrease the durability of concrete by changing the chemical nature of the cement paste, and of the mechanical properties of the concrete.

- Extensive cracking
- Expansion
- Loss of bond between the cement paste and aggregate
- Alteration of paste composition, with monosulfate phase converting to ettringite and, in later stages, gypsum formation. The necessary additional calcium is provided by the calcium hydroxide and calcium silicate hydrate in the cement paste
- The effect of these changes is an overall loss of concrete strength.

Core Cutting Test

Reliable Tests for Checking the Compressive Strength of the 'In situ concrete'

Principle & Procedure :-

This is one of the very reliable tests adopted for checking the comressive strength of the In situ
concrete. Other physical properties such as density, water absorption can also be measured from the core concrete. In addition chemical propeties of concrete Specimen for its cement content, carbonation depth, chloride and sulphate content may be measured.

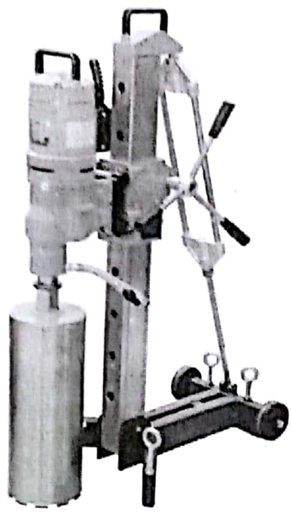
Though this test may become partially destructive for beams/columns but it can be used for slabs, walls, where partial destruction of concrete due to core cutting do not disturb the stability of the member. In this method concrete cores of sizes ranging from 20 mm to 150 mm in diameter and 50 mm to 500 mm long are drilled out by a diamond cutters. The recommended diameters are 100 to 150 mm, but if the drill depth is insufficient as in of case slabs, then smaller diameters may be used but not less than 3 times nominal aggregate size. The core diameter to length ratio shall be normally between 1.0 to 2.0 (Preferably 2.0) The core diameter shall be at least three times the nominal maximum size of aggregate. Reinforcement shall be avoided in the core. At least three cores shall be tested for acceptable accuracy. These cylindirical concrete cores are then made smooth at both ends (if requried) and then tested for compressive strength. If required capping of the faces shall be done. The strength of capping material shal be higher than that of concrete in the core. Cap shall be as thin as practicable. The specimen shall be cured in water for 48 hours before testing.

Applications :-

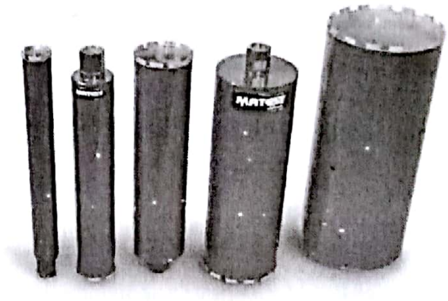
The core Cutting is mainly conducted for-
Determinine "In situ" compressive strength of structure.
Small cores for chemical tests.
Inserting water supply, plumbing pipes.
Inserting conducts for electrical cables.
Making pockets for machine foundation for inserting bolts.
Making weep holes in walls.
The cylindrical strength is then co-related to cube strength. IS- 516 suggest a multiplying factor of 1.25 for converting cylindrical strength to equivalent cube strength. In addition a correction factor for height to diameter ratio shall be applied as given in IS- 516. IS 456 states that the concrete in the member represented by a core test shall be considered acceptable, if the average equivalent cube strength of core is equal to at least 85 % of the cube strength of the grade of concrete specified, but no individual core has a strength less than 75%

NDT Core Cutting Test

By Vikas Devarth



Diamond Core Cutting Machine



Diamond Core Bits

Core Sample Extraction from a Beam

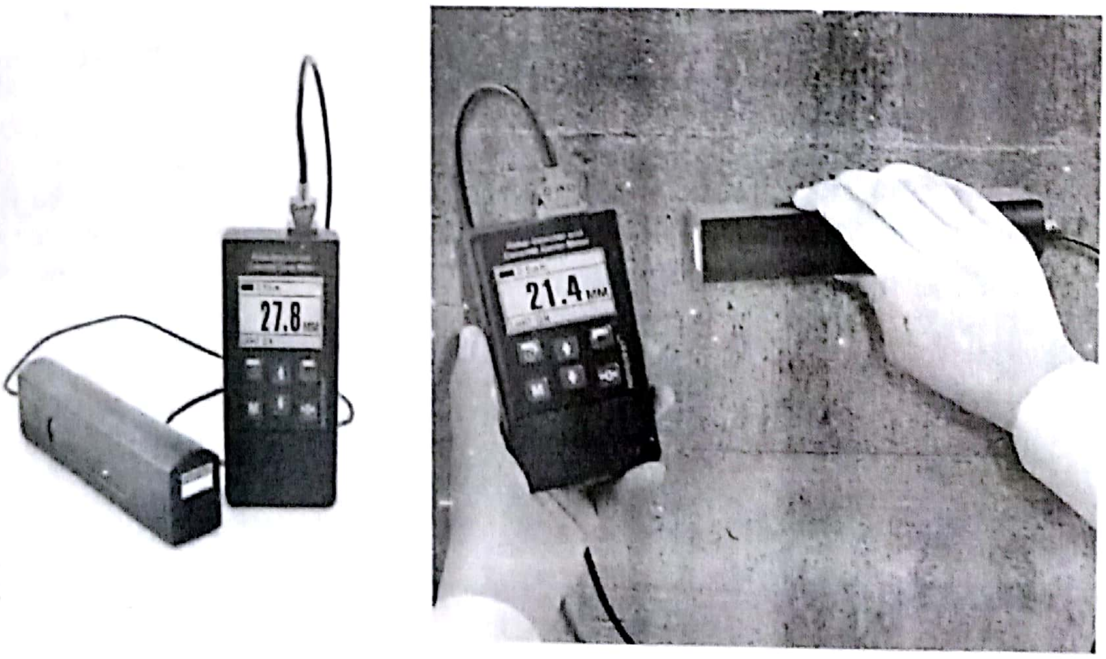
Reliability & Limitations:

As this test gives actual in situ strength of concrete is more acceptable, but due to partial destructiveness needs to be used very carefully. The reliability of small cores ie. 40- 50 mm is less as compared to normal cores. The detection of reinforcement shall be perfect. If the quality of concrete is not good, one may not even get a complete core for testing. The cost of core cutting is more compared with other ND tests, as it consumes diamond bits, which are costly.

Rebar Locator & Bar Sizer

Principle & Procedure:

The reinforcement bar is detected by magnetizing it and inducing a circulating "eddy current" in it. After the end of the pulse, the eddy current dies away, creating a weaker magnetic field as an echo of the initial pulse. The strength of the induced field is measured by a search head as it dies away and this signal is process give the depth measurement. The eddy current echo is determined by the depth of the bar the size of bar and the orientation of the bar. This detection of location of reinforcement is required as a pre process for core cutting.



Reinforcenent Detection

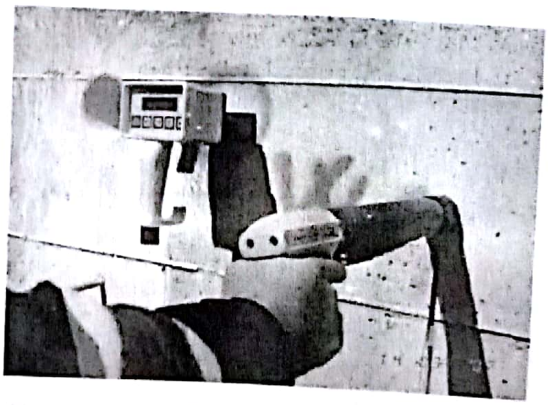
Reliability & Limitations:
With this instruments a cover to reinforcement can be measured up to 100 mm with an accuracy of 15 % and Manufacturers claim accuracy of a bar diameter measurement with an less than 2 to 3 mm. But it has observed that, most of the available detectors do not accurately measure the bar diameter. Proper calibration of these instruments is very essential.

The factors which affect the accuracy are-
very closely spaced bars or bundled bars or bars in layers, Binding wire, aggregate containing iron or magnetic properties

Corrosion mapping
Reinforcement in concrete will not corrode if the protective iron oxide film formed by the high alkaline condition of the concrete pore fluid with a pH around 13 is maintained. This film gets desiroyed chlorides or by carbonaton. if moisture and oxygen are present, resuling in corrosion. In the corrosion process anodic and cathodic areas are formed on the reinforcement, causing dissolution of the steel and the formation of expansive corrosion products at the anode.

Penetration Resistance Test / Windsor Probe Test

Principle :
A test commonly known as Windsor probe test, estimates the strength of concrete from the depth of penetraton by a metal rod driven into the concrete by a specific amount of energy generated by standard charge of powder. The penetration is a function of surfaces hardness, punching shear resistance and hardness of aggregatea expresed as Mohr No. The first two variables are closely related to compresive strength. The penetration is inversely proportional to the comprehensive strength of concrete, but the relation depends on the hardness of the aggregate.



Windsor Probe Penetration Test

NDT Core Cutting Test

By Vikas Devarth

Procedure

The probe diameter is 6.35 to 7.94 mn and length is about 79.5 mm. Probes are driven with a velocity of 183 m/s. The strong aggregate near surface may obstruct the probe, thus at least three tests are recommended at a location. The probes shall be driven at least 100 to 175 mm apart to avoid overlapping of zones of influences.

This test compared to rebound hammer test is better in the sense that, it does not test only the surface, but it in depth the probe actually fractures the aggregate and the compression of material is taken into account.

Reliability & Limitations :

This test is also not widely accepted, as it tests only thin layer to the tune of three times the impregnated depth. It is claimed that concrete between 25 to 75 mm below surface can be assessed by this method. The surface damage caused by this test is about 50- 100 mm. It is reported that, this test is not reliable for concrete with stength less than M-10. The probable accuracy of prediction of concrete strength of structure is ±25%.

Half- Cell Potentiometer Test

Principle & Procedure

The instrument measures the potential and electrical resistance between the reinforcenent and the surface to evaluate the corrosion activity as well as the actual condition of the cover layer during testing. The electrical activity of the steel reinforcement and the concrete leads them to be considered as one half of weak battery cell with the steel acting as one electrode and the concrete as the electrolyte. The name half-cell surveying derives from the fact that the one half of the battery cell is considered to be the steel reinforcing bar and the surrounding concrete. The electrical potential of a point on the surface of steel reinforcing bar can be measured comparing its poential with that of copper - copper sulphate reference electrode on the surface. Practically this achieved by connecting a wire from one terminal of a voltmeter to the reinforcement and another wire to the copper sulphate reference electrode. Then generally readings taken are at grid of 1 x 1 m for slabs, walls and at 0.5 m c/c for Column, beams. An Equi-potential contour map can be plotted to get an overall picture of the member. The risk of corrosion is evaluated by means of the potential gradient obtained, the higher the gradient, the higher risk of corrosion. The test results can be interpreted based on the following table.

Half- cell potential (mv) relative to Cu-Cu sulphate Ref. electrode	% chance of corrosion activity
Less than - 200	10%
Between - 200 to-350	50% (uncertain)
Above-350	90%

NDT Core Cutting Test

By Vikas Devarth

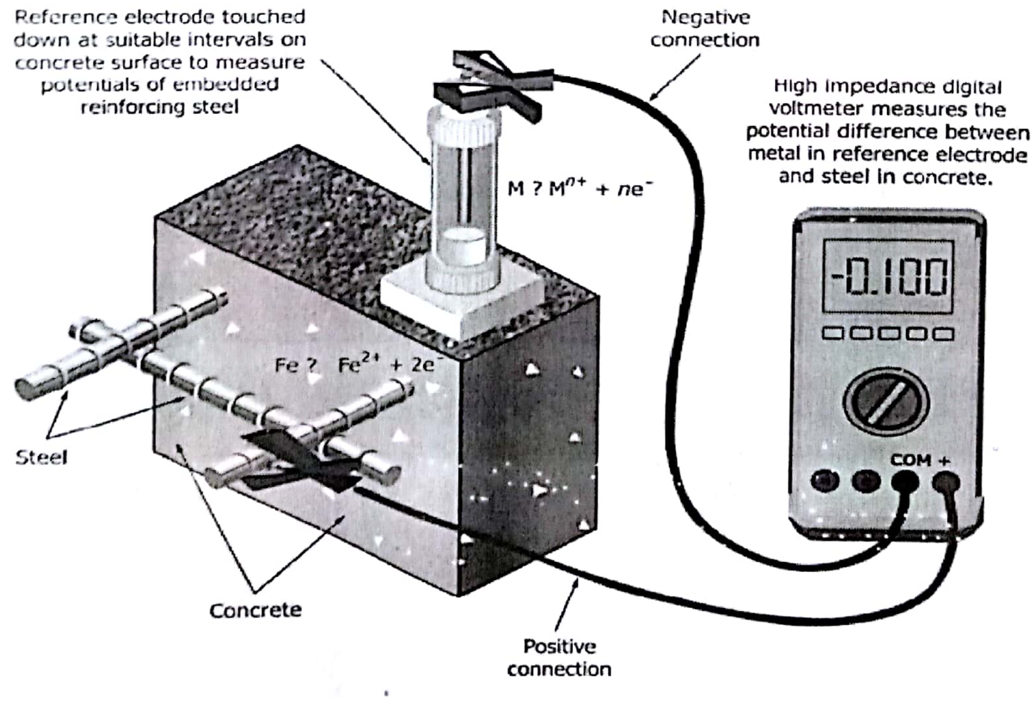
Significance and use:

1. This method may by used to indicate the corrosion activity associated with steel embeded in
   concrete.
2. This method can be applied to members regardless ofheir size orthe depth of concrete cover.
3. This method can be used at the any time during the life of concrete member.

Reliability & Limitations :

The test does not actual corrosion rate or whether corrosion activity has already started, but it indicates the probability of the corrosion activity dependung upon the actual surrounding conditions. If this method used in combination with resistivity measurement , the accuracy is higher.

If the concrete surface has dried to he extent that it is dielectric, then pre wetting of concrete is essential especially for Cement Silos, exposed roof slab. The Quality of the cover concrete, particularly its moisture condition and Contamination by carbonation and / or chlorides may affect the results



NDT Core Cutting Test

By Vikas Devarth

CORE TESTING OF CONCRETE

The test specimen, cube or cylinder is made from the representative sample of concrete used for a particular member, the strength of which we are interested. As the member can not be in fact tested, we test the parallel concrete by making cubes or cylinders. It is to be understood that the strength of the cube specimen cannot be same as that of the member because of the differences with respect to the degree of compaction, curing standard, uniformity of concrete, evaporation, loss of mixing water etc. At best the result of cube or cylinder can give only a rough estimate of the real strength of the member. To arrive at a better picture of the strength of the actual member, attempts are made to cut cores from the parent concrete and test the cores for strength. Perhaps this will give a better picture about the strength of actual concrete in the member.
Core can be drilled at the suspected part of the structure or to detect segregation or honey combing or to check the bond at construction joint or to verify the thickness of pavement. The disadvantages are that while cutting the core, the structural integrity of the concrete across the full cross-section may be affected to some extent and secondly that the diameter to height ratio may be other than that of the standard cylinder. Capping of both ends will be required which will again introduce some differences in the strength. Existence of reinforcement will also present difficulty in cutting a clean core. The cores cut to determine the strength of concrete of the actual structure may also indicate segregation and honey combing of concrete. In some cases, the beam specimens are also sawn from the road and airfield slabs for finding flexural strength. In practice, it is seen that the strength of the core is found to be less than that of the strength of standard cylinders. Apart from other reasons, it is mainly because site curing is invariably inferior to curing under standard moist condition.

Situations when core tests are performed:

When the standard 28 days cube strength test gives lower strength than acceptable and the primary aim of the core test is to ascertain whether the structural element is of adequate strength.
When it is required to estimate the load carrying capacity of the structure for its safety under change of loading contemplated for the structure.
To detect segregation, honey combing and to check the bond at construction joint or to verify the thickness of the pavement.

Location from where core is to be taken:

The core should be drilled at the suspected part of the structure.
The choice of core location primarily is governed by the basic purpose of the testing. For serviceability assessment, the core should normally be taken at the points where minimum strength and maximum stress coincide.
In case of slender member, core cutting may damage the future performance. Thus core should be taken at the nearest non-critical locations.
The reinforcement bars should be avoided as far as possible.
In fact core test should be performed when other non-destructive tests are not possible to perform.

NDT Core Cutting Test

By Vikas Devarth

SIZE OF CORES (REF IS: 1199-1959 (Reaffirmed 1999))

A core specimen for the determination of pavement thickness shall have a diameter of at least 10 cm. A core specimen for the determination of compressive strength shall have a diameter at least three times the maximum nominal size of the coarse aggregate used in the concrete, and in no case shall the diameter of the specimen be less than twice the maximum nominal size of the coarse aggregate. The length of the specimen, when capped, shall be as nearly as practicable twice its diameter.?

NUMBER OF CORES (REF IS:516-1959 (Reaffirmed 1999))

At least three specimens, preferably from different batches, shall be made for testing at each selected age?.

EQUIPMENT: For drilling the cores, the portable rotary drill having cutting tool with diamond bits and water supply arrangement to lubricate the cutter is sufficient.

TESTING: The cores obtained from drilling are trimmed and their ends either capped or grinded before visual examination, assessment of voids percentage & density.
First visual examination is done for honey combing, cracks, aggregate distribution, drilling damages and other defects that are easily seen on the dry surface.
Strength tests namely compressive testing & tensile strength test are done. In compressive strength test the core is centrally placed in the machine and loaded at a rate of 0.2 MPa to 0. 4 MPa per second and the mode of failure is noticed.

FACTORS INFLUENCING THE CORE COMPRESSIVE STRENGTH

MOISTURE & VOIDS: it has been observed that saturated specimen has a value of 10 to 15 % lower than dry specimen. Voids also reduce the measured strength.

LENGTH/DIAMETER RATIO OF CORE: As l/d ratio increases, the measured strength decreases due to the effect of specimen shape and stress distribution. Therefore a standard l/d ratio =2.0 is used for establishing a relation between core strength & standard cube strength.

DIAMETER OF CORE: The diameter of the core may influence the strength & variability. Measured concrete strength decreases with increase in the size of specimen. This effect is significant. However this effect will be small for sizes above 100 mm, but for smaller sizes this effect is significant.

NDT Core Cutting Test

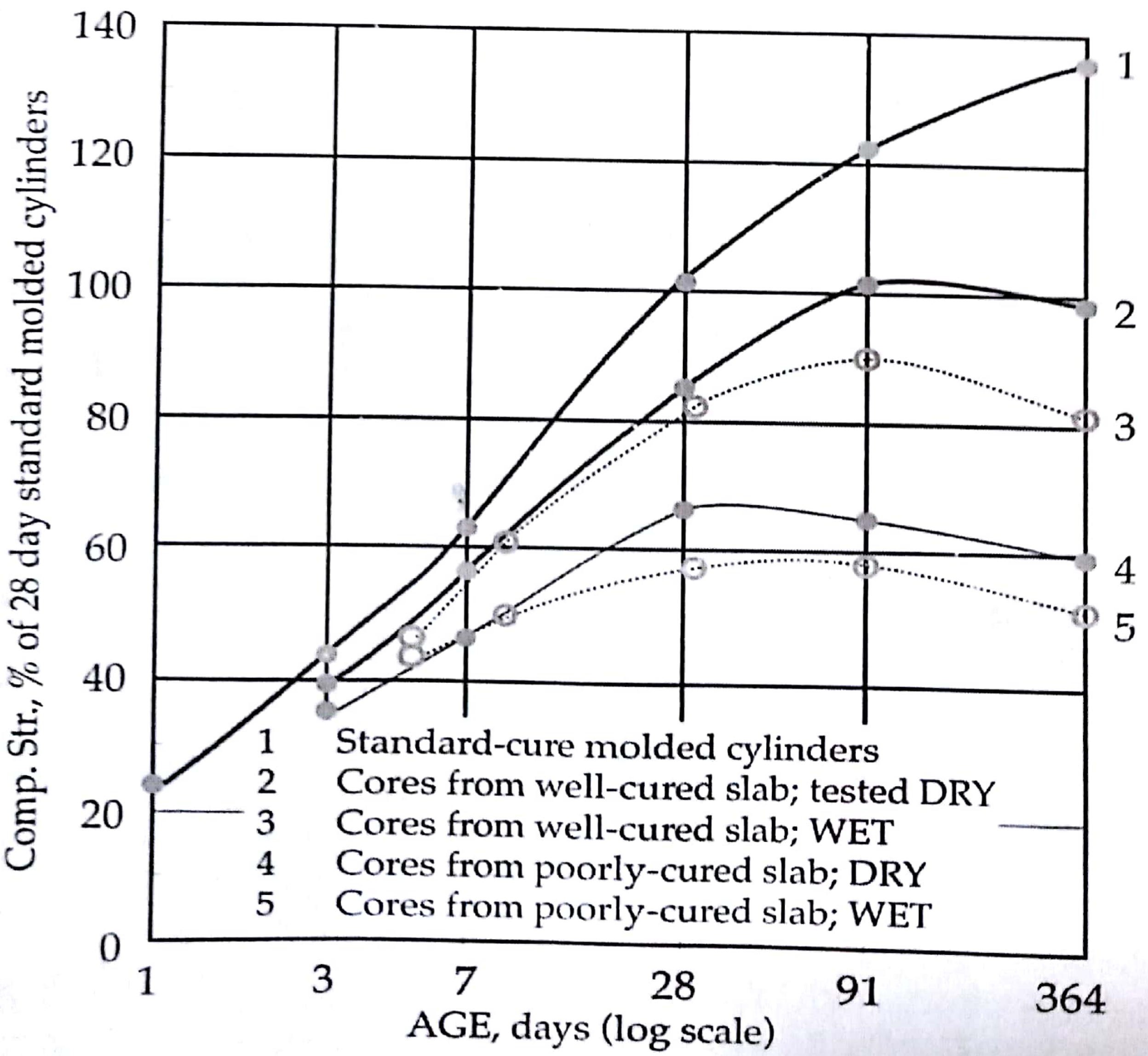
By Vikas Devarth

POSITION OF CUT OUT CONCRETE IN STRUCTURE: Cores taken from near the top of the surface have usually lowest strength. With increase in depth below the top surface, the strength increases, but at depths more than 300 mm, there is no further increase in strength.

DIRECTION OF DRILLING: Due to layering effect, the measured strength of specimen drilled vertically relative to the direction of the casting is likely to be greater than that for a horizontally drilled specimen for the same concrete.

EFFECT OF AGE:

CURVE 1- strength development of a standard cylinder
CURVE 2- strength development of well cured slab core tested dry
CURVE 3- strength development of well cured slab core tested wet
CURVE 4- strength development of poorly cured slab tested dry
CURVE 5- strength development of poorly cured slab core tested wet.



CORRUSION MAPPING

by Vikas Devarth

CORROSION MAPPING

The combination of steel and concrete is a viable construction material of proven durability. In the normally alkaline concrete environment, a thin oxide layer is formed on the surface of the reinforced steel. This oxide film isolates the steel from the environment and prevents corrosion for as long as the oxide layer remains intact. Protected within the concrete, the oxide layer is seldom disturbed and the structural integrity of the concrete-steel combination is unaffected by corrosion. The oxide is known as (Gamma-Fe_2O_3).

The rust product formed during the corrosion process occupies a much greater volume than the original steel member. The tensile stress exerted by the corrosion products can exceed the tensile fracture limits of the concrete and cause cracking or delamination which eventually becomes spalls. The identification of corrosion as a cause of concrete spalling prompted the need to determine the reasons for the corrosion of normally passive steel. The mechanism for the disruption of the passive oxide layer was found to be a complex reaction between the oxide and chloride layer in the concrete. The oxide layer in the presence of chlorides is transformed into $Fe(OH)_2$, rust. The chloride ions remain in solution to continue their degradation of the Gamma $Fe_2 O_3$. Once the passive films are removed, the reinforcing steel is subject to galvanic corrosion.

HALF-CELL POTENTIOMETER

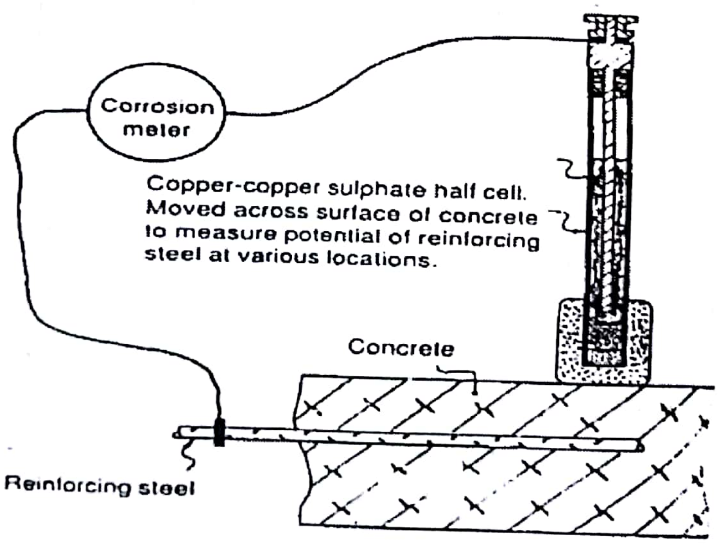
Principle and Procedure: The half-cell is usually a copper/copper sulphate or silver/silver chloride cell but other combinations are used. The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the immediate region of the test location may be related empirically to the measured potential difference.

The instrument measures the potential and the electrical resistance between the reinforcement and the surface to evaluate the corrosion activity as well as the actual condition of the cover layer during testing. The electrical activity of the steel reinforcement and the concrete leads them to be considered as one half of weak battery cell with the steel acting as one electrode and the concrete as the electrolyte. The name half-cell surveying

CORROSION MAPPING

by Vikas Devarth

derives from the fact that the one half of the battery cell is considered to be the steel reinforcing bar and the surrounding concrete. The electrical potential of a point on the surface of steel reinforcing bar can be measured comparing its potential with that of copper – copper sulphate reference electrode on the surface. Practically this achieved by connecting a wire from one terminal of a voltmeter to the reinforcement and another wire to the copper sulphate reference electrode. Then readings taken are at grid of 1 x 1 m.



Half-cell Potential Test

CORROSION MAPPING

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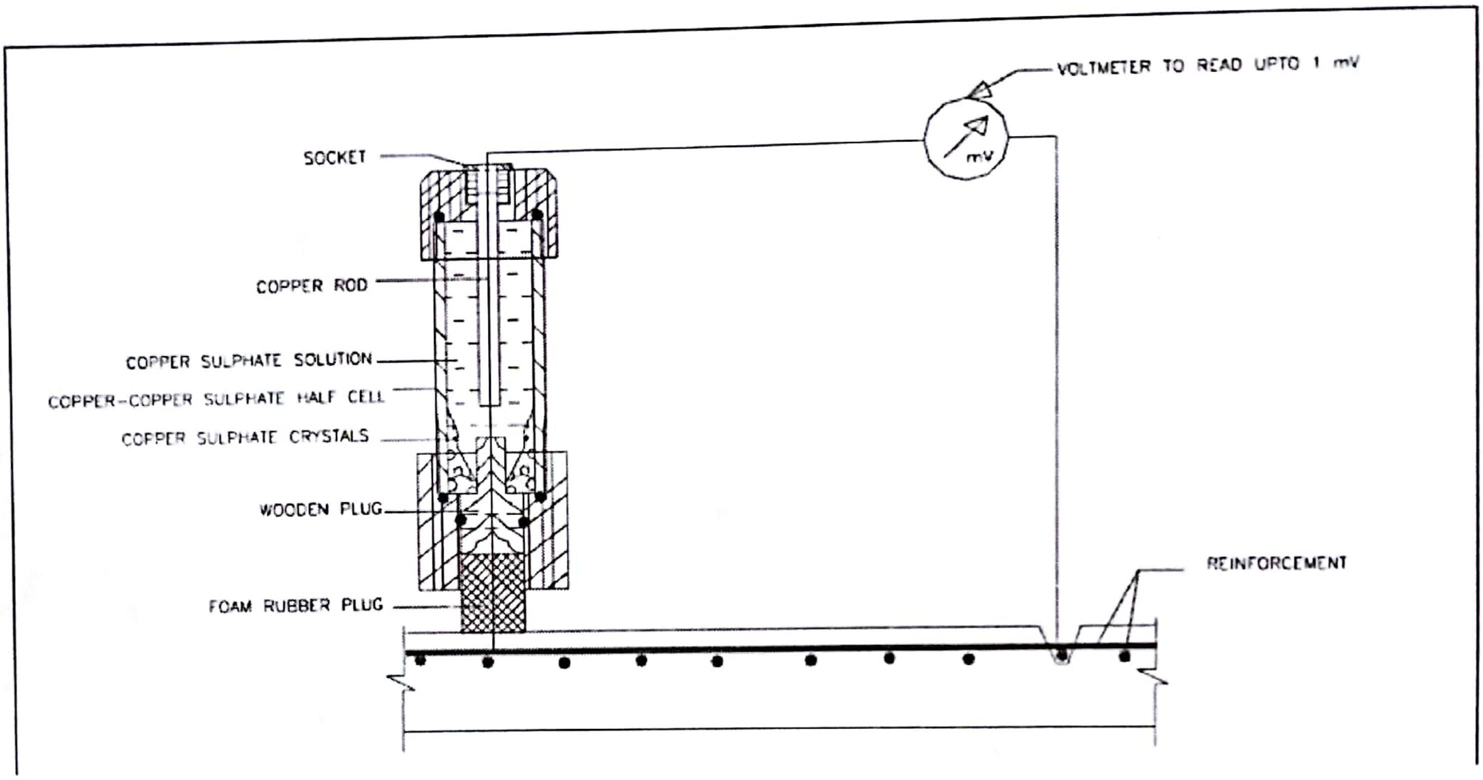


The risk of corrosion is evaluated by means of the potential gradient obtained, the higher the gradient, the higher risk of corrosion. The test results can be interpreted based on the following table.

Half Cell Potential Corresponding to Percentage Chance of Corrosion Activity

Half-cell potential (mv) relative to Cu-Cu sulphate Ref. Electrode	% chance of corrosion activity
Less than -200 Between -200 to -350 Above -350	10% 50% (uncertain) 90%

CORROSION MAPPING

by Vikas Devarth

Table 3.13 – Corrosion Risk by Half Cell Potentiometer

(Source: Indian Concrete Journal, June 1998)

Probability of Corrosion being active	Half Cell Potential Reading Range	
	$Cu-CuSO_4$ Electrode	Silver-Silver Chloride Electrode
>95 percent	More negative than –350mV	More negative than – 700 mV
50 percent	- 200 to - 350 mV	- 500 to - 700 mV
<5 percent	More positive than –200mV	More positive than –500mV

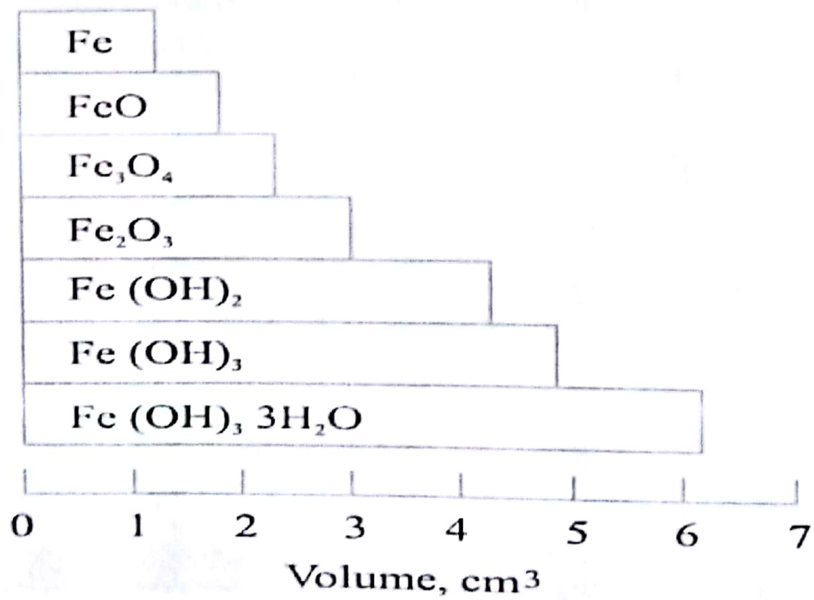
Significance and Use: This technique is most likely to be used for assessment of the durability of reinforced concrete members where reinforcement corrosion is suspected. Reported uses include the location of areas of high reinforcement corrosion risk in marine structures, bridge decks and abutments. Used in conjunction with other tests, it has been found helpful when investigating concrete contaminated by salts.
This method may be used to indicate the corrosion activity associated with steel embedded in concrete. This method can be applied to members regardless of their size or the depth of concrete cover. This method can be used at the any time during the life of concrete member.

Reliability and Limitation: The test does not measure corrosion rate or whether corrosion activity has already started, but it indicates the probability of the corrosion activity depending upon the actual surrounding conditions. If this method used in combination with resistivity measurement, the accuracy is higher. If the concrete surface has dried to the extent that it is dielectric, then pre wetting of concrete is essential.
The method has the advantage of being simple with equipment also simple. This allows an almost non-destructive survey to be made to produce isopotential contour maps of the surface of the concrete member. Zones of varying degrees of corrosion risk may be identified from these maps.
The limitation of the method is that the method cannot indicate the actual corrosion rate. It may require to drill a small hole to enable electrical

CORROSION

Corrosion is defined as the destruction (or deterioration) of materials due to chemical (or electrochemical) reaction with the environment, & also the loss of steel due to formation of rust. The corrosion of steel is the depassivation of steel with reduction in concrete alkalinity through carbonation.

Corrosion deteriorates concrete because the product of corrosion- FERRIC OXIDE brown in colour occupies a greater volume (more than 2 to 10 times) than steel & exerts substantial bursting stresses on the surrounding concrete. The outward manifestations of rusting include staining, cracking, & spalling of concrete. The progress of process of corrosion is generally in geometric progression with respect to time. Consequently, the cross-section of steel is reduced. With time, structural distress may occur either due to loss of the bond between steel & concrete, due to cracking and spalling of concrete, or as a result of reduced steel cross-sectional area. This latter effect can be of special concern in structures containing high-strength pre-stressing steel in which a small amount of metal loss could possibly induce a tendon failure.



CORROSION

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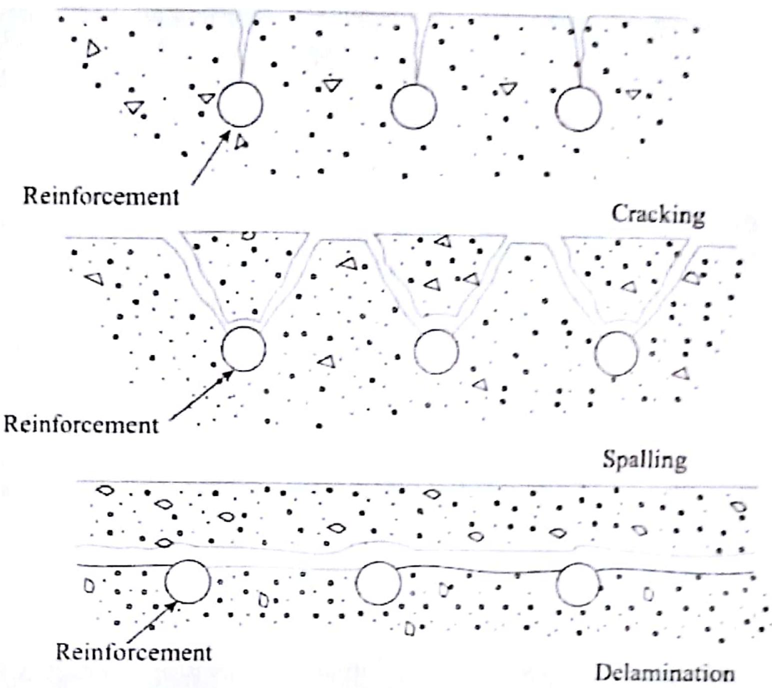
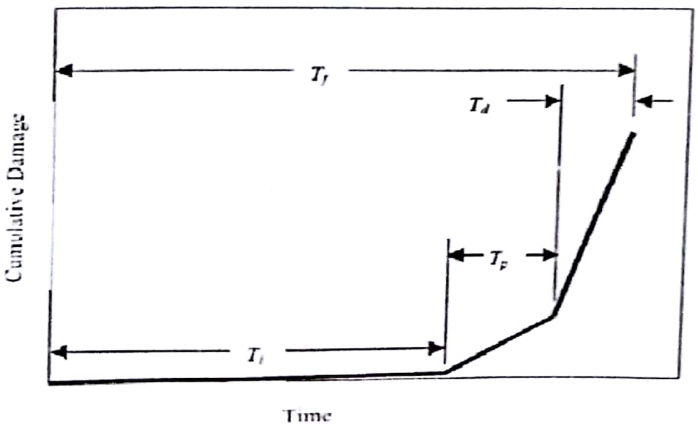


Corrosion-induced deterioration of reinforced concrete can be modeled in terms of three component steps: (1) time for corrosion initiation, T_i; (2) time, subsequent to corrosion initiation, for appearance of a crack on the external concrete surface (crack propagation), T_p; and (3) time for surface cracks to progress into further damage and develop into spalls, T_d, to the point where the functional service life, T_f, is reached. Figure illustrates these schematically as a plot of cumulative damage versus time.



CORROSION

By Vikas Devarth

Protection of reinforcement from corrosion is provided by the alkalinity of concrete, which leads to the passivation of steel. The reserve of calcium hydroxide (from hydration of cement) is very high, so there is no need to expect steel to corrode even when water penetrates to the the reinforcement in the concrete. Owing to this, even the occurrence of small cracks (upto 0.1 mm in width) in concrete need not necessarily lead to damage. However environmental influences & carbon-dioxide in particular, reduce the pH value of concrete from 12.6 to 8.0 and thus remove the passivation effect of alkalis. In conjunction with the existing humidity, a reduction in pH value leads to corrosion of reinforcement.

THE PRESENCE OF ELECTRICAL POTENTIAL IS THE PREREQUISITE FOR THE OCCURRENCE OF ELECTROCHEMICAL CORROSION.

The electrochemical potential may be created by any of the following:

- ✓ Differential aeration (difference in the concentration of oxygen on the steel surface)
- ✓ Differential ion concentration (metal ions, dissolved salts, & pH of concrete in the vicinity of the steel may cause this)
- ✓ Differential surface properties (small blemishes on the surface of the reinforcement formed during rolling generally termed as mill scales or breaks in coatings, impurities in concrete, etc may be responsible for this.

The reinforcement in concrete has a passivating layer of gamma Ferric Oxide (Fe_2O_3). Any cracks that occur in the protective film are quickly repaired in the presence of sufficiently high hydroxyl ion concentration, forming Ferrous Hydroxide first & then cubic Ferric Oxide (Fe_3O_4) and gamma oxide (Fe_2O_3)

CORROSION

By Vikas Devarth

➢ REACTION WITH CHLORIDE:

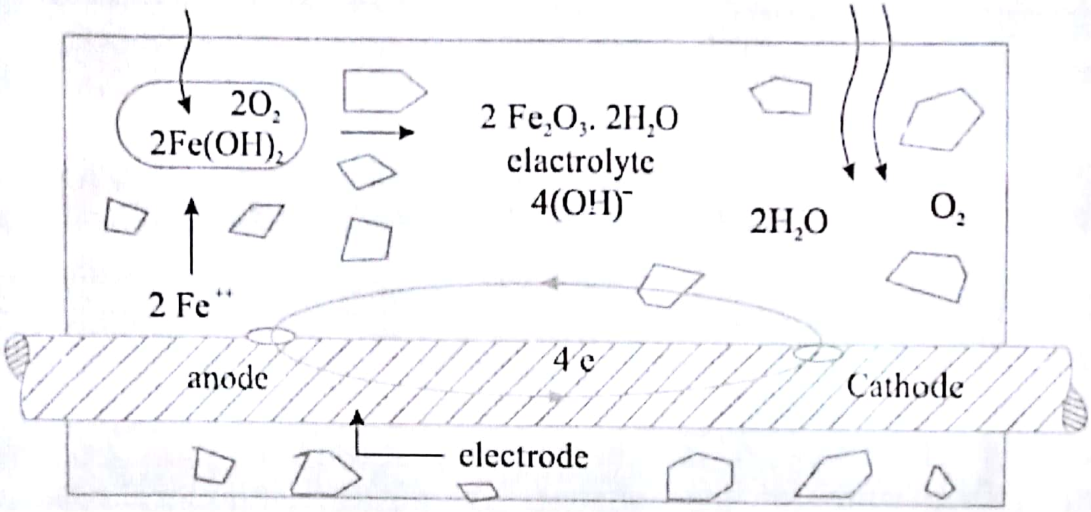
Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete. Chloride attack is particularly important because it primarily causes corrosion of reinforcement. The presence of $CaCl_2$ even in small percentages can lead to rapid corrosion of reinforcement, as it reduces the electrical resistivity of concrete and helps to promote galvanic cell action. Chloride enters the concrete from cement, water, aggregate and sometimes from admixtures. The present day admixtures are generally contain negligible quantity of chloride or what they call chloride free. Chloride can enter the concrete by diffusion from environment. The Bureau of Indian Standard earlier specified the maximum chloride content in cement as 0.05 per cent. But it is now increased the allowable chloride content in cement to 0.1 per cent. IS 456 of 2000 limits the chloride content as (cl) in the concrete at the time of placing is shown in Table below:

Sl. No	*Type or Use of Concrete*	*Maximum Total acid soluble chloride Content. Expressed as kg/m³ of concrete*
1.	Concrete containing metal and steam cured at elevated temperature and prestressed concrete	0.4
2.	Reinforced concrete or plain concrete containing embedded metal	0.6
3.	Concrete not containing embedded metal or any material requiring protection from chloride	3.0

Corrosion of steel in concrete is an electrochemical process. When there is a difference in electrical potential along the steel reinforcement in concrete, an electrochemical cell is set up. In the steel, one part becomes anode and other part becomes cathode connected by electrolyte in the form of pore water in the hardened cement paste. The positively charged ferrous ions Fe^{++} at the anode pass into solution while the negatively charged free electrons e^- pass through the steel into cathode where they are absorbed by the constituents of the electrolyte and combine with water and oxygen to form hydroxyl ions $(OH)^-$. These travel through the electrolyte and combine with the ferrous ions to form ferric hydroxide which is converted by further oxidation to rust.

CORROSION

By Vikas Devarth



The reactions are discribed below

Anodic reactions

$Fe \rightarrow Fe^{++} + 2e^-$

$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2$ (Ferrous hydroxide)

$4\ Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$ (Ferric oxide)

Cathodic reaction

$4e^- + O_2 + H_2O \rightarrow 4(OH)^-$

It can be noted that no corrosion takes place if the concrete is dry or probably below relative humidity of 60 percent because enough water is not there to promote corrosion. It can also be noted that corrosion does not take place if concrete is fully immersed in water because diffusion of oxygen does not take place into the concrete. Probably the optimum relative humidity for corrosion is 70 to 80 per cent. The products of corrosion occupy a volume as many as six times the original volume of steel depending upon the oxidation state. The increased volume of rust exerts thrust on cover concrete resulting in cracks, spalling or delamination of concrete. With this kind of situations concrete loses its integrity. The cross section of reinforcement progressively reduces and the structure is sure to collapse.

CORROSION RESISTANT REINFORCEMENT

Reinforced concrete is inherently a durable and near maintenance-free construction material under normal conditions. Harsh environmental conditions, such as exposure to deicing salts or seawater, however, can cause premature deterioration of the material. The expected service life of a reinforced concrete structure can be significantly reduced when chloride penetrates the concrete to the level of the steel reinforcement. When corrosion of the reinforcing steel is initiated, the products of corrosion expand and occupy a greater volume than the original steel and eventually cause cracking of the concrete. Once corrosion of the reinforcing steel has cracked the concrete, more chloride enters to attack the steel, and deterioration of the reinforced concrete component or structure proceeds at a faster pace. Premature deterioration of reinforced concrete structures due to corrosion of the reinforcing steel is of concern world-wide.

Because corrosion of reinforcement can result in concrete cracking, staining, spalling, and costly repairs, corrosion resistant reinforcement often is the obvious choice for concrete structures exposed to high chloride levels. Epoxy-coated, galvanized, glass-fiber-reinforced-polymer, solid stainless-steel, and stainless- steel-clad reinforcing bars all are designed to resist corrosion, especially chloride-ion induced corrosion.

EPOXY COATED REINFORCEMENT:

Designed to provide a physical barrier between chlorides and oxygen absorbed in the concrete and the reinforcing steel, epoxy coating consists of organic epoxy resins combined with curing agents. Epoxy coating is a thermoset material; meaning that it is not subject to damage by high temperatures once it is cured. The coating starts out as a dry powder, and is heat-treated to melt the powder and catalyze the chemical reaction that allows epoxy coating to adhere to the steel. EC is then applied by either spraying it directly on to steel or dipping the steel into epoxy baths.

The surface of the steel must be cleaned and roughened with abrasive material in order to provide an uneven surface for the epoxy to bond to mechanically as well as chemically. The steel is then heated and passed through a sprayer which charges them epoxy powder and causes it to evenly coat the surface of the steel. The heated steel melts the powder on contact, initiating the chemical reaction that forms complex polymers in the epoxy and bonds the epoxy molecules to each other and the rough steel surface.

In addition to providing a barrier for corrosive agents, epoxy coating also has a high electrical resistance, and prevents the flow of electrons that contribute to electrochemical corrosion. EC also possesses the necessary mechanical properties for use in coating steel, i.e. ductility, negligible shrinkage after application, and good heat resistance. Epoxy coating (EC) is also durable to rough handling and weathering, and is flexible enough to expand and contract with the steel. Epoxy coating is environmentally friendly thanks to a lack of hazardous materials and solvents and very efficient methods of manufacture and application to the steel.

Epoxy-coated reinforcement is generally required in roadways and bridge decks where deicing salts cause significant chloride contamination to the concrete.

- ✓ **Advantages of Epoxy coating Protection** - Epoxy coated rebar is designed to protect the rebar against rust and corrosion. Applying an epoxy coating to steel rebar prevents oxygen and chlorides from reaching the steel surface reducing corrosion.
- ✓ Environmentally friendly materials - Unlike many paints, the fusion-bonded epoxy coatings used for steel reinforcement do not contain appreciable solvents or other environmentally hazardous substances.
- ✓ **Disadvantages of Epoxy coating Special Handling** - ECR requires delicate handling to prevent damage to the epoxy coating. Any damage to the coating prior to placement will compromise the corrosion protection. Special handling must be used at the fabrication plant, in transit to the site and during handling and storage to the site. It is essential that damage to the coating is minimized.
- ✓ UV damage - ECR coatings break down under UV ray exposure.
- ✓ Touch up after placement may be required due to scratching and chipping during transport and placement
- ✓ Coating inconsistencies - ECR specifications allow for a percentage of the bar to have holidays and pinholes, compromising its protection mechanisms before it reaches the job site.
- ✓ Abrasion resistance - The coating lacks abrasion resistance, and thus is easily damaged in transport to the job site and installation.
- ✓ Poor bond to concrete - Loss of bond strength as a result of the epoxy coating. A disadvantage of substituting epoxy-coated reinforcement in the place of uncoated steel is that epoxy has poor chemical adhesion to the cement mortar matrix, resulting in lower bond strength between the rebar and concrete. Epoxy coating also reduces the

size of the rebar deformation ribs and provides less friction to resist bond slip. The reduction in bond strength is a product of the rebar size, with larger bar diameters resulting in lower relative bond strength. Bond slip creates cracking in the concrete, and epoxy coated bars were found to create fewer but wider cracks in concrete as a result of bond slip. Reduced bond strength between ECR and concrete affects the strength and development length of laps and splices, as well as the capacity of plastic hinges in reinforced concrete. In addition to the reduced bond strength between the epoxy surface and the concrete, the bond between the epoxy coating and the steel rebar also tends to deteriorate over time and exposure to moisture. The EC adhesion to steel deteriorates at an even higher rate in the presence of cracks in the concrete.

- ✓ Under film corrosion - ECR coatings are permeable and once corrosion begins, it spreads throughout the bar underneath the epoxy film.
- ✓ Installation conditions - ECR coatings may crack when handled in temperatures less than 50 F.
- ✓ Increased corrosion process - Pin holes or discontinuity of the epoxy layer on a bar will enhance the corrosion process faster and more aggressive than in the case of a bare uncoated bar.

GALVANISED REINFORCEMENT:

Galvanized reinforcing steel is effectively and economically used in concrete where unprotected reinforcement will not have adequate durability. The susceptibility of concrete structures to the intrusion of chlorides is the primary incentive for using galvanized steel

Tests also confirm that zinc corrosion products are powdery, non-adherent and capable of migrating from the surface of the galvanized reinforcement into the concrete matrix, reducing the likelihood of zinc corrosion-induced spalling of the concrete

GLASS FIBRE REINFORCED POLYMER REBAR (GFRP):

Composed of resin-impregnated glass fibers and containing no steel, GFRP rebar are immune to chloride and chemical attack. In addition, the bars are nonconductive and have high strength-to-weight ratios. They have a tensile strength as much as twice that of conventional steel reinforcement yet are only one-fourth the weight. Because GFRP rebar are nonconductive, they don't affect magnetic fields and radio frequencies, making the bars ideal reinforcement for concrete in the vicinity of magnetic resonance imaging (MRI) equipment, radio and compass calibration equipment, or high-voltage transformers, cables, and substations.

Since GFRP has different qualities than steel, important design differences and construction considerations exist. For example, the tensile modulus of GFRP reinforcement is only one-fifth that of steel, which may limit span lengths. All bends for GFRP rebar must be made at the factory; field bends are not allowed.

Cutting is allowed, but since high pH materials, such as concrete, will degrade the exposed glass fibers, manufacturers may recommend sealing of the cut ends. Some manufacturers, however, say sealing is not necessary because any degradation that occurs will be minor. GFRP rebar cannot be welded or mechanically spliced.

CRACKS IN CONCRETE & THEIR PREVENTION

Why does concrete crack? Most cracks occur as a result of shrinkage of concrete. Shrinkage is simply a reduction in the volume of concrete as it hardens. If this reduction in volume were unrestricted, then a crack would not occur. However, in reality, ground friction and a number of things such as structural connections inhibit free shrinkage and thus cause cracks.

DISTRESS CAN BE BROADLY CLASSIFIED AS :

- STRUCTURAL causes STRUCTURAL CRACKS
- NON-STRUCTURAL causes NON-STRUCTURAL CRACKS

Non-structural Cracks

Not every crack threatens the structural safety of a building. In fact, in many instances, cracks are merely cosmetic in nature. These cracks are typically seen in flat work such as driveways, patio, walkways and curbs. Typical causes of these cracks are

- Poor workmanship
- Inappropriate joint detailing
- Higher shrinkage of concrete

Sometimes such nonstructural cracks in driveways and sidewalks become more than just an eyesore. Tree roots and impact from vehicles can cause raveling as well as vertical and horizontal offsets at the cracks. When these offsets become trip hazards, repairs are necessary. Non-structural cracks may not endanger the safety of the building, but may look unsightly and create an impression of faulty work or a feeling of instability. These generally do not result in structural weakening, however they result in corrosion of reinforcement and thus render the structure unsafe and thus may lead to its collapse. Non-structural cracks are caused due to plastic shrinkage cracking (rapid evaporation of water), drying shrinkage cracking, plastic settlement cracking, thermal contraction cracking, cracking due to poor workmanship & alkali aggregate reaction.

CRACKS IN CONCRETE & THEIR PREVENTION

By Vikas Devarth

Structural Cracks

A majority of structural cracks occur as a result of the following conditions:

- Design deficiency
- Construction deficiency
- Settlement or heaving of soil
- Reinforcement corrosion

Sometimes structural cracks manifest themselves with some side effects. Doors and windows do not open and close easily. Floors feel uneven. Vinyl flooring Distresses in buildings are a common occurrence. A building component develops cracks whenever the stress on it exceeds its cracking strength. Structural distresses are generally caused by faulty design, faulty construction, and/or overloading. Non-structural distresses are caused by internally induced stresses in building components.

Classification of the cracks is done on the basis of their widths.

✓ THIN- LESS THAN 1 mm IN WIDTH

✓ MEDIUM- 1 to 2 mm IN WIDTH

✓ WIDE- MORE THAN 2 mm IN WIDTH

According to IS:456-2000, crack width is as follows:

- In general the crack width should not exceed 0.3 mm in members, where cracking is not harmful and does not have any serious effect upon the preservation of reinforcing steel nor upon the durability of concrete.
- Cracking in tensile zones of the member is harmful due to the exposure to the effect of weather or continuously exposed to moisture or in contact with soil or ground water. In such situations the maximum upper limit of the crack width is suggested as 0.2 mm.
- For aggressive environment such as severe category of exposed conditions, the surface width of cracks should not in general exceed 0.1 mm.

CRACKS IN CONCRETE & THEIR PREVENTION By Vikas Devarth

FACTORS CONTRIBUTING TO CRACKS IN CONCRETE:

(1) **WATER:** the more is the water, the greater is cracking tendency. Water increases shrinkage & reduces strength.

(2) **CEMENT:** richer concretes crack more. Increasing the volume of aggregates by 10% can be expected to reduce the shrinkage by about 50%.

(3) **AGGREGATE:** presence of clay binders in aggregates causes high shrinkage and cracking. The smaller the maximum size of well-graded aggregates, the greater is the shrinkage of concrete at the same strength.

(4) **BLEEDING:** Excessive bleeding induces cracks

(5) **IMPROPER CURING:** when rate of evaporation is very high, the fresh concrete dries rapidly. In such cases early curing & appropriate screening is essential.

(6) **EXPOSURE:** the southern & western exposures of structure are usually more severe than northern & eastern exposures.

(7) **COVER:** clear cover less than the specified value expedites corrosion of reinforcement.

TYPES OF CRACKS:

SULFHATE ATTACK CRACK:

Sulfate attack can be 'external' or 'internal'.

External: due to penetration of sulfates in solution into the concrete from outside.

Internal: due to a soluble source incorporated into concrete at the time of mixing.

External sulfate attack

This is the more common type and typically occurs where water containing dissolved sulfate penetrates the concrete. A fairly well-defined reaction front can often be seen in polished sections; ahead of the front the concrete is normal, or near normal. Behind the reaction front, the composition and microstructure of the concrete will have changed. The effect of these changes is an overall loss of concrete strength.

These changes may vary in type or severity but commonly include:

- ✓ Extensive cracking
- ✓ Expansion
- ✓ Loss of bond between the cement paste and aggregate
- ✓ Alteration of paste composition

Sources of sulfate which can cause sulfate attack include:

- Seawater
- Oxidation of sulfide minerals in clay
- Bacterial action in sewers - anaerobic bacterial produce sulfur dioxide
- Masonry - sulfates in bricks can be gradually released over a long period

Internal sulfate attack

Internal sulfate attack occurs when a source of sulfate is incorporated into the concrete when mixed. Examples include the use of sulfate-rich aggregate, excess of added gypsum in the cement or contamination. Proper screening and testing procedures should generally avoid internal sulfate attack.

Delayed ettringite formation

Delayed ettringite formation (DEF) is a special case of internal sulfate attack. It occurs in concrete which has been cured at elevated temperatures, for example, where steam curing has been used. It can also occur in large concrete pours where the heat of hydration has resulted in high temperatures within the concrete. DEF causes expansion of the concrete due to ettringite formation within the paste and can cause serious damage to concrete structures. DEF is not usually due to excess sulfate in the cement, or from sources other than the cement in the concrete. A definition of delayed ettringite formation DEF occurs if the ettringite which normally forms during hydration is decomposed, and then subsequently re-forms in the hardened concrete. Damage to the concrete occurs when the ettringite crystals exert an expansive force within the concrete as they grow. If expansion causes cracking, ettringite may subsequently form in the cracks but this does not mean the ettringite in the cracks caused the cracks initially. DEF causes a characteristic form of damage to the concrete.

CRACKS IN CONCRETE & THEIR PREVENTION

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LOADING CRACK

A loading crack is a result of the loading to which the structure is subjected. A properly designed structure would not exhibit these cracks, but an improperly designed structure is very susceptible to this damage. Vertical cracking at the end of a structure is typically due to a concentrated force being applied at the top of a structure which exceeds the shear capacity within the end section of the structure. This type crack typically maintains a tight appearance at the top and at the bottom but may show a wider gap at approximately mid-height of the structure. This would tend to indicate a bulging effect of the end segment of the structure away from the remainder of the structure.

PLASTIC SHRINKAGE CRACKS

When water evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete, resulting in shallow cracks of varying depth. These cracks are often fairly wide at the surface.

DRYING SHRINKAGE CRACKS

Because almost all concrete is mixed with more water than is needed to hydrate the cement, much of the remaining water evaporates, causing the concrete to shrink. Restraint to shrinkage, provided by the sub grade, reinforcement, or another part of the structure, causes tensile stresses to develop in the hardened concrete. Restraint to drying shrinkage is the most common cause of concrete cracking. In many applications, drying shrinkage cracking is inevitable. Therefore, contraction (control) joints are placed in concrete to predetermine the location of drying shrinkage cracks.

D-CRACKING

D-cracking is a form of freeze-thaw deterioration that has been observed in some pavements after three or more years of service. Due to the natural accumulation of water in the base and sub base of pavements, the aggregate may eventually become saturated. Then with freezing and thawing cycles, cracking of the concrete starts in the saturated aggregate at the bottom of the slab and progresses upward until it reaches the wearing surface. D-cracking usually starts near pavement joints.

CRACKS IN CONCRETE & THEIR PREVENTION

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ALKALI AGGREGATE REACTION CRACK

Alkali-aggregate reactivity is a type of concrete deterioration that occurs when the active mineral constituents of some aggregates react with the alkali hydroxides in the concrete. Alkali-aggregate reactivity occurs in two forms alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). Indications of the presence of alkali-aggregate reactivity may be a network of cracks, closed or spalling joints, or displacement of different portions of a structure.

THERMAL CRACK

Temperature rise (especially significant in mass concrete) results from the heat of hydration of cementitious materials. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that may result in thermal cracks at the surface if the temperature differential between the surface and center is too great. The width and depth of cracks depends upon the temperature differential, physical properties of the concrete, and the reinforcing steel.

SETTLEMENT CRACK

Loss of support beneath concrete structures, usually caused by settling or washout of soils and sub base materials, can cause a variety of problems in concrete structures, from cracking and performance problems to structural failure. Loss of support can also occur during construction due to inadequate formwork support or premature removal of forms.

CORROSION CRACK

Steel reinforcement, in the alkaline environment provided by concrete, is in a stable condition because a protective oxide layer forms on the steel surface, which stops corrosion. There are, however, two situations where this passivating environment at the reinforcement can be disrupted. The first is known as carbonation. This is when atmospheric carbon dioxide dissolves in water to form carbonic acid, which neutralises the concrete alkalinity. The carbonation proceeds through the concrete cover and eventually reaches the reinforcement, at which point the passive layer is no longer sustained and corrosion occurs. The second disruptive effect is chloride attack.

Chlorides may have been cast in the original mix, or may be introduced from an external source such as de-icing salts or a marine environment. When in sufficient concentration at the reinforcement, they will disrupt the passive film on the steel and also cause corrosion to occur rapidly. To support the corrosion activity there must be oxygen and water available and this is normally the case in atmospherically exposed concrete. Corrosion of reinforcing steel and other embedded metals is one of the leading causes of deterioration of concrete. When steel corrodes, the resulting rust occupies a greater volume than steel. The expansion creates tensile stresses in the concrete, which can eventually cause delamination and spalling.

PREVENTION OF CRACKING:

Optimum water ratio

Shrinkage is a primary cause of cracking. As concrete hardens and dries, it shrinks. This is due to the loss, thru evaporation, of excess mixing water. Thus, in most cases, the wetter the concrete mix, the greater the shrinkage will be. Concrete slabs can shrink as much as 1/2 inch per 100 feet. The actual amount is 1/16th inch for every ten feet of horizontal distance. This shrinkage causes forces in the concrete which literally pull the slab apart. Cracks are the end result of these forces. Concrete does not require much water to achieve maximum strength. In fact, a wide majority of concrete used in residential work, in many cases, has too much water. This water is added to make the concrete easier to install. It is a labor saving device. This excess water not only promotes cracking, but it can severely weaken the concrete.

Curing method

Rapid drying of the slab will significantly increase the possibility of cracking. The chemical reaction which causes concrete to go from the liquid or plastic state to a solid state requires water. This chemical reaction, or hydration, continues to occur for days and weeks after concrete was poured. Engineers must make sure that the necessary water is available for this reaction by adequately curing the slab. The use of liquid curing compounds, covering the slab with plastic, wet burlap, and other methods can be used to cure concrete.

CRACKS IN CONCRETE & THEIR PREVENTION By Vikas Devarth

Solid ground

The ground upon which the concrete will be placed must be compacted. Never pour concrete on frozen ground as once the ice melt it will cause void in the soil. If the new concrete is poured over soft, uncompacted soil, a heavy delivery truck will easily bend and crack the concrete as it passes over the soft spot. This is why concrete needs to be poured on solid and compacted soils.

Proper usage of material

Many people had wondered why ancient structures are so strong and still standing till now. Engineers had found that these buildings were over-designed or in other words, maximum usage of construction material. Let's take an example of a driveway concrete slab. A 5-inch thick slab is definitely better in sustaining heavy vehicles than a 4-inch thick slab which is more likely to crack under loading. Some contractors might suggest that 4-inch is just enough when cost comes into consideration but a 5-inch thick is even safer in reality. Thicker concrete is a good idea for better load bearing structure (for this case, it was slab). Cracking can be minimized by following other guidelines as well. Installing proper strength concrete for intended use is always a good practice as concrete is available in many different strengths.

Control joints

Professionals who install concrete driveways install crisp tooled lines in the slabs.

These are called control joints. Installing adequate control and isolation joints at regular intervals in the slab helps to account for horizontal and vertical movement in slabs. These joints can also be formed with a tool or saw-cut soon after the slab has hardened. The purpose of these joints is to create a zone of weakness where the forces which are pulling on the slab will relieve themselves. Isolation joints allow a slab to move independently of other fixed or stationary objects. The control joints must be deep enough to perform their job. The minimum depth of the joint should be 1/4 the thickness of the slab.

CRACKS IN CONCRETE & THEIR PREVENTION By Vikas Devarth

Reinforcement steel

Reinforcing steel for residential purposes comes in two basic varieties, wire mesh, or rigid reinforcing bars. The use of reinforcing steel can help in the event a crack develops. Steel will hold cracked slabs together. Without steel, cracks can grow in size and you can get offsets where one part of the slab is higher or lower than an adjacent piece. Steel needs to be placed no more than 2 inches down from the top of the slab for maximum performance. Reinforcing steel is also quite inexpensive. It is usually very easy to properly install. Steel can significantly enhance the strength and durability of concrete. In addition to all of the other measures taken to prevent concrete from cracking, steel offers a low cost last line of defense.

Cover for reinforcement

The deterioration of reinforced concrete is mainly due to reinforcement corrosion. The mechanism of this deterioration is to be reminded. Reinforcements corrode when they are in contact with a high amount of aggressive agents. This is the reason why, the prevention of reinforcement corrosion, in structures to be built, is obtained mainly by controlling the thickness and the quality of the concrete cover. The concrete cover thickness around reinforcement also depends on the environment aggressiveness. But, in addition to the requirements given by the designer, it is significant to consider the implementation (reinforcements positioning) to estimate the durability of a reinforced concrete really in place.

Coating on reinforcement

When reinforced concrete structures are exposed to a very aggressive environment, an additional protection can be considered by covering the reinforcement steel. The two types of the most frequent covers on steel are organic coatings and metal coatings (hot-dip galvanising). These protective coatings which must adhere to steel must also ensure good a bond between reinforcement and concrete.

Coating on concrete

In some cases, concrete reinforcement corrodes in a slow pace. Therefore, its cover seems physically satisfactory and has neither crack nor delamination. But, it is then convenient to slow down this corrosion rate, even to stop it.

The methods which can be proposed are either concrete impregnation with waterproof products (sealants) or inhibitors. Paintings and coatings of various thicknesses can also be applied on concrete to improve its resistance to liquid penetration. It deals, for example, with either of coatings containing epoxy resin or polyurethane, or with mortar containing modified hydraulic binder. Sometimes, paint isn't the right choice for concrete floors. Epoxy coatings specially formulated for concrete are both protective and decorative.

Corrosion inhibitor

The risk of corrosion of a new structure is likely to be due to chloride attack. The latest developments in corrosion prevention are the use of corrosion inhibitors in the concrete mix. There are a variety of generic types available, the principal ones being calcium nitrite and amino alcohols. These materials are added to the concrete and form a very thin chemical layer on the reinforcement, which inhibits the corrosion activity. They are consumed and will only work up to a given chloride level. It is important to ensure that the correct dosage level is used and to remember that the inhibitor will have a finite service life.

Cathodic protection

Arguably, the most established system of all is cathodic protection (CP). The principals of CP have been known since 1824 when Sir Humphrey Davey first used sacrificial anodes to protect ships hulls. Corrosion is an electrochemical process where the corrosion sites are anodic and passive sites are cathodic.

Cathodic protection is by introducing an anode to the concrete and making all the steel cathodic. A small direct current is passed between the anode and the reinforcement to cathodically protect the reinforcement. The anode is a permanent addition to the structure and the system is computer controlled to minimize future monitoring costs. Sacrificial anode systems are based on the use of a galvanic anode such as zinc, which are directly connected to the reinforcement and corrodes in favor of the steel.

The cathodic protection system is monitored by using silver/silver chloride reference electrodes, which are buried in the concrete alongside the cathodically protected steel reinforcement. These are cabled back to the computer control system, which usually has a modem link to enable the CP system to be remotely monitored.

✓ **GROUTING:**

- **Portland cement grouting**-Wide cracks, particularly in gravity dams and thick concrete walls, may be repaired by filling with portland cement grout. This method is effective in stopping water leaks, but it will not structurally bond cracked sections. The procedure consists of cleaning the concrete along the crack; installing built-up seats (grout nipples) at intervals astride the crack (to provide a pressure tight connection with the injection apparatus); sealing the crack between the seats with a cement paint, sealant, or grout; flushing the crack to clean it and test the seal; and then grouting the whole area.

  Grout mixtures may contain cement and water or cement plus sand and water, depending on the width of the crack. However, the water-cement ratio should be kept as low as practical to maximize the strength and minimize shrinkage. Water reducers or other admixtures may be used to improve the properties of the grout. For small volumes, a manual injection gun may be used; for larger volumes, a pump should be used. After the crack is filled, the pressure should be maintained for several minutes to insure good penetration.
- **Chemical grouting:** Chemical grouts consist of solutions of two or more chemicals (such as urethanes, sodium silicates, and acrylomides) that combine to form a gel, a solid precipitate, or foam, as opposed to cement grouts that consist of suspensions of solid particles in a fluid. Cracks in concrete as narrow as 0.002 in. (0.05 mm) have been filled with chemical grout. The advantages of chemical grouts include applicability in moist environments (excess moisture available), wide limits of control of gel time, and their ability to be applied in very fine fractures. Disadvantages are the high degree of skill needed for satisfactory use and their lack of strength.

✓ **POLYMER IMPREGNATION:**
Monomer systems can be used for effective repair of some cracks. A monomer system is a liquid consisting of monomers which will polymerize into a solid. Suitable monomers have varying degrees of volatility, toxicity and flammability, and they do not mix with water. They are very low in viscosity and will soak into dry concrete, filling the cracks, much as water does. The most common monomer used for this purpose is methyl methacrylate. Monomer systems used for impregnation contain a catalyst or initiator plus the basic monomer (or combination of monomers). They may also contain a crosslinking agent. When heated, the monomers join together, or polymerize, creating a tough, strong, durable plastic that greatly enhances a number of concrete properties. If a cracked concrete surface is dried, flooded with the monomer, and polymerized in place, some of the cracks will be filled and structurally repaired. However, if the cracks contain moisture, the monomer will not soak into the concrete at each crack face, and consequently, the repair will be unsatisfactory. If a volatile monomer evaporates before polymerization, it will be ineffective. Polymer impregnation has not been used successfully to repair fine cracks. Polymer impregnation has primarily been used to provide more durable, impermeable surfaces. Badly fractured beams have been repaired using polymer impregnation. The procedure consists of drying the fracture, temporarily encasing it in a watertight (monomer proof) band of sheet metal, soaking the fractures with monomer, and polymerizing the monomer. Large voids or broken areas in compression zones can be filled with fine and coarse aggregate before being flooded with monomer, providing a polymer concrete repair.

✓ **EXTERNAL STRESSING:** Development of cracking in concrete is due to tensile stress and can be arrested by removing these stresses. Cracks can be closed by external stressing by inducting compression force sufficient to overcome the tension which has caused the cracking. The compression force can be applied by use of usual pre-stressing wires or rods. The compressive force can also be applied by wedging i.e. by opening the crack & filling it with the expanding mortar.

FIBRE REINFORCED CONCRETE

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal microcracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such microcracks, eventually leading to brittle fracture of the concrete.

In plain concrete and similar brittle materials, structural cracks (micro -cracks) develop even before loading, particularly due to drying shrinkage or other causes of volume change. The width of these initial cracks seldom exceeds a few microns, but their other two dimensions may be of higher magnitude.

When loaded, the micro cracks propagate and open up, and owing to the effect of stress concentration, additional cracks form in places of minor defects. The structural cracks proceed slowly or by tiny jumps because they are retarded by various obstacles, changes of direction in bypassing the more resistant grains in matrix. The development of such microcracks is the main cause of inelastic deformations in concrete.

It has been recognised that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete. Fibre reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibres.

Some of the fibres that could be used are steel fibres, polypropylene, nylons, asbestos, coir, glass and carbon. Fibre is a small piece of reinforcing material possessing certain characteristic properties. **They can be circular or flat. The fibre is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fibre is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150.**

Steel fibre is one of the most commonly used fibre. Generally, round fibres are used. The diameter may vary from 0.25 to 0.75 mm. The steel fibre is likely to get rusted and lose some of its strengths. But investigations have shown that the rusting of the fibres takes place only at the surface. Use of steel fibre makes significant improvements in flexural, impact and fatigue strength of concrete, It has been extensively used in various types of structures, particularly for overlays of roads, airfield pavements and bridge decks. Thin shells and plates have also been constructed using steel fibres.

Polypropylene and nylon fibres are found to be suitable to increase the impact strength. They possess very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to the flexural strength.

Asbestos is a mineral fibre and has proved to be most successful of all fibres as it can be mixed with Portland cement. Tensile strength of asbestos varies between 560 to 980 N/mm^2. The composite product called asbestos cement has considerably higher flexural strength than the Portland cement paste. For unimportant fibre concrete, organic fibres like coir, jute, canesplits are also used.

Glass fibre is a recent introduction in making fibre concrete. It has very high tensile strength 1020 to 4080 N/mm^2. Glass fibre which is originally used in conjunction with cement was found to be effected by alkaline condition of cement.

Carbon fibres perhaps posses very high tensile strength 2110 to 2815 N/mm^2 and Young's modulus. It has been reported that cement composite made with carbon fibre as reinforcement will have very high modulus of elasticity and flexural strength. The limited studies have shown good durability. The use of carbon fibres for structures like clading, panels and shells will have promising future.

Fibre reinforced concrete is the composite material containing fibres in the cement matrix in an orderly manner or randomly distributed manner. **Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibres, which is largely dependent on the type of fibre, fibre geometry, fibre content, orientation and distribution of the fibres, mixing and compaction techniques of concrete, and size and shape of the aggregate.** These factors are briefly discussed below:

Relative Fibre Matrix Stiffness

The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer. Low modulus of fibers such as nylons and polypropylene are, therefore, unlikelyto give strength improvement, but they help in the absorption of large energy and, therefore, impart greater degree of toughness and resistance to impact. High modulus fibres such as steel, glass and carbon impart strength and stiffness to the composite.

Interfacial bond between the matrix and the fibres also determine the effectiveness of stress transfer, from the matrix to the fibre. A good bond is essential for improving tensile strength of the composite. The interfacial bond could be improved by larger area of contact, improving the frictional properties and degree of gripping and by treating the steel fibres with sodium hydroxide or acetone.

Volume of Fibres

The strength of the composite largely depends on the quantity of fibres used in it. Figure shows the effect of volume on the toughness and strength. It can be seen from Figure that the increase in the volume of fibres, increase approximately linearly, the tensile strength and toughness of the composite. Use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.

GUNITING & SHOTCRETE

By Vikas Devarth

Guniting is known as shotcreting sometimes, the nomenclature is generally adopted when coarse aggregate is also used. Basically the technique comprises applying cement mortar under high pressure directly on a surface. The high pressure application ensures dense surface of high strength and low permeability. Besides, the technique ensures good bond between old surface and low permeability, better bond between old concrete and fresh concrete, when adequate care is taken in surface preparation, mix design and application.

Gunite and shotcrete are both applied in much the same way; however, there are subtle differences in the general makeup of both materials, but mostly it is the application that varies. Both are cement, sand and aggregate mixes (concrete), but it is how they are mixed and shot out that is different. Gunite and shotcrete are both force applied concrete applications and shot at sprayed or blasted onto a surface.

Gunite is cement, mostly sand and small aggregate (concrete) shot through a hose in its dry form and then mixed with water at the end of the nozzle on the jobsite.

Shotcrete is pre-mixed concrete pumped in its wet form through a hose and sprayed, shot or blasted onto a surface.

With both types of applications, the skill of the operator is just as important as the choice of the material being used.

Gunite is typically described as the faster setting, stronger of the two material types and is considered to be the best material to be used for swimming pools and similar applications. "Because gunite is a dry mix and the water is added at the end of the hose nozzle, it gives complete control to the applicator. Gunite applicators can adjust the mix and make it as dry or wet as they want or need. By reducing the water content you can make the material stick better which is great for walls, waterfalls, and vertical applications. Since gunite is moving at a high velocity as it comes out of the hose, this can result in a higher PSI (pounds per square inch) application, packing material tighter than shotcrete could ever do. By reducing water in concrete it makes it even stronger so you can ultimately achieve a very strong concrete pool.

GUNITING & SHOTCRETE

By Vikas Devarth

Guniting is a particularly useful method for repairing R.C.C. columns and beams which have cracked or where reinforcement has deteriorated. Formwork is not usually necessary, and even intricate shapes can be successfully constructed.

The total thickness of shotcrete should not be less than about 75 mm so that a clear cover of 25 mm to the additional reinforcement in the case of columns is ensured. The average thickness of shotcrete should be 50 mm, if no additional reinforcement is provided. Careful guniting ensures long service life of structures.

Properly applied shotcrete is a structurally sound and durable construction material which exhibits excellent bonding characteristics to existing concrete, rock, steel, and many other materials. It can have high strength, low absorption, good resistance to weathering, and resistance to some forms of chemical attack. Many of the physical properties of sound shotcrete are comparable or superior to those of conventional concrete or mortar having the same composition. Improperly applied shotcrete may create conditions much worse than the untreated condition.

ADVANTAGES OF SHOTCRETE

Shotcrete is used in lieu of conventional concrete, in most instances, for reasons of cost or convenience. Shotcrete is advantageous in situations when formwork is cost prohibitive or impractical and where forms can be reduced or eliminated, access to the work area is difficult, thin layers or variable thicknesses are required, or normal casting techniques cannot be employed. Additional savings are possible because shotcrete requires only a small, portable plant for manufacture and placement. Shotcreting operations can often be accomplished in areas of limited access to make repairs to structures.

GUNITING & SHOTCRETE

By Vikas Devarth

APPLICATIONS OF SHOTCRETE:

A) REPAIR: Shotcrete can be used to repair the damaged surface of concrete, wood, or steel structures provided there is access to the surface needing repair. The following examples indicate a few ways in which shotcrete can be used in repairs:

- ✓ Bridges. Shotcrete repair can be used for bridge deck rehabilitation, but it has generally been uneconomical for major full-thickness repairs. It is very useful, however, for beam repairs of variable depths, caps, columns, abutments, wingwalls, and underdecks from the standpoint of technique and cost.
- ✓ Buildings. In building repairs, shotcrete is commonly used for repair of fire and earthquake damage and deterioration, strengthening walls, and encasing structural steel for fireproofing. The repair of structural members such as beams, columns, and connections is common for structures damaged by an earthquake.
- ✓ Marine structures. Damage to marine structures can result from deterioration of the concrete and of the reinforcement. Damaging conditions are corrosion of the steel, freezing and thawing action, impact loading, structural distress, physical abrasion from the action of waves, sand, gravel, and floating ice, and chemical attack due to sulfates. These problems can occur in most marine structures such as bridge decks, piles, pile caps, beams, piers, navigation locks, guide walls, dams, powerhouses, and discharge tunnels. In many cases, shotcrete can be used to repair the deteriorated surfaces of these structures.
- ✓ Spillway surfaces. Surfaces subject to high velocity flows may be damaged by cavitation erosion or abrasion erosion. Shotcrete repairs are advantageous because of the relatively short outage necessary to complete the repairs.

B) UNDERGROUND EXCAVATIONS: For the most part, shotcrete is used in underground excavations in rock; but on occasion, it has been successfully used in the advancement of tunnels through altered, cohesionless, and loose soils.

GUNITING & SHOTCRETE

By Vikas Devarth

Typical underground shotcrete applications range from supplementing or replacing conventional support materials such as lagging and steel sets, sealing rock surfaces, channeling water flows, and installing temporary support and permanent linings.

C) SLOPE & SURFACE PROTECTION: Shotcrete is often used for temporary protection of exposed rock surfacesthat will deteriorate when exposed to air. Shotcrete is also used to permanently cover slopes or cuts that may erode in time or otherwise deteriorate. Slope protection should be properly drained to prevent damage from excessive uplift pressure. Application of shotcrete to the surface of landfills and other waste areas is beneficial to prevent surface water infiltration.

D) NEW STRUCTURES: Shotcrete is not necessarily the fastest method of placing concrete on all jobs, but where thin sections and large areas are involved, shotcreting can be used effectively to save time. The following paragraphs describe some of the applications involved with construction of new structures.

- ✓ Pools and tanks. Shotcrete has been used extensively to construct concrete swimming pools. More recently, large aquariums have been constructed using shotcrete.
- ✓ Shotcrete floors and walls. Shotcrete floors in tanks and pools on well compacted subbase or on undisturbed earth have generally given excellent service. Vertical and overhead construction for walls, slabs,columns, and other structural members has been frequently shotcreted.
- ✓ Shotcrete domes. Construction techniques using inflatable air-forming systems have made the construction of shotcrete shells or domes practical. These large structures have been used for residential housing, warehousing, bridge, and culvert applications.

DRY MIX SHOTCRETE:

The cementitious material and aggregate are thoroughly mi...
bagged in a dry condition ...

GUNITING & SHOTCRETE

By Vikas Devarth

The mixture is normally fed to a pneumatically operated gun which delivers a continuous flow of material through the delivery hose to the nozzle. The interior of the nozzle is fitted with a water ring which uniformly injects water into the mixture as it is being discharged from the nozzle and propelled against the receiving surface. Dry-mix shot Crete suffers high dust generation and rebound losses varying from about 15 % upto 50 %.

WET MIX SHOTCRETE:

...ntitious material, aggregate, water, and admixtures are ...tional concrete. The mixed

MATERIALS FOR REPAIR

By Vikas Devarth

Depending on the proportions of the expansive-cement component and Portland cement component, the resulting concrete either expands as it cures or does not change volume at all. Generally 8 to 20 parts of suplho-aluminate clinker are mixed with 100 parts of the Portland cement & 15 parts of stabilizer.

USES OF EXPANSIVE CEMENT:

- Utilization of the expansive cement that expands as the concrete cures is aimed at making self-stressing concrete members. After taking an initial set, the concrete expands, stretching reinforcing steel embedded in it. The tension imparted to reinforcing bars or strands precompresses the concrete member by reaction just as mechanical pretensioning and post-tensioning systems precompress conventional prestressed concrete. At present, self-stressing concrete, though still conservatively limited to a precompression of about 300 psi, should find applications in precast concrete pipe, precast architectural panels, highway pavement, sidewalks, and tunnel linings.
- The other formulation of expansive cement produces concrete that does not shrink. Just enough expansive component is blended and ground with portland cement to produce an expansive cement to compensate for the normal shrinkage that portland cement concrete undergoes as it cures. It should find application in thinshell concrete roofs, folded-plate concrete roofs, and thin concrete roof slabs, with the possibility of eliminating the need for additional waterproofing, and in bridge deck or bridge-deck wearing course construction, with the promise of reducing or eliminating cracks and hence deterioration.

At the present time, expansive cements are mostly used for pavements, and also for structural members and pipe

POLYMER CONCRETE

Although its physical properties and relatively low cost make it the most widely used construction material, conventional Portland cement concrete has a number of limitations, such as low flexural strength, low failure strain, susceptibility to frost damage and low resistance to chemicals. These drawbacks are well recognized by the engineer and can usually be allowed for in most applications. In certain situations, these problems can be solved by using materials which contain an organic polymer or resin (commercial polymer) instead of or in conjunction with Portland cement. These relatively new materials offer the advantages of higher strength, improved durability, good resistance to corrosion and reduced water permeability. There are three principal classes of composite materials containing polymers: polymer impregnated concrete; polymer cement concrete and polymer concrete.

Polymer concrete is part of group of concretes that use polymers to supplement or replace cement as a binder. The types include polymer-impregnated concrete, polymer concrete, and polymer-Portland-cement concrete. Polymer concrete (PC) is a composite material in which the binder consists entirely of a synthetic organic polymer. It is variously known as synthetic resin concrete, plastic resin concrete or simply resin concrete. Because the use of a polymer instead of Portland cement represents a substantial increase in cost, polymers should be used only in applications in which the higher cost can be justified by superior properties, low labor cost or low energy requirements during processing and handling. Polymer concrete composites have generally good resistance to attack by chemicals and other corrosive agents; have very low water sorption properties, good resistance to abrasion and marked freeze-thaw stability. Also, the greater strength of polymer concrete in comparison to that of Portland cement concrete permits the use of up to 50 percent less material. This puts polymer concrete on a competitive basis with cement concrete in certain special applications.

WHAT ARE POLYMERS: Polymers are chemical compounds formed by a chemical reaction in which relatively simple chemical units, called monomers, are reacted together to form larger molecules that contain repeating structural units of the original molecule. Because polymers are relatively expensive, they are often extended by the addition of other lower cost materials to form composite material such as polymer concrete (PC), polymer cement concrete (PCC), and polymer-impregnated concrete (PIC).

ADVANTAGES OF POLYMER CONCRETE:

- Rapid curing at ambient temperatures
- High tensile, flexural, and compressive strengths
- Good adhesion to most surfaces
- Good long-term durability with respect to freeze and thaw cycles
- Low permeability to water and aggressive solutions
- Good chemical resistance
- Good resistance against corrosion
- Lightweight
- May be used in regular wood and steel formwork
- May be vibrated to fill voids in forms
- Allows use of regular form-release agents
- Dialectric

DISADVANTAGES OF POLYMER CONCRETE:

Some safety issues arise out of the use of polymer concrete. The monomers can be volatile, combustible, and toxic. Initiators, which are used as catalysts, are combustible and harmful to human skin.

USES OF POLYMER CONCRETE:

Polymer concrete may be used for new construction or repairing of old concrete. The adhesion properties of polymer concrete allow patching for both polymer and cementitious concretes. The low permeability of polymer concrete allows it to be used in swimming pools, sewer pipes, drainage channels, electrolytic cells for base metal recovery, and other structures that contain liquids. It can also be used as a replacement for asphalt pavement, for higher durability and higher strength.

TYPES OF POLYMERS:

1. Epoxies.

A. Typical applications.

- ✓ Bonding fresh concrete to old concrete
- ✓ Bonding old concrete to old concrete
- ✓ Bonding other materials to concrete
- ✓ Patches
- ✓ Protective coating
- ✓ Overlays
- ✓ Sealing water leakage(injection)
- ✓ Structural restoration of cracks (injection)
- ✓ Anchor grouting
- ✓ Grouting preplaced aggregate

B. Physical properties.

- ✓ Vary with formulation
- ✓ Vary with temperature
- ✓ Coefficient of thermal expansion greater than that of concrete

C. Advantages.

- ✓ Good adhesion
- ✓ High compressive/tensile/flexural strength
- ✓ Excellent resistance to cycles of freezing and thawing
- ✓ Good resistance to chemical attack
- ✓ Good wear resistance
- ✓ Impermeable
- ✓ Minimal shrinkage
- ✓ Excellent radiation resistance
- ✓ ome formulations are water compatible
- ✓ Viscosity can be varied

- ✓ Dimensionally stable

D. **Disadvantages or limitations.**
- ✓ Physical properties different from concrete
- ✓ Adversely affected by improper proportioning and lack of mixing
- ✓ Can cause allergic reaction in workers
- ✓ High exothermic reaction when used neat
- ✓ Limited thickness
- ✓ High coefficient of thermal expansion
- ✓ Physical characteristics are reduced at elevated temperature
- ✓ Higher creep than that of concrete
- ✓ Curing time dependent upon application temperature
- ✓ Some systems cannot be used in a moist environment

2. **Polyesters.**

A. **Typical applications.**
- ✓ Protective coatings
- ✓ Anchoring
- ✓ Adhesive bonder or sealer
- ✓ Floor coatings
- ✓ Sealer for epoxy injection
- ✓ Binder for polymer mortar
- ✓ Binder for fiberglass
- ✓ Thin overlays

B. **Physical properties.**
- ✓ Vary with formulation
- ✓ Vary with temperature
- ✓ Coefficient of thermal expansion greater than that of concrete

C. **Advantages.**

- ✓ Good chemical resistance
- ✓ Easy to use
- ✓ Good physical properties (some formulations)
- ✓ Good wear resistance
- ✓ Resistant to staining
- ✓ Impact resistance similar to concrete
- ✓ Impermeable

D. Disadvantages or limitations.

- ✓ Higher shrinkage and expansion than that of concrete
- ✓ Relatively poor adhesive properties (some formulations)
- ✓ Hydrolysis
- ✓ High exothermic reaction
- ✓ Strong odor

3. Urethanes.

A. Typical applications.

- ✓ Waterproofing
- ✓ Water control grouting (moist cured)
- ✓ Protective coating
- ✓ Insulation
- ✓ Floor coating Anchor

B. Physical properties.

- ✓ Vary with formulation
- ✓ Vary with temperature
- ✓ Coefficient of thermal expansion greater than that of concrete

C. Advantages.

- ✓ Easy to use
- ✓ Good chemical resistance
- ✓ Good wear resistance

- ✓ Impermeable
- ✓ Minimal shrinkage
- ✓ Adequate working time

D. Disadvantages or limitations.

- ✓ Curing affected by humidity
- ✓ Sensitive to temperature differentials
- ✓ Stability questionable under certain conditions

4. Methyl-methacrylate (MMA).

A. Typical applications.

- ✓ Polymer concrete
- ✓ Patches
- ✓ Impregnation
- ✓ Overlays
- ✓ Thin toppings
- ✓ Precast elements

B. Physical properties.

- ✓ Vary with formulation
- ✓ Vary with temperature
- ✓ Low viscosity
- ✓ Coefficient of thermal expansion greater than that of concrete

C. Advantages.

- ✓ Rapid strength gain
- ✓ Good bond to dry surface
- ✓ Easy to mix
- ✓ Available as prepackaged material
- ✓ High compressive/flexural/shear/tensile strength
- ✓ Impermeable to water
- ✓ Excellent resistance to acid
- ✓ Good abrasion resistance

D. Disadvantages or limitations.

- ✓ Expensive
- ✓ Hazardous (flammable)
- ✓ Sharp pungent odor
- ✓ Moisture sensitive (aggregate or surface must be dry)
- ✓ Higher expansion or shrinkage than that of concrete

5. Styrene butadiene rubber (SBR).

A. Typical applications.

- ✓ Bond fresh concrete to old concrete
- ✓ Patches and overlays
- ✓ Areas subjected to mild chemical attack

B. Physical properties.

- ✓ Vary according to concentration

C. Advantages.

- ✓ Good adhesion
- ✓ Good chemical resistance with some materials
- ✓ Improves flexural/compressive/tensile bond strength
- ✓ Reduces permeability
- ✓ Good stability and aging characteristics
- ✓ Unaffected by addition of calcium chloride
- ✓ Requires minimal curing

D. Disadvantages or limitations.

- ✓ Short working time
- ✓ Requires special equipment for dispensing in concrete
- ✓ Placing temperature must be above 5 degree Centigrade
- ✓ Discolors with age
- ✓ May coagulate if subjected to high temperatures
- ✓ Not stable with most air-entraining agents
- ✓ Wet cure and air dry can give different results
- ✓ Addition rates will affect strength
- ✓ Requires special finishing skill

MATERIALS FOR REPAIR

By Vikas Devarth

6. Polyvinyl acetate (PVA).

A. Typical applications.

- ✓ Adhesive for patches or overlays
- ✓ Concrete or mortar additive
- ✓ Adhesive bond coat
- ✓ Bonding agent for plaster

B. Physical properties.

- ✓ Vary according to concentration

C. Advantages.

- ✓ Easy to use
- ✓ Stable under sunlight
- ✓ Improved aging characteristics

D. Disadvantages or limitations.

- ✓ Must be protected before drying (some formulations)
- ✓ Poor resistance to cycles of freezing and thawing

POLYMER IMPREGNATED CONCRETE

Polymer impregnated concrete is made by impregnation of pre-cast hardened Portland cement concrete with low viscosity monomers (in either liquid or gaseous form) that are converted to solid polymer under the influence of physical agents (ultraviolet radiation or heat) or chemical agents (catalysts). It is produced by drying conventional concrete; displacing the air from the open pores (by vacuum or monomer displacement and pressure); saturating the open pore structure by diffusion of low viscosity monomers or a pre-polymer-monomer mixture and in-situ polymerization of the monomer or pre-polymer-monomer mixture, using the most economical and convenient method (radiation, heat or chemical initiation). **The important feature of this material is that a large proportion of the void volume is filled with polymer, which forms a continuous reinforcing network.** The concrete structure may be impregnated to varying depths or in the surface layer only, depending on whether increased strength and/or durability is sought. **The main disadvantages of polymer impregnated concrete products are their** relatively high cost, as the monomers used in impregnation are expensive and the fabrication process is more complicated than for unmodified concrete.

Impregnation of concrete results in a remarkable improvement in tensile, compressive and impact strength, enhanced durability and reduced permeability to water and aqueous salt solutions such as sulfates and chlorides. The compressive strength can be increased from 35 MPa to 140 MPa, the water absorption can be reduced significantly. And the freeze-thaw resistance is considerably enhanced. The greatest strength can be achieved by impregnation of auto-claved concrete. This material can have a compressive-strength-to-density ratio nearly three times that of steel. Although its modulus of elasticity is only moderately greater than that of non-autoclaved polymer impregnated concrete, the maximum strain at break is significantly higher.

Acrylic monomer systems such as methyl methacrylate or its mixtures with acrylonitrile are the preferred impregnating materials, because they have low viscosity, good wetting properties, high reactivity, relatively low cost and result in products with superior properties.

Applications of concrete impregnated in depth in building and construction include structural floors, high performance structures, food processing buildings, sewer pipes, storage tanks for seawater, desalination plants and distilled water plants. Marine structures, wall panels, tunnel liners, prefabricated tunnel sections and swimming pools. Partially impregnated concrete is used for the protection of bridges and concrete structures against deterioration and repair of deteriorated building structures, such as ceiling slabs, underground garage decks and bridge decks.

POLYMER CEMENT CONCRETE

Polymer cement concrete is a modified concrete in which part (10 to 15% by weight) of the cement binder is replaced by a synthetic organic polymer. It is produced by incorporating a monomer, pre-polymer-monomer mixture, or a dispersed polymer (latex) into a cement-concrete mix. To effect the polymerization of the monomer or pre-polymer-monomer, a catalyst is added to the mixture. The process technology used is very similar to that of relatively high cost, as the monomers used in impregnation are expensive and the fabrication process is more complicated than for unmodified concrete .

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Modification of concrete with a polymer latex (colloidal dispersion of polymer particles in water) results in greatly improved properties, at a reasonable cost. Therefore, a great variety of latexes is now available for use in polymer cement concrete products and mortars. The most common latexes are based on poly (methyl methacrylate) also called acrylic latex, poly (vinyl acetate), vinyl chloride copolymers, poly (vinylidene chloride), (styrene-butadiene) copolymer, nitrile rubber and natural rubber. Each polymer produces characteristic physical properties. The acrylic latex provides a very good water-resistant bond between the modifying polymer and the concrete components, whereas use of latexes of styrene-based polymers results in a high compressive strength.

Generally, polymer cement concrete made with polymer latex exhibits excellent bonding to steel reinforcement and to old concrete. Its flexural strength and toughness are usually higher than those of unmodified concrete.

Generally, as the polymer forms a low modulus phase with the polymer cement concrete, the creep is higher than that of plain concrete. The drying shrinkage of polymer cement concrete is generally lower than that of conventional concrete; the amount of shrinkage depends on the water-to-cement ratio, cement content, polymer content and curing conditions. It is more susceptible to higher temperatures than ordinary cement concrete. For example, creep increases with temperature to a greater extent than in ordinary cement concrete, whereas flexural strength, flexural modulus and modulus of elasticity decrease. These effects are greater in materials made with elastomeric latex (e.g., styrene-butadiene rubber) than in those made with thermoplastic polymers (e.g., acrylic). Typically, at about 45°C, polymer cement concrete made with a thermoplastic latex retains only approximately 50 percent of its flexural strength and modulus of elasticity.

The main application of latex-containing polymer cement concrete is in floor surfacing, as it is non-dusting and relatively cheap. Because of lower shrinkage, good resistance to permeation by various liquids such as water and salt solutions, and good bonding properties to old concrete, it is particularly suitable for thin (25 mm) floor toppings, concrete bridge deck overlays, anti-corrosive overlays, concrete repairs and patching.

MATERIALS FOR REPAIR

By Vikas Devarth

SULPHUR INFILTRATED CONCRETE

Research has been done for the purpose of producing concretes with high strength at early ages at a price competitive with conventional concrete or cheaper. Expensive monomers that require high pressure to impregnate the concrete were ruled out. Instead, simple and effective procedures for using cheaper materials such as sulfur were sought.

Sulphur infiltrated concrete was developed as an economical alternative to POLYMER IMPREGNATED CONCRETE (PIC) to be used for higher strength & durable precast elements. Since Sulphur is considerably cheaper than polymers & the technique of impregnation is simpler, hence there is saving in cost.

Advantages: Sulphur impregnation has shown great improvement in strength. Physical properties have been found to improve by several hundred percent & large improvements in water impermeability & resistance to corrosion has also been achieved.

The concrete to be infiltrated should be produced using normal aggregates with aggregate/cement ratios between 3:1 to 5:1. The water/cement ratios should be high between 0.7 & 0.8. The size of coarse aggregates should be 10 mm & below. The fine aggregates should be of good quality. Sulphur also should be of high purity 99.9%.

USES OF SULPHUR INFILTRATED CONCRETE (SIC): The techniques of production of SIC are simple, inexpensive & effective. The attainment of strength in about 2 days makes this process all the more attractive.

As the high strength concrete can be achieved in a very short interval of time, SIC can be used for the manufacture of precast roofing elements, fencing posts, sewer pipes & railway sleepers. It can be used in industry, where high corrosion resistant concrete is required. Further it has been observed that SIC units are cheaper than normal concrete.

MATERIALS FOR REPAIR

By Vikas Devarth

DURABILITY OF SIC:

1. Satisfactory against FREEZING & THAWING, SEA WATER ATTACK, WETTING & DRYING CONDITIONS.
2. More durable in high concentrations of suphuric acid & hydrochloric acid
3. Strength properties are not affected when exposed to short term temperature upto 100 degree centigrade.
4. Increased abrasion resistance. The sulphur filling the pores of the concrete provide an uninterrupted path for heat flow, resulting in increased thermal conductivity over that of normal dry concrete.
5. Provides a corrosive protection cover to the embedded steel

FERRO-CEMENT

The term ferrocement is most commonly applied to a mixture of Portland cement and sand reinforced with layers of woven or expanded steel mesh and closely spaced small-diameter steel rods rebar. It can be used to form relatively thin, compound curved sheets to make hulls for boats, shell roofs, water tanks, etc. It has been used in a wide range of other applications including sculpture and prefabricated building components.

The term "ferrocement" was given to this product by its inventor in France, Joseph Monier. Ferro concrete has relatively good strength and resistance to impact. When used in house construction in developing countries, it can provide better resistance to fire, earthquake, and corrosion than traditional materials, such as wood, adobe and stone masonry. It has been popular in developed countries for yacht building because the technique can be learned relatively quickly, allowing people to cut costs by supplying their own labor.

It is well known that conventional RCC elements are heavy, brittle, develop cracks & cannot be repaired satisfactorily if damaged. The reinforcement is likely to be corroded. Due to these shortcomings of the normal reinforced concrete, Ferro-cement can be considered as one of its substitutes in many situations.

Essentially Ferro-cement is a form of reinforced concrete, but it differs from the conventional type of reinforced concrete. The reinforcement used in it consists of closely spaced, multiple layers of wire mesh or fine rods completely surrounded by cement mortar. Ferro-cement is much thinner than reinforced concrete & the mesh can be formed in any shape without a conventional form. Then it can be plastered or motared by any method

MATERIALS USED: The wire mesh is usually 0.5 to 1.0 mm dia wire at 5 mm to 10 mm spacing & cement mortar is of cement sand ratio 1:2 to 1:3 with water cement ratio 0.4 to 0.45.

The ferrocement elements are usually of the order of 2 to 3 cms in thickness with 2 to 3 mm external cover to reinforcement.

The steel content varies between 300 to 500 kg per cubic metre of the mortar.

ADVANTAGES OF FERRO-CEMENT:

- ✓ The advantages of a well built ferro concrete construction are the low weight, maintenance costs and long lifetime in comparison with purely steel construction.
- ✓ When a ferro concrete sheet is mechanically overloaded, it will tend to fold instead of break or crumble like stone or pottery. So it is not brittle. As a container, it may fail and leak but possibly hold together.
- ✓ Easy repair ability , non-corrosive nature & easy mouldability to any shape.
- ✓ Highly suitable for precast products because of its easy adaptability to prefabrication & lesser dead weight of the units cast.

DISADVANTAGES OF FERRO-CEMENT: The disadvantage of ferro concrete construction is the labor intensive nature of it, which makes it expensive for industrial application in the western world. In addition, threats to degradation (rust) of the steel components is a possibility if air voids are left in the original construction, due to too dry a mixture of the concrete being applied, or not forcing the air out of the structure while it is in its wet stage of construction, through vibration, pressurized spraying techniques, or other means. These air voids can turn to pools of water as the cured material absorbs moisture. If the voids occur where there is untreated steel, the steel will rust and expand, causing the system to fail.

APPLICATIONS OF FERRO-CEMENT:

- **MARINE APPLICATIONS:** construction of Boats, fishing vessels, barrages, docks, floating buoys, water & fuel tanks. Here it is used for water tightness, impact resistance ,small thickness & light weight.
- **WATER SUPPLY & SANITATION APPLICATION:** water tanks, sedimentation tanks, sanitary tanks.
- **AGRICULTURAL APPLICATIONS:** grain storage bins, silos, water tanks, pipes, irrigation channels.
- **HOUSING APPLICATIONS:** mosque domes, shelters, precast housing elements, corrugated roofing sheets, water tanks, repair & rehabilitation of existing houses.
- **MAN HOLE COVER MANUFACTURE:** Ferrocement manholes are 1/10 the cost of cast iron covers.
- **RURAL ENERGY APPLICATIONS:** Biogas digestors, Biogas holders, incinerators & panels for solar energy collectors.

NON DESTRUCTIVE TESTING

by Vikas Devarth

VISUAL INSPECTION

Visual testing is probably the most important of all non-destructive tests. It can often provide valuable information to the well trained eye. Visual features may be related to workmanship, structural serviceability, and material deterioration and it is particularly important that the engineer is able to differentiate between the various signs of distress which may be encountered. These include for instance, cracks, pop-outs, spalling, disintegration, colour change, weathering, staining, surface blemishes and lack of uniformity. Extensive information can be gathered from visual inspection to give a preliminary indication of the condition of the structure and allow formulation of a subsequent testing programme. The visual inspection however should not be confined only to the structure being investigated. It should also include neighbouring structures, the surrounding environment and the climatic condition. This is probably the most difficult aspect of the whole structural investigation or any diagnostic works since what appears obvious to one may not be so to another. The importance and benefits of a visual survey should not be underrated. Often the omission of what appears to be insignificant evidence can lead to a wrong conclusion being made.

SCHMIDT'S REBOUND HAMMER TEST

The rebound hammer method could be used for :

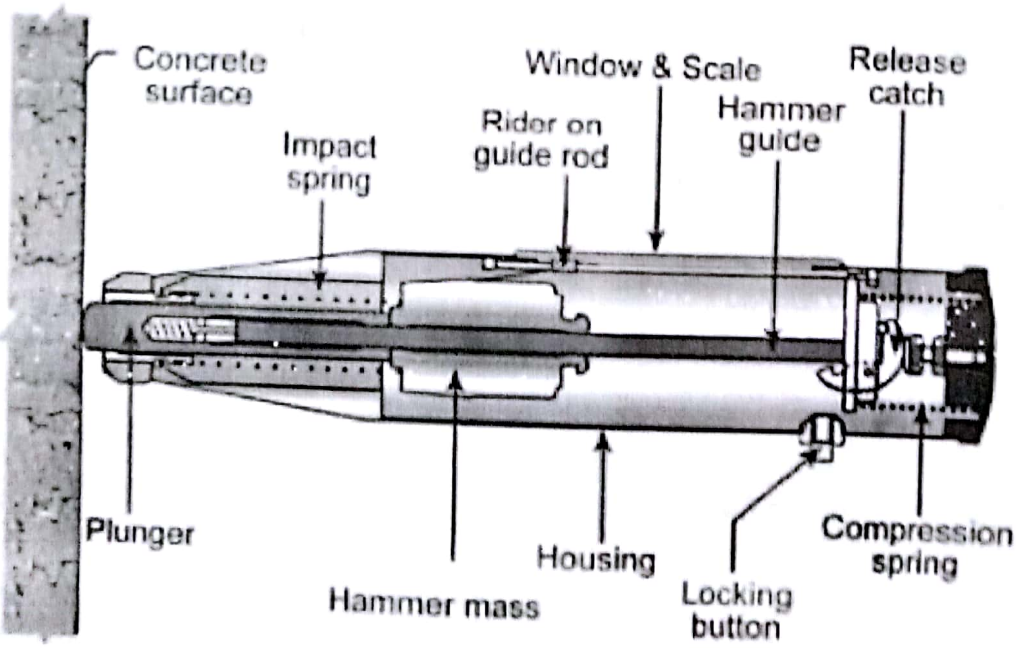
- Assessing the compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength
- Assessing the uniformity of the concrete
- Assessing the quality of concrete in relation to the standard requirements
- Assessing the quality of one element of concrete in relation to another.

NON DESTRUCTIVE TESTING

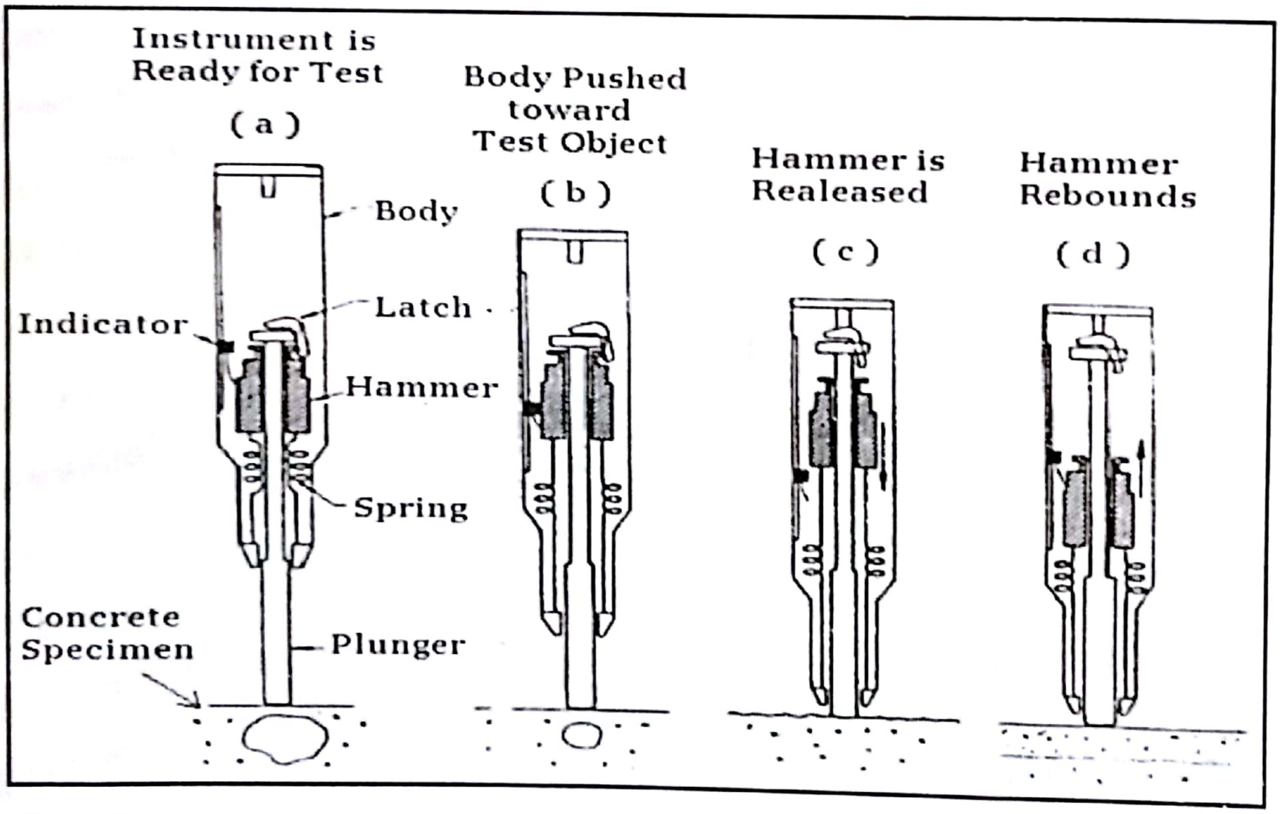
by Vikas Devarth

Principle of test: The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface upon which it impinges. When the plunger of the rebound hammer pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depend upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

Working of rebound hammer: A schematic cut way view of schmidt rebound hammer is shown in figure. The hammer weight about 1.8 kg., is suitable for use both in a laboratory and in the field. When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete.



The rebound distance is measured on a graduated scale and is designated as rebound number. Basically, the rebound distance depends on the value of kinetic energy in the hammer, prior to impact with the shoulder of the plunger and how much of that energy is absorbed during impact. The energy absorbed by the concrete depends on the stress-strain relationship of concrete. Thus, a low strength low stiffness concrete will absorb more energy than high strength concrete and will give a lower rebound number.



Limitations: Although the rebound hammer provides a quick inexpensive means of checking the uniformity of concrete, it has serious limitations and these must be understood clearly for interpretation of test results.

Factors affecting rebound number

The results of Schmidt rebound hammer are significantly influenced by the following factors:

1. Smoothness of the test surface

Hammer has to be used against a smooth surface, preferably a formed one. Open textured concrete cannot therefore be tested. If the surface is rough, e.g. a trowelled surface, it should be rubbed smooth with a carborundum stone.

NON DESTRUCTIVE TESTING

by Vikas Devarth

2. Size, shape and rigidity of the specimen

If the concrete does not form part of a large mass any movement caused by the impact of the hammer will result in a reduction in the rebound number. In such cases the member has to be rigidly held or backed up by a heavy mass.

3. Age of the specimen

For equal strengths, higher rebound numbers are obtained with a 7 day old concrete than with a 28 day old. Therefore, when old concrete is to be tested in a structure a direct correlation is necessary between the rebound numbers and compressive strengths of cores taken from the structure. Rebound testing should not be carried out on low strength concrete at early ages or when the concrete strength is less than 7 MPa since the concrete surface could be damaged by the hammer.

4. Surface and internal moisture conditions of concrete

The rebound numbers are lower for well-cured air dried specimens than for the same specimens tested after being soaked in water and tested in the saturated surface dried conditions. Therefore, whenever the actual moisture condition of the field concrete or specimen is unknown, the surface should be pre-saturated for several hours before testing. A correlation curve for tests performed on saturated surface dried specimens should then be used to estimate the compressive strength.

5. Type of coarse aggregate

Even though the same aggregate type is used in the concrete mix, the correlation curves can be different if the source of the aggregate is different.

6. Type of cement

High alumina cement can have a compressive strength 100% higher than the strength estimated using a correlation curve based on ordinary Portland cement. Also, super sulphated cement concrete can have strength 50% lower than ordinary Portland cement.

7. Carbonation of the concrete surface

In older concrete the carbonation depth can be several millimeters thick and, in extreme cases, up to 20 mm thick. In such cases the rebound numbers can be up to 50% higher than those obtained on an uncarbonated concrete surface.

Influence of these factors has different magnitudes. Hammer orientation will also influence the measured values, although correction factors can be used to allow for this effect.

Precautions to be taken while using rebound hammer: The following precautionary measures are taken while using the rebound hammer which may give rise to minimize error

- The surface on which the hammer strikes should be smooth and uniform. Moulded faces in such cases may be preferred over the Trowelled faces.
- The test hammer should not be used within about 20 mm from the edge of the specimen.
- Rebound hammer should not be used over the same points more than once.
- The rebound test must be conducted closely placed to test points, on at least 10 to 12 locations while taking the average extremely high and low values of the index number should be neglected.

NON-DESTRUCTIVE TESTING OF CONCRETE BY ULTRASONIC PULSE VELOCITY METHOD

The ultrasonic pulse velocity method is used for non-destructive testing of plain, reinforced and prestressed concrete whether it is precast or cast in-situ

Objects: The main objects of the ultrasonic pulse velocity method are to establish

- The Homogeneity of the Concrete
- The Presence of Cracks, Voids and other Imperfections

- Changes in the Structure of the Concrete Caused by the Exposure Condition, Corrosion, Wear etc. which may occur with time,
- The Quality of the Concrete in Relation to the Specified Standard Requirements.
- The Quality of One Element of Concrete in Relation to the Another.
- The Values of the Dynamic Elastic Modulus of the Concrete.

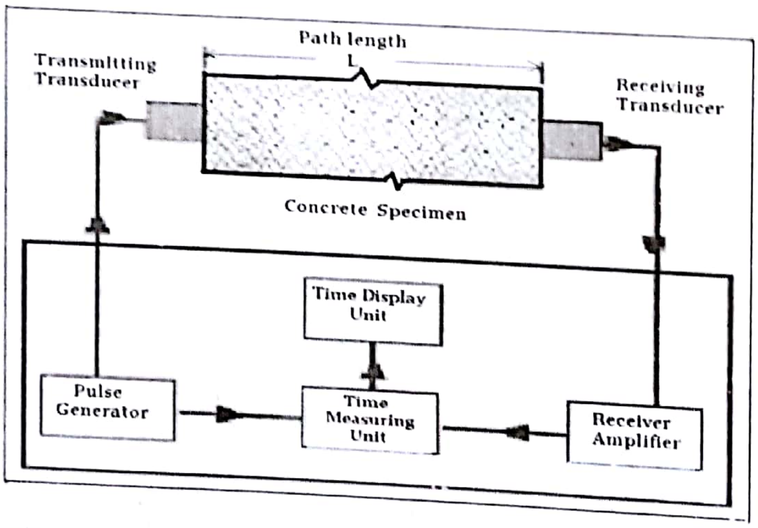
Principle: This is one of the most commonly used method in which the ultrasonic pulses generated by electro-acoustical transducer are transmitted through the concrete. In solids, the particles can oscillate along the direction of sound propagation as longitudinal waves or the oscillations can be perpendicular to the direction of sound waves as transverse waves. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (Compressional), shear (Transverse) and surface (Rayleigh) waves. This transducers convert electrical signals into mechanical vibrations (transmit mode) and mechanical vibration into electrical signals (receive mode). The travel time is measured with an accuracy of +/- 0.1 microseconds. Transducers with natural frequencies between 20 kHz and 200 kHz are available, but 50 kHz to 100 kHz transducers are common.

The receiving transducer detects the onset of the longitudinal waves which is the fastest wave. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic property. Under certain specified conditions, the velocity and strength of concrete are directly related. The common factor is the density of concrete; a change in the density results in a change in a pulse velocity, likewise for a same mix with change in density, the strength of concrete changes. Thus lowering of the density caused by increase in water-cement ratio decreases both the compressive strength of concrete as well as the velocity of a pulse transmitted through it.

Pulse Velocity method is a convenient technique for investigating structural concrete. The underlying principle of assessing the quality of concrete is that comparative higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good.

In case poorer quality of concrete, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the material and the mix proportion of the concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity.

Transducers: Piezoelectric and magnetostrictive types of transducers are available in the range of 20 kHz to 150 kHz of natural frequency. Generally, high frequency transducers are preferable for short path length and low frequency transducers for long path lengths. Transducers with a frequency of 50 to 60 kHz are useful for most all-round applications.



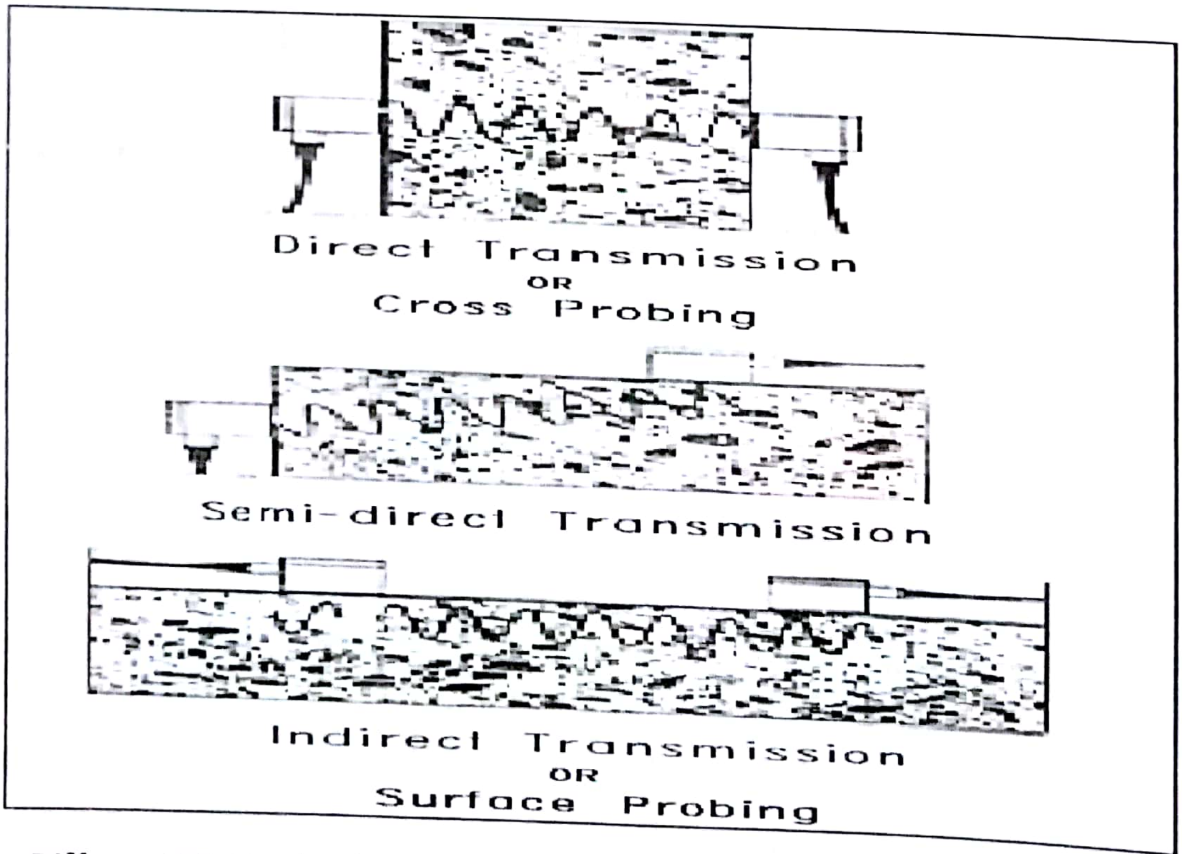
Schematic Diagram of Ultrasonic Pulse Velocity Method

There are three possible ways of measuring pulse velocity through concrete :

a. **Direct Transmission (Cross Probing) through Concrete** : In this method transducers are held on opposite face of the concrete specimen under test as shown in fig. The method is most commonly used and is to be preferred to the other two methods because this results in maximum sensitivity and provides a well defined path length.

b. **Semi-direct Transmission through Concrete :** Sometimes one of the face of the concrete specimen under test is not accessible, in that case we have to apply semi-direct method as shown in fig. In this method, the sensitivity will be smaller than cross probing and the path length is not clearly defined.

c. **Indirect Transmission (Surface Probing) through Concrete :** This method of pulse transmission is used when only one face of concrete is accessible. Surface probing is the least satisfactory of the three methods because the pulse velocity measurements indicate the quality of concrete only near the surface and do not give information about deeper layers of concrete. The weaker concrete that may be below a strong surface can not be detected. Also in this method path length is less well defined. Surface probing in general gives lower pulse velocity than in the case of cross probing and depending on number of parameters.



Different Methods of Propagating Ultrasonic Pulses through Concrete

NON DESTRUCTIVE TESTING

by Vikas Devarth

Velocity Criteria For Concrete Quality Grading
As per Table 2 of IS 13311 (Part 1) : 1992

Sr. No.	Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

Combined methods: There are different non-destructive testing methods which can be broadly classified as those which measure the overall quality of the concrete, dynamic or vibration methods like resonance frequency and ultrasonic pulse velocity tests and those which involve measurement of parameters like surface hardness, rebound, penetration, pull-out strength etc. are believed to be indirectly related to the compressive strength of concrete. In addition, radiographic, radiometric, nuclear, magnetic and electrical methods are also available. Since such non-destructive tests are at best indirect methods of monitoring the particulars, characteristics of concrete. The measurements are influenced by materials, concrete mix proportions and environmental factors. When the data of the materials and mix proportions used in the construction are not available, as is often the case. In view of the limitation of the methods for the predicting the strength of concrete in the structure, IS 13311 (Part 1) : 1992 Code has suggested to use combined method of ultrasonic pulse velocity and rebound hammer methods to alleviate the errors arising out of influence of materials, concrete mix proportions and environmental parameters on the respective measurement.

The use of more than one methods are capable of providing useful information and statically improved accuracy for estimation of in situ strength of concrete.

NON DESTRUCTIVE TESTING

by Vikas Devarth

PENETRATION RESISTANCE OR WINDSOR PROBE TEST

The Windsor probe, like the rebound hammer, is a hardness tester, and its inventors' claim that the penetration of the probe reflects the precise compressive strength in a localized area is not strictly true. However, the probe penetration does relate to some property of the concrete below the surface, and, within limits, it has been possible to develop empirical correlations between strength properties and the penetration of the probe.

The Windsor probe consists of a powder-actuated gun or driver, hardened alloy steel probes, loaded cartridges, a depth gauge for measuring the penetration of probes, and other related equipment. As the device looks like a firearm it may be necessary to obtain official approval for its use in some countries. The probes have a tip diameter of 6.3 mm, a length of 79.5 mm, and a conical point. Probes of 7.9 mm diameter are also available for the testing of concrete made with lightweight aggregates. The rear of the probe is threaded and screws into a probe driving head, which is 12.7 mm in diameter and fits snugly into the bore of the driver. The probe is driven into the concrete by the firing of a precision powder charge that develops energy of 79.5 m kg. For the testing of relatively low strength concrete, the power level can be reduced by pushing the driver head further into the barrel.

APPLICATIONS OF WINDSOR PROBE TEST

Formwork removal

The Windsor probe test has been used to estimate the early age strength of concrete in order to determine when formwork can be removed. The simplicity of the test is its greatest attraction. The depth of penetration of the probe, based on previously established criteria, allows a decision to be made on the time when the formwork can be stripped.

As a substitute for core testing

If the standard cylinder compression tests do not reach the specified values or the quality of the concrete is being questioned because of inadequate placing methods or curing problems, it may be necessary to establish the in situ compressive strength of the concrete.

This need may also arise if an older structure is being investigated and an estimate of the compressive strength is required. In all those situations the usual option is to take a drill core sample since the specification will generally require a compressive strength to be achieved. It is claimed, however, that the Windsor probe test is superior to taking a core. With a core test, the area from which the cores are taken needs to be soaked for 40 h before the sample is drilled. Also the sample often has to be transported to a testing laboratory which may be some distance from the structure being tested and can result in an appreciable delay before the test result is known. Swamy and Al-Hamedreport that the Windsor probe estimated the wet cube strength to be better than small diameter cores for ages up to 28 days. For older concrete the cores estimated the strength better than the probe.

ADVANTAGES OF WINSDOR PROBE TEST

- ✓ The test is relatively quick and the result is achieved immediately provided an appropriate correlation curve is available.
- ✓ The probe is simple to operate, requires little maintenance except cleaning the barrel and is not sensitive to operator technique.
- ✓ Access is only needed to one surface.
- ✓ The correlation with concrete strength is affected by a relatively small number of variables.
- ✓ The test result is likely to represent the concrete at a depth of from 25 mm to 75 mm from the surface rather than just the property of the surface layer as in the Schmidt rebound test.

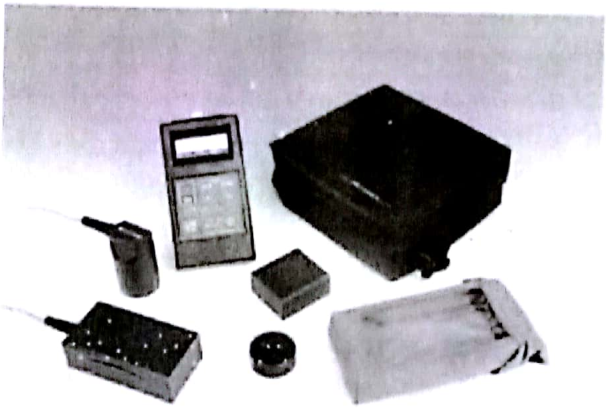
LIMITATIONS OF WINSDOR PROBE TEST

- ✓ The minimum acceptable distance from a test location to any edges of the concrete member or between two test locations is of the order of 150 mm to 200 mm.
- ✓ The minimum thickness of the member, which can be tested, is about three times the expected depth of probe penetration.
- ✓ The distance from reinforcement can also have an effect on the depth of probe penetration especially when the distance is less than about 100 mm.

NON-DESTRUCTIVE TECHNIQUES

By Vikas Devarth

COVERMETER TEST: This test is useful for the determination of concrete cover, location of embedded rebars & estimation of size of embedded rebars. The instrument is based on the magnetic technique & is calibrated for different purposes. The cover thickness is important from the point of view of estimation of initiation of corrosion. The location & estimation of bar diameter becomes useful in structures where there are no structural drawings available.



The basic principle is that the presence of steel affects magnetic field. An electromagnetic search probe is swept over the surface of the concrete under test. The presence of reinforcement within the range of the instrument is shown by movement of the indicator needle. When the probe is moved until the deflection of the needle is at a maximum, the bar in question is then parallel to the alignment of the probe and directly beneath it. The needle indicates the cover on the appropriate scale for the diameter of the reinforcing bar.

It is used for determining the presence, location and depth of rebars in concrete and masonry components. Advanced versions of covermeter can also indicate bar diameter when cover is known. It is moderately easy to operate. However, some training or experience is required to interpret the results.

The presence of closely spaced reinforcing bar, laps, transverse steel, metal tie, wires or aggregates with magnetic properties can give misleading results. The meter has several scales for different bar sizes, therefore the bar diameter must be known if a true indication of cover is to be obtained.

The maximum range of the instrument for practical purposes is about 100 mm. It does not give indication of the quality of concrete cover or the degree of protection afforded to the reinforcement.

GROUND PENETRATING RADAR: Radio frequency waves (0.5 to 2GHz) from radar transmitter are directed into the material. The waves propagate through the material until a boundary of different electrical characteristic is encountered. Then part of the incident energy is reflected and the remainder travels across the boundary at a new velocity. The reflected (echo) wave is picked up by a receiver. The transducer is drawn over a surface and forms a continuous profile of the material condition below. The equipment consists of a radar console, a graphic scanning recorder and a combined transmitting and receiving transducer.
It is capable of detecting a number of parameters in reinforced concrete structures:

- the location of reinforcement
- the depth of cover
- the location of voids
- the location of cracks
- in situ density
- moisture content variations

✓ It can be used to survey large areas rapidly for locating reinforcement, voids and cracks.

Results must be correlated to test results on samples obtained. **Any features screened by steel reinforcement will not be recorded. With increasing depth, low level signals from small targets are harder to detect due to signal attenuation. It is expensive to use and uneconomical for surveying small areas.**

NON-DESTRUCTIVE TECHNIQUES

By Vikas Devarth

PULL-OUT TEST (SEMI-DESTRUCTIVE): The test involves drilling a hole in which a standard threaded or wedge anchor is placed. This is then pulled until the concrete ruptures. With the help of calibration charts the maximum force gives an indication of the strength of concrete. Pullout devices can be inserted during casting of concrete.

- ✓ **It provides an estimation of the compressive and tensile strengths of hardened concrete.**

- ✓ **In-place strength of concrete can be measured quickly and appears to give good prediction of concrete strength.**

- ❖ Pullout devices must be preplanned and inserted during the construction stage, or inserted in hole drilled in hardened concrete. A cone of concrete may be pulled out, necessitating minor repairs. It can only test a limited depth of material. As it is a surface method, and in reinforced concrete could only be used to assess the concrete cover quality.

THERMOGRAPHY: An infrared scanning camera is used to detect variations in infrared radiation output of a surface. Thermal gradients arise because of difference in surface temperature between sound and unsound concrete. Hence delaminations in concrete surfaces can be detected. The temperature gradients are displayed on a TV screen in the form of colour thermal contours.

- ✓ **It can be used for detecting delamination, heat loss and moisture movement through concrete elements especially for flat surfaces.**

It is portable and permanent records can be made. Testing can be done without direct access to surface and large areas can be rapidly inspected using infrared cameras.

It is an expensive technique. Reference standards are needed and a heat source to produce thermal gradient in the test specimen may also be required. It is very sensitive to thermal interference from other heat sources. Moisture on the surfaces can also mask temperature differences.

SELF COMPACTING CONCRETE by Vikas Devarth

When large quantity of heavy reinforcement is to be placed in a reinforced concrete (RC) member, it is difficult to ensure that the formwork gets completely filled with concrete, that is, fully compacted without voids or honeycombs. Compaction by manual or by mechanical vibrators is very difficult in this situation. The typical method of compaction, vibration, generates delays and additional cost in the projects. Underwater concreting always required fresh concrete, which could be placed without the need to compaction; in such circumstances vibration had been simply impossible. This problem can now be solved with self-compacting concrete. This type of concrete flows easily around the reinforcement and into all corners of the formwork. Self-compacting concrete (SCC) describes a concrete with the ability to compact itself only by means of its own weight without the requirement of vibration. Self-compacting concrete also known as Self-consolidating concrete or self levelling concrete.

Self-compacting concrete is placed or poured in the same way as ordinary concrete but without vibration. It is very fluid and can pass around obstructions and fill all the nooks and corners without the risk of either mortar or other ingredients of concrete separating out, at the same time there are no entrapped air or rock pockets. This type of concrete mixture does not require any compaction and is saves time, labour and energy. The surface finish produced by self-compacting concrete is exceptionally good and patching will not be necessary.

ADVANTAGES OF SELF-COMPACTING CONCRETE

- ✓ Simple inclusion even in complicated formwork and tight reinforcement
- ✓ Higher installation performance since no compaction work is necessary which leads to reduced construction times, especially at large construction sites.
- ✓ Reduced noise pollution since vibrators are not necessary.

SELF COMPACTING CONCRETE by Vikas Devarth

- ✓ Higher and more homogenous concrete quality across the entire concrete cross-section, especially around the reinforcement.
- ✓ Improved concrete surfaces (visible concrete quality).
- ✓ Typically higher early strength of the concrete so that formwork removal can be performed more quickly.
- ✓ be placed at a faster rate with no mechanical vibration and less screeding, resulting in savings in placement costs.
- ✓ and more uniform architectural surface finish with little to no remedial surface work.
- ✓ of filling restricted sections and hard-to-reach areas. Opportunities to create structural and architectural shapes and surface finishes not achievable with conventional concrete.
- ✓ consolidation around reinforcement and bond with reinforcement.
- ✓ pumpability.
- ✓ uniformity of in-place concrete by eliminating variable operator-related effort of consolidation.
- ✓ savings.
- ✓ Shorter construction periods and resulting cost savings.
- ✓ concrete truck turn-around times enabling the producer to service the project more efficiently.
- ✓ or elimination of vibrator noise potentially increasing construction hours in urban areas.
- ✓ movement of ready mixed trucks and pumps during placement.
- ✓ jobsite safety by eliminating the need for consolidation.

SELF COMPACTING CONCRETE by Vikas Devarth

MATERIALS

The Materials used in SCC are the same as in conventional concrete except that an excess of fine material and chemical admixtures are used. Also, a viscosity-modifying agent (VMA) will be required because slight variations in the amount of water or in the proportions of aggregate and sand will make the SCC unstable, that is, water or slurry may separate from the remaining material. The powdered materials are fly ash, silica fume, lime stone powder, glass filler and quartzite filler. The use of pozzolanic materials helps the SCC to flow better. The pozzolanic reaction in SCC, as well as in Conventional Slump Concrete (CSC), provides more durable concrete to permeability and chemical attacks.

To achieve a high workability and avoid obstruction by closely spaced reinforcing, SCC is designed with limits on the nominal maximum size (NMS) of the aggregate, the amount of aggregate and aggregate grading. However, when the workability is high, the potential for segregation and loss of entrained air voids increases. These problems can be alleviated by designing a concrete with a high fine-to-coarse-aggregate ratio, a low water–cementitious material ratio (w/cm), good aggregate grading, and a high-range water-reducing admixture (HRWRA).

Following are bases which are commonly used as superplasticizers.

- Modified Lignosulfonates(MLS).
- Sulfonated Melamine Formaldehyde (SMF)
- Sulfonated Naphthalene Formaldehyde(SNF)
- Acrylic Polymer based(AP)
    - Coplymer of Carboxilic Acrylic
    - Acid with Acrylic Ester(CAE)
    - Cross Linked Acrylic Ploymer(CLAP)
    - Polycarboxylatethers(PCE)
    - Multicarboxylatethers(MCE)
    - Polyacrylates

SELF COMPACTING CONCRETE by Vikas Devarth

Combination of above different bases of New Generation super Plasticizers or High Water reducing agents (HRWRA) have different water reduction capacities. The advantage of this water reduction can be taken either to increase the strength as in high strength concrete or to obtain a better flow ability as in case of self compacting concrete.

STRENGTHENING OF CONCRETE STRUCTURES USING FIBRE REINFORCED CONCRETE COMPOSITES

By Vikas Devarth

The majority of structural strengthening involves improving the ability of the structural element to safely resist one or more of the following internal forces caused by loading: flexure, shear, axial, and torsion. Strengthening is accomplished by either reducing the magnitude of these forces or by enhancing the member's resistance to them. Typical strengthening techniques such as section enlargement, externally bonded reinforcement, post-tensioning, and supplemental supports may be used to achieve improved strength and serviceability.

Strengthening systems can improve the resistance of the existing structure to internal forces in either a passive or active manner. Passive strengthening systems are typically engaged only when additional loads, beyond those existing at the time of installation, are applied to the structure. Bonding steel plates or fiber-reinforced polymer (FRP) composites on the structural members are examples of passive strengthening systems. Active strengthening systems typically engage the structure instantaneously and may be accomplished by introducing external forces to the member that counteract the effects of internal forces. Examples of this include the use of external post-tensioning systems or by jacking the member to relieve or transfer existing load. Whether passive or active, the main challenge is to achieve composite behavior between the existing structure and the new strengthening elements.

STRENGHTENING USING FRP COMPOSITES:

FRP is a composite material generally consisting of high strength carbon, aramid, or glass fibers in a polymeric matrix (e.g., thermosetting resin) where the fibers are the main load carrying element.

FRPs exhibit several improved properties, such as high strength-weight ratio, high stiffness-weight ratio, flexibility in design, non-corrosiveness, high fatigue strength, and ease of application. The use of FRP sheets or plates bonded to concrete beams has been studied by several researchers. Strengthening with adhesive bonded fiber reinforced polymers has been established as an effective method applicable to many types of concrete structures such as columns, beams, slabs, and walls. Because the FRP materials are non-corrosive, non-magnetic, and resistant to various types of chemicals, they are increasingly being used for external reinforcement of existing concrete structures. Externally bonded glass fiber

STRENGTHENING OF CONCRETE STRUCTURES USING FIBRE REINFORCED CONCRETE COMPOSITES By Vikas Devarth

-reinforced polymers (GFRP) can be used to enhance the flexural, shear and torsional capacity of RC beams. Due to the flexible nature and ease of handling and application, combined with high tensile strength-weight ratio and stiffness, the flexible glass fiber sheets are found to be highly effective for strengthening of RC beams. The use of fiber reinforced polymers (FRPs) for the rehabilitation of existing concrete structures has grown very rapidly over the last few years. Research has shown that FRP can be used very efficiently in strengthening the concrete beams weak in flexure, shear and torsion.

FRP BONDED SHEETS:

Among many options, this reinforcement may be in the form of preformed laminates or flexible sheets. The laminates are stiff plates or shells that come pre-cured and are installed by bonding them to the concrete surface with a thermosetting resin. The sheets are either dry or pre-impregnated with resin (known as pre-preg) and cured after installation onto the concrete surface. This installation technique is known as wet lay-up. **FRP materials offer the engineer an outstanding combination of physical and mechanical properties, such as high tensile strength, lightweight, high stiffness, high fatigue strength, and excellent durability.** The lightweight and formability of FRP reinforcement make FRP systems easy to install. Since these systems are non-corrosive, non-magnetic, and generally resistant to chemicals, they are an excellent option for external reinforcement. The properties of FRP composites and their versatility have resulted in significant saving in construction costs and reduction in shut down time of facilities as compared to the conventional strengthening methods (e.g., section enlargement, external post-tensioning, and bonded steel plates). Strengthening with externally bonded FRP sheets has been shown to be applicable to many types of RC structural elements. FRP sheets may be adhered to the tension side of structural members (e.g., slabs or beams) to provide additional flexural strength. They may be adhered to web sides of joists and beams or wrapped around columns to provide additional shear strength. They may be wrapped around columns to increase concrete confinement and thus strength and ductility of columns.

Among many other applications, FRP sheets may be used to strengthen concrete and masonry walls to better resist lateral loads as well as circular structures (e.g., tanks and pipelines) to resist internal pressure and reduce corrosion.

ADVANTAGES OF FRP COMPOSITES:

- Fiber composite strengthening materials have higher ultimate strength and lower density than steel. When taken together these two properties lead to fiber composites having a strength/weight ratio higher than steel plate in some cases (though it is often not possible to use this fully). The lower weight makes handling and installation significantly easier than steel. This is particularly important when installing material in cramped locations.
- Work on soffits of bridges and building floor slabs can often be carried out from man-access platforms rather than full scaffolding.
- Steel plate requires heavy lifting gear and must be held in place while the adhesive gains strength. Bolts must be fitted through the steel plate into the parent concrete to support the plate while the adhesive cures and to reduce the effects of peeling at the ends.
- The application of FRP plate or sheet material has been likened to applying wallpaper; once it has been rolled on carefully to remove entrapped air and excess adhesive it may be left unsupported. In general, no bolts are required; in fact, the use of bolts would seriously weaken the material unless additional cover plates are bonded on. Furthermore, because there is no need to drill into the structure to fix bolts or other mechanical anchors there is no risk of damaging the existing reinforcement.
- Fiber composite materials are available in very long lengths while steel plate is generally limited to 6 m. The availability of long lengths and the flexibility of the material also simplify installation:
  - ✓ Laps and joints are not required
  - ✓ The material can take up irregularities in the shape of the concrete surface
  - ✓ The material can follow a curved profile; steel plate would have to be pre-bent to the required radius
  - ✓ The material can be readily installed behind existing services
  - ✓ Overlapping, required when strengthening in two directions, is not a problem because the material is thin.

STRENGTHENING OF CONCRETE STRUCTURES USING FIBRE REINFORCED CONCRETE COMPOSITES

By Vikas Devarth

- The materials fibers and resins are durable if correctly specified, and require little maintenance. If they are damaged in service, it is relatively simple to repair them, by adding an additional layer.
- The use of fiber composites does not significantly increase the weight of the structure or the dimensions of the member. The latter may be particularly important for bridges and other structures with limited headroom and for tunnels.
- In terms of environmental impact and sustainability, studies have shown that the energy required to produce FRP materials is less than that for conventional materials. Because of their light weight, the transport of FRP materials has minimal environmental impact.

DISADVANTAGES

- ✓ The main disadvantage of externally strengthening structures with fiber composite materials is the risk of fire, vandalism or accidental damage, unless the strengthening is protected. A particular concern for bridges over roads is the risk of soffit reinforcement being hit by over-height vehicles.
- ✓ However, strengthening using plates is generally provided to carry additional live load and the ability of the un-strengthened structure to carry

  Its own self-weight is unimpaired. Damage to the plate strengthening material only reduces the overall factor of safety and is unlikely to lead to collapse.
- ✓ Experience of the long-term durability of fiber composites is not yet available. This may be a disadvantage for structures for which a very long design life is required but can be overcome by appropriate monitoring.
- ✓ A perceived disadvantage of using FRP for strengthening is the relatively high cost of the materials. However, comparisons should be made on the basis of the complete strengthening exercise; in certain cases the costs can be less than that of steel plate bonding.
- ✓ A disadvantage in the eyes of many clients will be the lack of experience of the techniques and suitably qualified staff to carry out the work. Finally, a significant disadvantage is the lack of accepted design standards.