DADI INSTITUTE OF ENGINEERING & TECHNOLOGY

(Approved by A.I.C.T.E., New Delhi & Affiliated to JNTUK, Kakinada)

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Department of CIVIL Engineering

ADD ON COURSE

SUBJECT: Repairs and Rehabilitation of Structures

Branch: CIVIL Engineering Year: III Year Batch: 2019-2023

AY: 2021-22

1) Why choose this Course

Repair and Rehabilitation of Structures: Maintenance and Repairs Strategies. Maintenance Engineering is defined as the work done to keep the civil Engineering structures and work in conditions so as to enable them to carry out the functions for which they are constructed. It is preventive in nature.

2) Course Learning Objectives:

The objective of this course is:

1. Familiarize Students with deterioration of concrete in structures
2. Equip student with concepts of NDT and evaluation
3. Understand failures and causes for failures in structures
4. Familiarize different materials and techniques for repairs
5. Understand procedure to carryout Physical evaluation of buildings and prepare report.

3) Course Outcomes: At the end of this course the student will be able to a. Explain deterioration of concrete in structures

b. Carryout analysis using NDT and evaluate structures

c. Assess failures and causes of failures in structures

d. Carryout Physical evaluation and submit report on condition of the structure.

3) Contents:(SYLLABUS)

Module - I Deterioration of concrete in structures: Physical processes of deterioration like Freezing and Thawing, Wetting and Drying, Abrasion, Erosion, Pitting, Chemical processes like Carbonation, Chloride ingress, Corrosion, Alkali aggregate reaction, Sulphate attack Acid attack, temperature and their causes, Mechanism, Effect, preventive measures. - Cracks:Cracks in concrete, type, pattern, quantification, measurement & preventive measures.

Module- II Non Destructive Testing- Non destructive test methods for concrete including Rebound hammer, Ultrasonic pulse velocity, Rebar locator, Corrosion meter, Penetration resistance and Pull out test, Core cuttingCorrosion: Methods for corrosion measurement and assessment including half-cell potential and resistivity, Mapping of data. Civil Engineering 217

Module-III Failure of buildings: Definition of building failure-types of failures- Causes of Failures- Faulty Design, Accidental over Loading, Poor quality of material and Poor Construction practices- Fire damage - Methodology for investigation of failures-diagnostic testing methods and equipments-repair of cracks in concrete .

Module: IV Repair Techniques: Grouting, Jacketing, Shotcreting, externally bonded plates, Nailing, Underpinning and under water repair; Materials, Equipments, Precautions and Processes.

Module: V Investigation of structures: Distress, observation and preliminary test methods. Case studies: related to rehabilitation of bridge piers, dams, canals, heritage structures, corrosion and erosion damaged structures.

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5)Lecture Notes

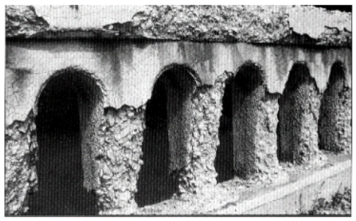
Module-1

DETERIORATION OF CONCRETE STRUCTURES

PHYSICAL PROCESSES

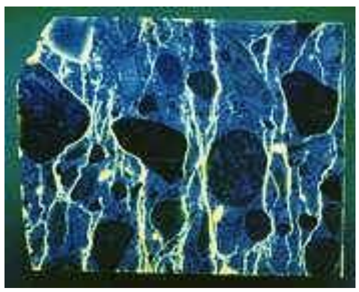
Freeze - Thaw Deterioration of Concrete

Concrete Experts International has extensive knowledge in theory and diagnosis of concrete deteriorated by freeze thaw actions (F/T). Diagnosing deterioration from freeze thaw action is an integrated part of our petrographic analysis of concrete.



Typical example of concrete deteriorated from freeze thaw actions. Non-air-entrained concrete railing. PCA vol. 19/1, April 1998

Why may concrete deteriorate from freeze thaw actions?



Surface parallel cracks

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.

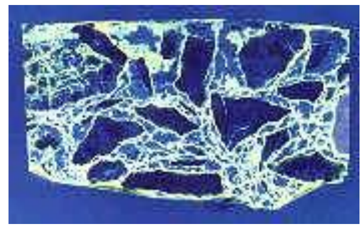
Concrete with high water content and high water to cement ratio is less frost resistant than concrete with lower water content.

Macro- & microscopic appearance

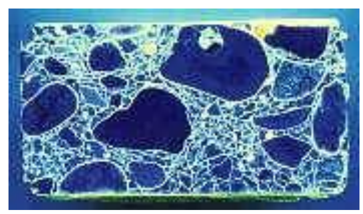
Deterioration of concrete by freeze thaw actions may be difficult to diagnose as other types of deterioration mechanisms such as ASR often go hand in hand with F/T. Often is may be difficult to evaluate which mechanism caused the initial damage, however, if all other mechanisms can be excluded the typical signs of F/T are:

- Spalling and scaling of the surface
- Large chunks (cm size) are coming of
- Exposing of aggregate
- Usually exposed aggregate are un-cracked
- Surface parallel cracking

in a Danish concrete suffering from freeze thaw damage.



Russian concrete cracked by freeze thaw actions. Gaps are visible around aggregate.



Gaps around aggregate in concrete tested for freeze thaw durability. Laboratory test.

- Gaps around aggregate - in the ideal case

Please to not hesitate to contact CXI if you have some problems regarding freeze thaw deterioration of concrete or any other deterioration mechanisms.

When water freezes, it expands about 9 percent. As the water in moist concrete freezes it produces pressure in the pores of the concrete. If the pressure developed exceeds the tensile strength of the concrete, the cavity will dilate and rupture. The accumulative effect of successive freeze-thaw cycles and disruption of paste and aggregate can eventually cause expansion and cracking, scaling, and crumbling of the concrete.

Deicing chemicals for pavements include sodium chloride, calcium chloride, magnesium chloride, and potassium chloride. These chemicals reduce the freezing point of the precipitation as it falls on pavements. A recent trend has seen a wide variety of blends of these materials to improve performance while reducing costs, and best practice indicates that a liberal dosage greater than four percent in solution tends to decrease the potential for scaling of pavement surfaces. The high concentration of deicers reduces the number of freezing and thawing cycle exposures to the pavement by significantly lowering the freezing point.

Deicers for special applications such as airport pavements require non-chloride materials to prevent damage to aircraft. The list of deicers used for these applications includes urea, potassium acetate, propylene glycol, and ethylene glycols.

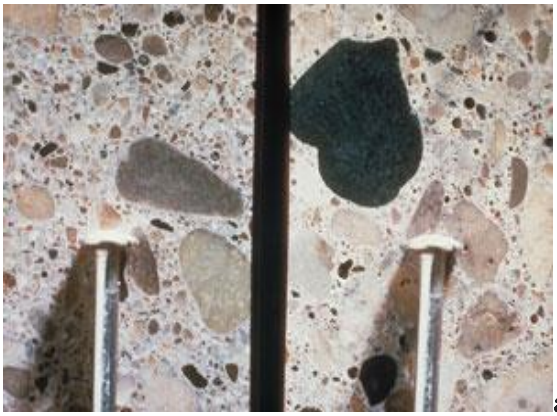
Since scaling damage to pavements of all types is caused by physical salt attack, the use of high strength (4,000 psi or more), low permeability, air entrained concrete is crucial to good durability in these applications.

Table 11-5 of Design and Control of Concrete Mixtures 15th edition, provides excellent guidance on the effective temperatures and includes the effects on the concrete, practical temperature limits, chemical form, and corrosion of metal potentials.

Click here for a case study on conductive concrete used for bridge deck deicing.

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 multiple outward from the joints toward the center of the pavement panel. D-cracking is a function of the core 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.

Freeze-Thaw Resistance

Air entrainment - The severity of freeze-thaw exposure varies with different areas of the United States. Local weather records can help determine the severity of exposure. The resistance of concrete to freezing and thawing in a moist condition is significantly improved by the use of intentionally entrained air. The tiny entrained air voids act as empty chambers in the paste for the freezing and migrating water to enter, thus relieving the pressure in the pores and preventing damage to the concrete. Concrete with a low permeability (that is, a low water-cement ratio and adequate curing) is better able to resist freeze-thaw cycles. In rare cases, air-void clustering can occur, leading to a loss of compressive strength.

Typical example of scaled concrete surface

Prevention of Concrete Scaling

Scaling is defined as a general loss of surface mortar or mortar surrounding the coarse aggregate particles on a concrete surface. This problem is typically caused by the expansion of water due to freezing and thawing cycles and the use of deicing chemicals; however properly specified, produced, finished, and cured quality concrete need not suffer this type of deterioration. There is a distinct chain of responsibility for the production of scale resistant concrete.

Closeup view of ice impressions in paste of frozen fresh concrete. The ice crystal formations occur as unhardened concrete freezes.

Freezing temperatures. Concrete gains very little strength at low temperatures. Accordingly, freshly placed concrete must be protected against freezing until the degree of saturation of the concrete has been sufficiently reduced by cement hydration. The time at which this reduction is accomplished corresponds roughly to the time required for the concrete to attain a compressive strength of 500 psi. Concrete to be exposed to deicers should attain a strength of 4,000 psi prior to repeated cycles of freezing and thawing.

Optimizing the Use of Fly Ash in Concrete Cold weather and winter conditions can be challenging when concrete contains fly ash. Especially when used at higher levels, fly ash concrete typically has extended setting times and slow strength gain, leading to low early-age strengths and delays in rate of construction. In addition, concretes containing fly ash are often reported to be more susceptible to surface scaling when exposed to deicing chemicals than portland cement concrete. It is therefore important to know how to adjust the amount of fly ash to minimize the drawbacks, while maximizing the benefits.

The architect for the Bayview high-rise apartment optimized the amount of fly ash on the basis of the requirements of the concrete specification, the construction schedule and the temperature. He limited the amount of fly ash in slabs on grade placed during winter months to 20 percent. If adequate curing cannot be provided or if the concrete is exposed to freezing and thawing in the presence of deicer salts, the amount of fly ash should always be less than 25 percent.

WETTING & DRYING

Cyclic Wetting and Drying C yclic wetting and drying causes continuous moisture movement through concrete pores [Crumpton, et al., 19891. This cyclic effect accelerates durabiiity problems because it subjects the concrete to the motion and accumulation of ha& materials, such as sulphates, ahlies, acids, and chiorides. Cyclic wetting and drying is a problem for RC structures exposed to chlorides and its effects are most severe in mainly three locations: 1. marine structures, particularly in the splash and tidai zones, 2. in parking garages exposed to deicer sdts, and 3. highway structures, such as bridges and other elevated roadways for instance the Gardner expressway. When concrete is dry or partially dry, and then exposed to salt water, it will imbibe the salt water by capillary suction. The concrete will continue to suck in the salt water untii saturation, or until there is no more reservoir of salt water. A concentration gradient of chlorides will develop in the concrete, stopping at some point in the interior of the concrete. If the extenial environment becomes dry, then pure water will evaporate fiom the pores, and salts that were originally in solution may precipitate out in the pores close to the surface. The point of highest chloride concentration rnay now exist within the concrete. On subsequent wetting, more sait solution will enter the pores, while re-dissolving and canying existing chlorides deeper into the concrete. The rate to which the chlorides will penetrate the concrete depends on the duration of the wetting and the drying periods. If the concrete remains wet, some salts may migrate in from the concrete surface by diffusion. However, if the wetting penod is short, the entry of salt water by absorption will cany the salts into the interior the concrete and be Mer concentrated during drying.

Cyclic wetting and drying increases the concentrations of ions such as chlorides, by evaporation of water. The drying of the concrete also helps to increase the availability of the oxygen required for steel corrosion, as oxygen has a substantially lower diffusion coefficient in saturated concrete. In fact diaision of oxygen through air can be as high as 10,000 times the diffusion of oxygen in water [Escalante, 19901. As the concrete dries and the pores become less saturated, oxygen will have a better chance to diffuse into the concrete and attain the level necessary to induce and sustain corrosion. For example; concrete structures subjected to seawater wetting and drying exposure are most prone to detenoration, compared to concrete structures pemanently submerged in seawater [Abdul-Hamid, 19901. in this case there is an increased availability of oxygen that also contributes to the deterioration compared to the subrnerged part of the structure. As well, for the concrete that is Mly submerged, less chlonde would enter the concrete as the dominant penetration rnechanism is diffusion through the pore solution.

There are several factors that can affect the degree that chlorides will enter concrete through cyclic wetting and drymg. The ingress of chlorides into concrete is strongly influenced by the sequence of wetîing and drymg, and on the duration. Specifically, the degree of dryness is very important, and therefore the dryhg conditions. Drying to a greater depth (chier concrete) allows subsequent wettings to carry the chlondes deeper into the concrete, thus speeding up the penetration of chloride ions [Neville, 19961. In fact the moistute content, or in other words, the extent of drying in the concrete "has a direct influence on durability, as it govems the amount of oxygen and moisture available at the rebat, and the magnitude of the capillary suction forces, which dictates the rate of penetration of water" WcCarter et al, 19971.

Concrete Drying Similar to other porous media, concrete dries in two stages [Selih et al., 19961. The initial portion occurs in the first 3 to 7 days, and in the initial stages of dryuig, the rate of drying is high and constant. This constant drying rate shows that there is a presence of fiee liquid water in the concrete. The outward flow of water is driven by capillary forces [Selih et al., 19961. During the second penod, when saturation rates are much lower, the drying rate decreases with time. The rate of dryhg is related to the square root of time since it is also a diffusion process. When the concrete reduces to a moishue content of 70 - 80 % of its the initial saturation, the rate of drying becomes controlIed by diffusion [Selih et al.. 19961. In general there are two conditions that can alter the rate of concrete drying: relative hurnidity (RH), and characteristics of the concrete itself. RH is the amount of moisture in the air relative to the saturated water vapour content, and varies fkom O to 100 %. The rate of concrete drymg is also af5ected by the microstructure of the concrete, and the materials with which it was made. In tems of the material, the pore size, pore size distribution, pore continuity, tortuosity and micro-cracking within the surface region will affect the rate with which moisture will be ernitted fiom the sample.

Concrete Wetting The wetting process also occurs in two distinct stage, although wetting occurs faster than drying. For most concretes, the initial stage of wetting will occur within several hours and is best represented by the sorptivity equation (Equation 2.4). As the concrete reaches a certain point of saturation, there is a deviation fiom the square root of time relationship, that is best explained by a polynomial equations wl, 1987 and McCarter, 19961. Eventually, when the concrete becomes completely saturated, chloride ingress will follow the laws of diffusion.

Abrasion of Concrete

Occurrence of abrasion in concrete hydraulic structures Abrasion is caused by the impact of elements transported by water in hydraulic structures of concrete. How much more turbulent are the flows, along with the impact forces caused by debris, the greater the abrasion. The debris transported by water flows ranging from their hardness until their types, and can be sand, stones, rubble, gravel, etc. The hydraulic structures most affected by abrasive processes are the surfaces of the spillways, stilling basin, walls of the upstream reservoir, drain pipes and hydraulic tunnels. In hydraulic structures of concrete dams, turbulent flows of water with suspended debris, colliding into their concrete surfaces, can cause abrasions to various depths. Great damage by abrasion occurred at Dworshak Dam, whose abrasion consumed an approximate volume of concrete and foundation rock of 1,530 m3, and approximate depths of 2 and 3 m (ACI, 1999)

The main factors affecting the resistance of concrete abrasion The main factors affecting the abrasion resistance of concrete are the environmental conditions and dosing of aggregates, concrete strength, the mix ratio, the use of special cement, the use of supplementary materials, such as adding fiber and fly ash . Two other factors have an important effect on the abrasion resistance, surface finish and curing conditions (Horszczaruk, 2005). The compressive strength proved to be one of the most important factors that correlate with the abrasion resistance of concrete. The compressive strength does not influence the abrasion resistance however is verified a correlation between them, if one is high; the other tends to be too.

Holland et al. (1987) established dependence between the concrete compressive strength and abrasion resistance underwater method in 72 hours. The tests showed that the abrasion resistance increases with the compressive strength. Holland studied the abrasion resistance of concrete with 11 to 15% silica fume and water/cement ratio (w/c) ranging between 0.24 and 0.34 to repair the Kinzua Dam in Pennsylvania. The concrete had, after 28 days, compressive strength of until 79MPa. The use of silica fume improved abrasion resistance compared to conventional concrete.

Repair of concrete hydraulic structures Repairs to damaged concrete structures are important not only to ensure the planned useful life, but also to provide good performance and security facing the most severe applications. An adequate repair improves the function and performance of the structure, restores and increases its strength and stiffness, improves the appearance of the concrete surface, provides impermeability to water, prevents the penetration of aggressive species at the interface concrete/steel and improves its durability (Al-Zahrani et al, 2003). The surfaces of hydraulic concrete dams are subject to wear by erosion (American Concrete Institute, 1999), fissures caused by the pressure of crystallization of salts in the pores (Tambelli et al, 2006) and by exposure to contaminants (Irassar et al, 2003), causing defects and constant maintenance and repair applications. Various materials are marketed for repair of deteriorated concrete structures. The RM is the most commonly used is the mortars with silica fume, epoxy resin and polyester resin, the concrete with polymers and concrete reinforced with fibers. To carry out repairs to a concrete structure should be considered the main causes of defects, the extent of deterioration, environmental conditions and external stresses imposed. Since then, it follows by the choice of RM itself, which meets the design specifications, as schematic design presented in Fig. 1. The recovery services of hydraulic structures are extremely expensive. According to Smoak (1998), recovery operations and maintenance of infrastructure of water resources, located mainly in the most severe climatic zones of the United States accounted for spending more than U$ 17 billion.

Repair materials

a. Mortar with silica fume According Ghafoor & Diawara (1999), the optimum silica fume content is around 10% mass of cement, replacing the fine aggregate. The proportion of the mixture used to construct the mortar with silica fume was 1: 3.66: 0.5: 0.1 (cement: sand: water: silica).

b. Epoxy mortar The epoxy mortar was measured according to manufacturer's instructions. This type of material is composed of components A (resin) + B (hardener) and C (quartz sand).

c. Polymer mortar For the production of polymer mortar was used an industrial product in which it was necessary to add only water. The water content indicated by the manufacturer was around 18%. However, the best workability was checked with a water content of 11%, which was then used in making the RM.

d. Concrete with steel fiber The mixture used to prepare the RM of concrete with addition of steel fibers was 1: 1.985: 2.77: 0.45: 2.42 (cement: sand: gravel: water: steel fibers).

e. Concrete Reference Although the mixture was made of the material considered as the reference concrete (RC) with characteristics similar to concrete used in dam construction. The content of the mixture of the RC was 1: 1.61: 2.99: 0.376 (cement: sand: gravel: water) with cement content of 426 kg/m3.

Erosion

Erosion is one form of wearing of ***concrete*** that is observed in contact with flowing water. The water body that results erosion may carry solid particles which leads to serious erosion to concrete.

Another term cavitation is closely related to erosion that will be discussed in the next post. Let's concentrate to this topic. We are listing the factors that determine the degree of erosion:

a. Quantity of the transported particles

b. Shape of these particles

c. Size of these particles

d. Hardness of these particles

e. Velocity of particle movement

f. Formation of eddies

g. At last quality of concrete

The concrete quality, especially in surface zone is very important to resist erosion of concrete. We will provide factors and ways to control erosion in the very next post. Like abrasion the resistance against erosion is also related to the strength of concrete but mix composition of concrete is also vital. We will discuss this later.

Erosion is a mechanical damage of concrete which is frequently associated with corrosion. Marine concrete is the ideal example of such damage. With this corrosion effects, erosion is happened when mechanical damage to concrete is occurred by the waves of water with gravel and sand carried by them. Sometimes crystallized salt takes the part of impacting from carried particles.

PITTING

What Are the Causes of Pitting in Concrete?

Pitting in concrete is caused by a wide variety of conditions. Some pitting and spalling, as it is sometimes called, is from natural aging and sometimes it can be caused by abuse or misuse. In some circumstances it occurs from faulty aggregates in the concrete, and there are examples of concrete that has degraded prematurely due to improper placement and finishing techniques. To properly diagnose degradation in concrete, it helps to know a list of details which are, at times, hard to assemble. Age, climate, mix details of the concrete, conditions under which the slab was poured and patterns of maintenance, such as snow removal, salting in winter and application of sealer, are all important.

Concrete and Climate

Climate in the parts of the United States that have snow and ice in the winter can be especially brutal on concrete. Ice and snow that are left on the surface can cause pitting from the cycle of freezing and melting from night to day. In the sunlight, ice may melt and the water penetrates the surface of the concrete, and will freeze again at night. The expansion of the ice within the top surface of the concrete slowly ruptures, forming tiny craters which continue to expand. Over subsequent seasons, those pockets continue to grow until they are visible and ultimately can start breaking apart the structure. The freeze-thaw cycle, as it is known, is the most common cause of pitting in concrete.

Concrete Pitting From Inadequate Mix

Under circumstances in which concrete was placed using an inadequate mix design for the local climate, pitting and degradation can occur prematurely. If the age of the slab is known to be relatively new, less than five years for example, this can be the cause. A low psi mix design can degrade faster in the less temperate climates than one of a higher strength. Local building codes usually specify strength of mixes for their climate conditions. A lower strength concrete is less waterproof, and less resistant to the effects of winter ice and snow detailed in the first section of this article.

Concrete Degradation From Improper Placement and Finishing Techniques

Concrete can begin to break down on the surface if it was placed, finished or cured improperly. If a slab was not cured, too much water can escape via evaporation from the surface as the concrete sets up, especially if it was poured on a hot day. If the concrete finisher added water to the surface to aid in finishing, that surface is weakened and can degrade sooner. The sub-grade can affect the concrete's strength by drawing water from it prematurely if was not sprayed down with water prior to concrete placement. These three effects have their greatest implications on the hottest summer days.

Aggregates and Concrete Degradation

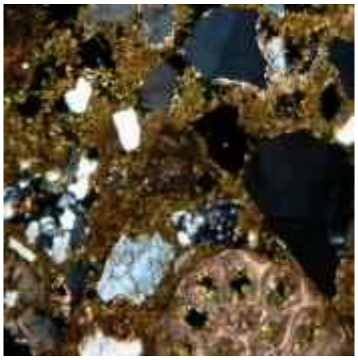
On rare occasions, premature pitting and degradation of a concrete slab can be attributed to an aggregate that is not suitable for use in concrete. This scenario typically happens quickly and in a variety of conditions and can usually only be determined in a lab. A bad aggregate will either create a chemical reaction that breaks down the concrete or has excess porosity that poorly resists the freeze-thaw cycle. Concrete materials are standardized and tested. If something slips through, many times it is from a small vein of material in the rock quarry that goes unnoticed.

Age, Maintenance and Prevention

All concrete eventually can succumb to the rigors of winter and use. There are preventative methods that can increase its life span. Winter is the most brutal stress on concrete, and is ultimately the main overall cause of pitting in concrete. Snow and ice removal can drastically reduce pitting over the years. Salt and other ice melting compounds can be an obvious necessity for safety, but use in limited amounts after physical removal of the bulk of the snow and ice is best. Applying a concrete sealer to the slab on a periodic basis reduces the amount of water it can absorb. This protective action can add years to a concrete slab.

CHEMICAL PROCESSES

Concrete Experts International has extensive, world-wide experience with concrete petrography. Carbonation is an integrated part of our petrographic analysis of concrete.



Fully carbonated paste in the concrete surface. Carbonated paste appears orange-brown in crossed polarized light.

What is Carbonation?

Carbonation occurs in concrete because the calcium bearing phases present are attacked by carbon dioxide of the air and converted to calcium carbonate.Cement paste contains 25-50 wt% calcium hydroxide ($Ca(OH)_2$), which mean that the pH of the fresh cement paste is at least 12.5. The pH of a fully carbonated paste is about 7.

The concrete will carbonate if CO_2 from air or from water enters the concrete according to:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

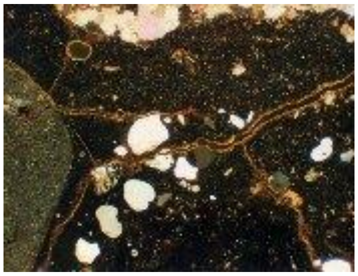
When $Ca(OH)_2$ is removed from the paste hydrated CSH will liberate CaO which will also carbonate. The rate of carbonation depends on porosity & moisture content of the concrete.

The carbonation process requires the presence of water because CO_2 dissolves in water forming H_2CO_3. If the concrete is too dry (RH <40%) CO_2 cannot dissolve and no carbonation occurs. If on the other hand it is too wet (RH >90%) CO_2 cannot enter the concrete and the concrete will not carbonate. Optimal conditions for carbonation occur at a RH of 50% (range 40-90%).

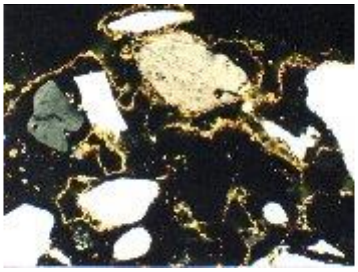
Normal carbonation results in a decrease of the porosity making the carbonated paste stronger. Carbonation is therefore an advantage in non-reinforced concrete. However, it is a disadvantage in reinforced concrete, as pH of carbonated concrete drops to about 7; a value below the passivation threshold of steel.

How do you recognize carbonation?

Carbonation may be recognized in the field by the presence of a discolored zone in the surface of the concrete. The color may vary from light gray and difficult to recognize to



Carbonated paste along cracks inside a concrete. The cracks are formed due to alkali silica reaction.



Weak carbonation of paste at the rim of large connected voids in zero slump concrete.

"Pop-corn" like calcite crystalspresent in carbonated paste. The concrete is suffering from bi-carbonation.

strong orange and easy to recognize. Carbonation can be visualized by using phenolphthalein.

In the optical microscope carbonation is recognized by the presence of calcite crystals and the absence of calcium hydroxide, ettringite and un-hydrated cement grains. Porosity is unchanged or lower in the carbonated zone.

Bi-carbonation - what is that?

Occasionally concrete may suffer from the so called bi-carbonation process. Bi-carbonation may occur in concrete with very high water to cement ratio due to formation of hydrogen carbonate ions at pH lower than 10. Contrary to normal carbonation, bi-carbonation results in an increase in porosity making the concrete soft and friable. Bi-carbonation may be recognized by the presence of large "pop-corn" like calcite crystals and the highly porous paste.

Please to not hesitate to contact CXI if you have any questions regarding carbonation or any other deterioration mechanisms.

CHLORIDE TRANSPORT IN CONCRETE

Chloride transport in concrete is a rather complex process. It involves diffusion, physical and chemical binding, capillary suction and migration. The two main mechanisms of chloride transportation in concrete are diffusion and migration. (Luping et al. 2012) “Diffusion is the movement of a substance under a gradient of concentration, more strictly speaking, chemical potential, from an area of high concentration to an area with of low concentration.”(Luping et al. 2012) Where only the free chloride ions in a solution can contribute to a concentration or chemical potential. "Migration is the movement of a charged substance under the action of an electrical field. As in diffusion, only free chloride ions in a solution can contribute to the flow of migration."(Luping et al. 2012) Diffusion and migration assume that there are no water movement or exchange within the concrete. In reality concrete structures may be exposed to an environment where a gradient of water pressure exists. In these cases, other transportation mechanisms may occur such as: - Hydraulic flow - Capillary suction in an unsaturated pore system, caused by the surface tension of pore walls (Luping et al. 2012)

CHLORIDE INGRESS

Chloride-ingress models generally make the assumption that the concrete is crackfree, homogeneous and that the chloride ingress is one dimensional at macro-scale. This might be too simplistic, even if the concrete is well mixed and compacted. The wall effect will create a binder content profile that is closer to a cast surface, if the penetration depth is small enough this will have a significant effect on the chloride profile. Vertical separation will result in differences in the water-to-binder ratio across the height of the structural element. (Luping et al. 2012) Over time a number of different effects will change the concrete, these changes can be different at different depths depending on the initial curing conditions and the exposure conditions during the structures service life, these include: - Continues binder reaction, resulting in a densification of the concrete and as a consequence a change in the pore system. - Wetting and drying of the concrete causing shrinkage and swelling - Carbonation (Luping et al. 2012) When working with chloride transport in concrete it is important to be aware of the effect of chloride binding. Bound chloride is usually assumed to be harmless to the reinforcement, but mechanisms such as sulphate ingress and carbonation can cause the bound chlorides to be released inside the concrete, effectively increasing the content of free chlorides inside the concrete. (Luping et al. 2012).

CORROSION OF CONCRETE

Concrete Corrosion

Definition - What does *Concrete Corrosion* mean?

Concrete corrosion is the chemical, colloidal or physicochemical deterioration and disintegration of solid concrete components and structures, due to attack by reactive liquids and gases.

This type of corrosion causes widespread damage to critical sewage pipelines, bridges and other critical assets made of concrete. Coatings and other preventive measures are used to combat this type of corrosion. Different types of cements and production techniques are being developed to monitor and minimize damage.

Corrosionpedia explains *Concrete Corrosion*

While concrete structures are corroded by chemical reaction, the steel reinforcement in many of these structures is corroded by electrochemical reaction.

Concrete corrosion is mainly caused by :

- Salt water or acidic ground water
- Microbes in sewer pipes
- Sulphates
- Chlorides
- Nitrates
- Fluorides
- Sulphides
- Industrial waste like slag and corrosive gases

Preventive measures include:

- Paint application such as varnish, oil or lacquer-based paint
- Surface treatment
- Appropriate choice of cement mix and chemicals during cement production
- Action to prevent attack of corrosive water or other liquids and gases

Biological sulfuric acid attack is a chronic problem in sewage pipes, leading to rapid deterioration of concrete. Because of the role of bacteria in the corrosion reaction, mechanical engineers have focused on the study of corrosion resistance of different concrete mixes in an effort to prevent this type of corrosion.

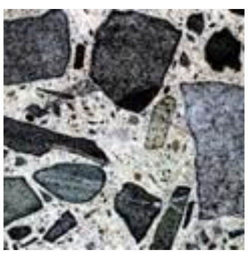
Alkali-Aggregate Reaction

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 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 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. Petrographic examination can conclusively identify ASR.

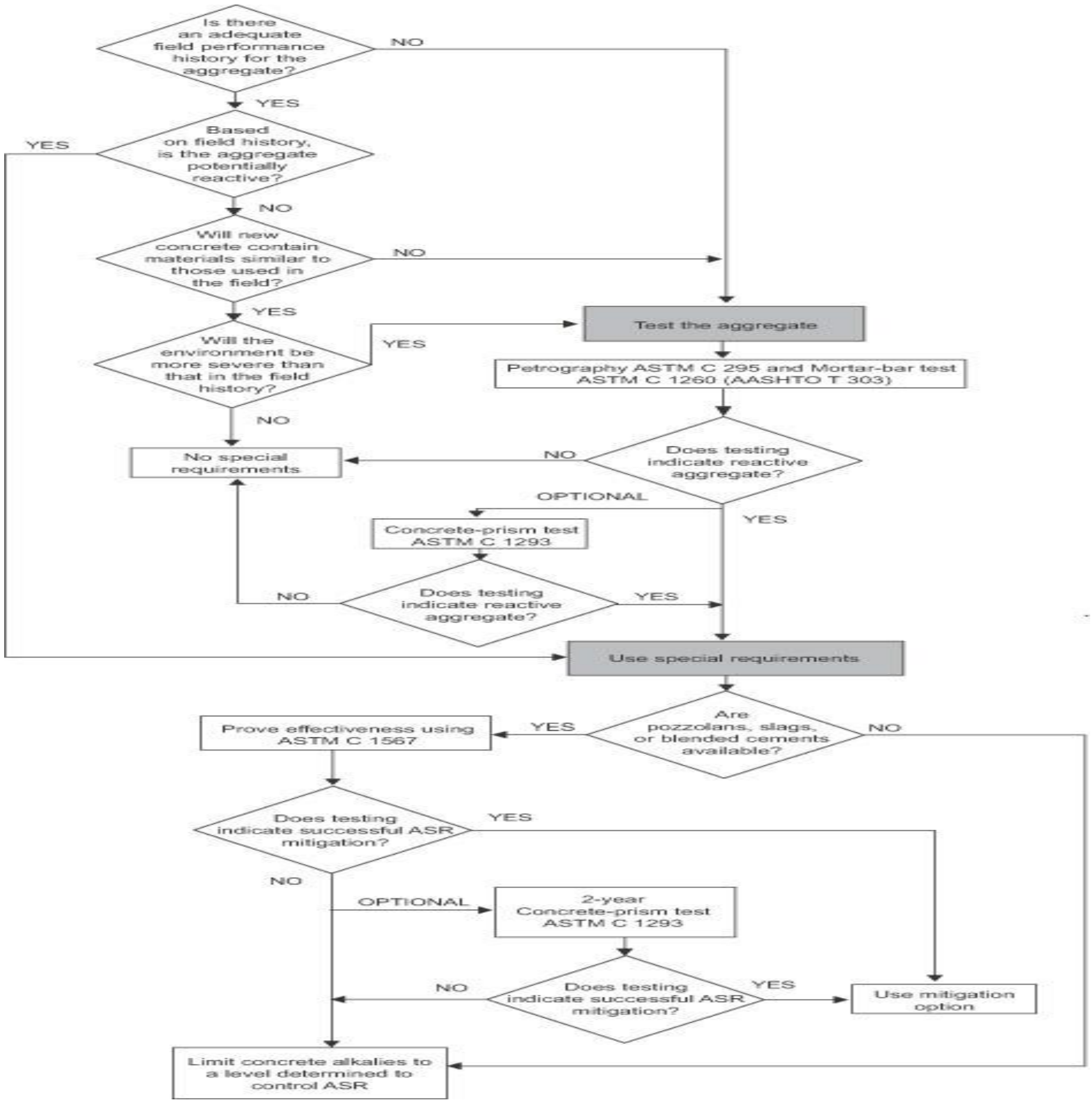
Alkali-silica reaction can be controlled using certain supplementary cementitious materials. In-proper proportions, silica fume, fly ash, and ground granulated blast-furnace slag have significantly reduced or eliminated expansion due to alkali-silica reactivity. In addition, lithium compounds have been used to reduce ASR. Although potentially reactive aggregates exist throughout North America, alkali-silica reaction distress in concrete is not that common because of the measures taken to control it. It is also important to note that not all ASR gel reactions produce destructive swelling.



Alkali-carbonate reaction (ACR) is 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 alkali-carbonate reactions 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. Aggregates susceptible to ACR tend to have a characteristic texture that can be identified by petrographers. Unlike alkali carbonate reaction, the use of supplementary cementing materials does not prevent deleterious expansion due to ACR. It is recommended that ACR susceptible aggregates not be used in concrete.

Prevention of Alkali-Silica Reaction in New Concrete

Follow the steps in the flowchart below to determine if potential for ASR exists and to select materials to control it. For more information move your mouse over the individual flowchart boxes.



Sulphate Attack on Concrete – Process and Control of Sulphate Attack

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

Forms of Sulphate Attack on Concrete

Sulphate attack on concrete might show itself in different forms depending on:

- The chemical form of the sulphate
- The atmospheric environment which the concrete is exposed to.

What happens when sulphates get into concrete?

When sulphates enters into concrete:

- It combines with the C-S-H, or concrete paste, and begins destroying the paste that holds the concrete together. As sulphate 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.

Sources of Sulphates in Concrete

Following are the sources of sulphates which are responsible for sulphate attack:

1. Internal Sources

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

- Portland cement might be over-sulphated.
- presence of natural gypsum in the aggregate.
- Admixtures also can contain small amounts of sulphates.

2. External Sources

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

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

Reactions of Sulphate Attack on Concrete

Nature of reaction: Chemical and physical reactions

Sulphate attack process decrease the durability of concrete by changing the chemical nature of the cement paste, and of the mechanical properties of the concrete.

1. Chemical Process of Sulphate Attack

The sulphate ion + hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste + water = ettringite (calcium sulphoaluminate hydrate)

C3A.Cs.H18 + 2CH +2s+12H = C3A.3Cs.H32

C3A.CH.H18 + 2CH +3s + 11H = C3A.3Cs.H32

The sulphate ion + hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste + water = gypsum (calcium sulphate hydrate)

$Na_2SO_4+Ca(OH)_2 +2H_2O = CaSO_4.2H_2O +2NaOH$

$MgSO_4 + Ca(OH)_2 + 2H_2O = CaSO_4.2H_2O + Mg(OH)_2$

Two forms of chemical reaction occurs depending on:

- Concentration and source of sulphate ions .Diagnosis
- Composition of cement paste in concrete.

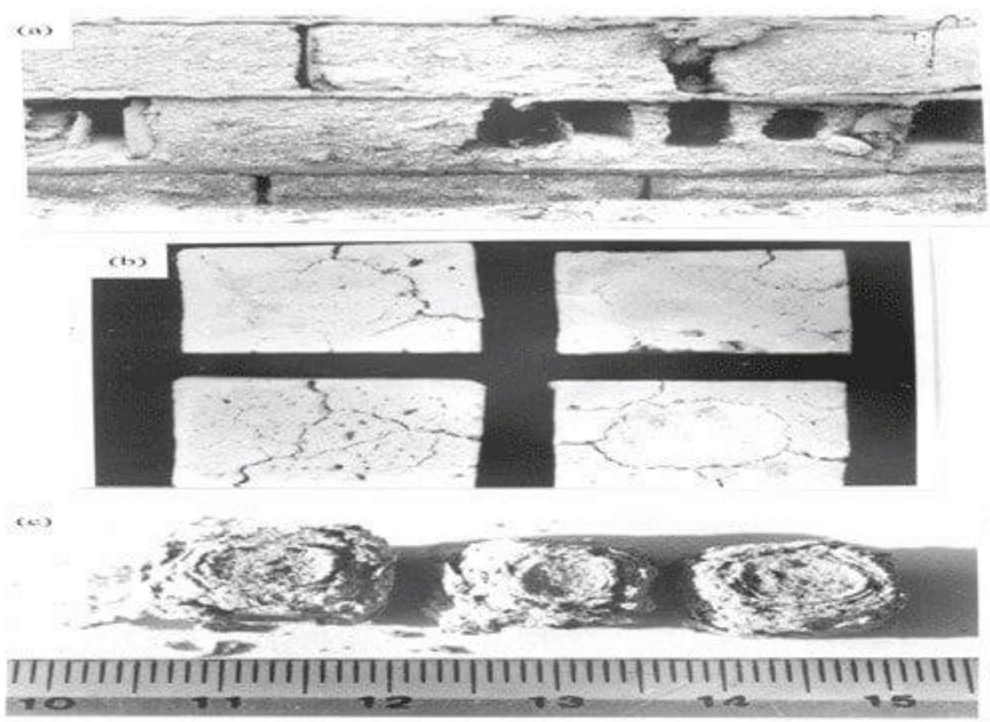
2. Physical Process of Sulphate Attack

- The complex physicochemical process of “sulphate attack” are interdependent as is the resulting damage.
- physical sulphate attack, often evidenced by bloom (the presence of sodium sulphates Na_2SO_4 and/or $Na_2SO_4.10H_2O$) at exposed concrete surfaces.
- It is not only a cosmetic problem, but it is the visible displaying of possible chemical and microstructural problems within the concrete matrix.

Both chemical and physical phenomena observed as sulphate attack, and their separation is inappropriate.

Diagnosis of Sulphate Attack on Concrete

- Spalling of concrete due to sulphate attack.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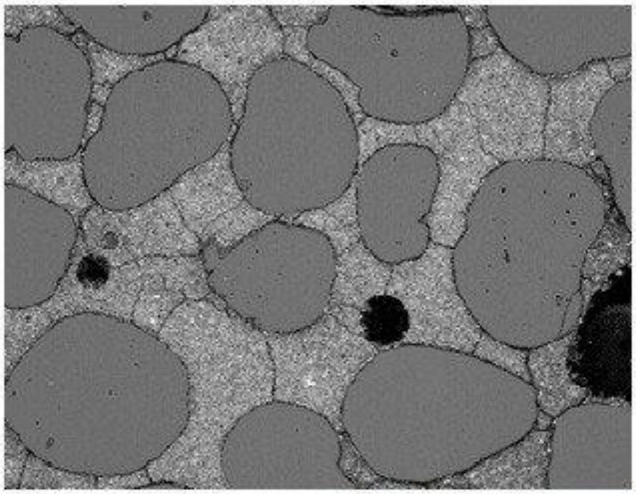
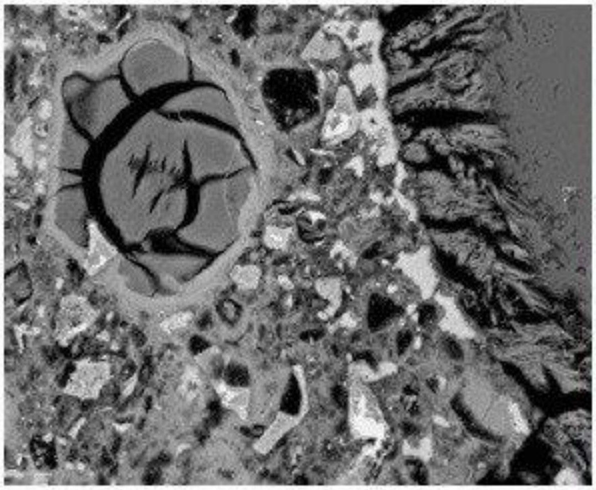
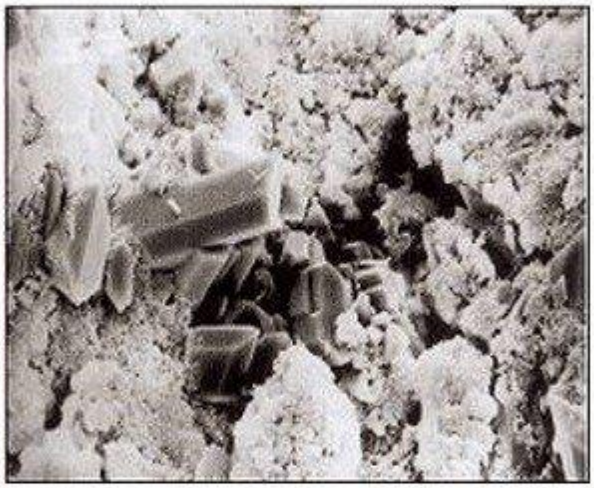
Microscopical Examination of Sulphate Attack







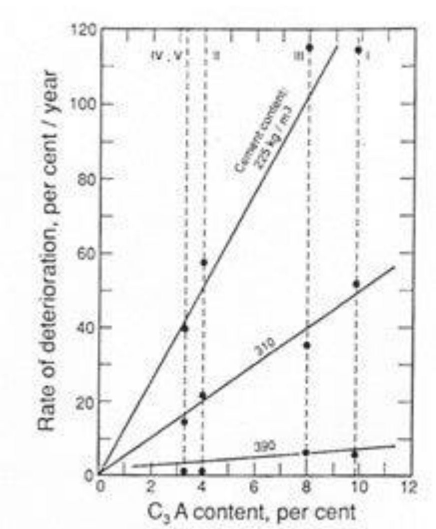
Prevention of Sulphate Attack on Concrete

To prevent the sulphate attack on concrete, we must understand the factors which affect the sulphate attack.

Main factors affecting sulphate attack are:

1. Type of Cement and its Content

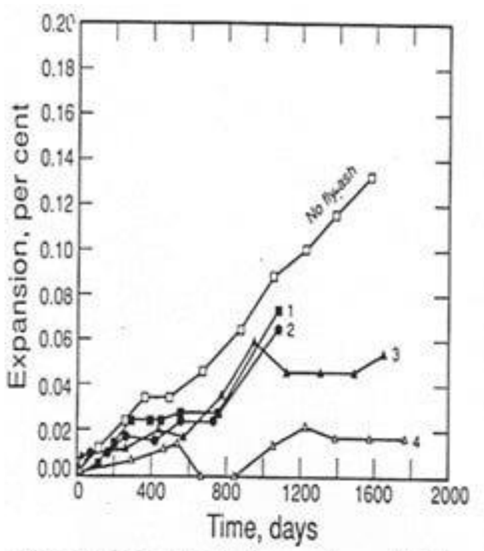
The most important mineralogical phases of cement that affect the intensity of sulphate attack are: C3A, C3S/C2S ratio and C4AF.



Effect of the C_3A content in Portland cement on the rate of deterioration of concrete exposed to sulphate bearing soils

Fly ash addition

The addition of a pozzolanic admixture such as fly ash reduces the C3A content of cement.



Sulphate expansion of concrete containing low-calcium fly-ash of different compositions marked 1 to 4.

3. Types of Sulphate and its Concentration

The sulphate attack tends to increase with an increase in the concentration of the sulphate solution up to a certain level.

4. Chloride ions

Other factors:

- The level of the water table and its seasonal variation
- The flow of groundwater and soil porosity
- The form of construction
- The quality of concrete

Control of Sulphate Attack on Concrete

Following measures help to control sulphate attack””:

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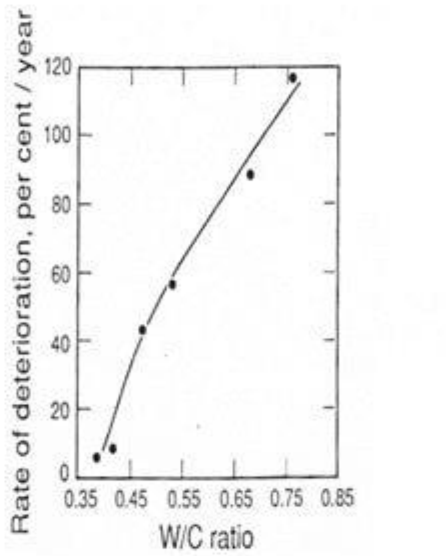
1. The **quality of concrete**, specifically a low permeability, is the best protection against sulphate attack.
   - Adequate concrete thickness
   - High cement content
   - Low w/c ratio
   - Proper compaction and curing



Effect of W/C ratio on rate of deterioration of concrete made of ordinary Portland cement and exposed to sulphate bearing soils.

Fig: Effect of water-cement ratio on sulphate attack

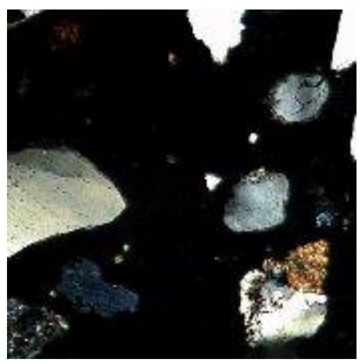
The **use of sulphate resisting cements** provide additional safety against sulphate attack

Exposure	**Concentration of water-soluble sulphates in soil percent**	**Concentration of water-soluble sulphates in water ppm**

Mild	<0.1	<150
Moderate	0.1 to 0.2	150 to 1500
Severe	0.2 to 2	1500 to 10000
Very severe	>2	>10000

Acid Attack on Concrete

Concrete Experts International has extensive, world-wide experience with deteriorated concrete suffering from acid attack caused by acid smoke, rain and exhausting gasses. Diagnosing acid attack is an integrated part of our petrographic analysis of concrete.



Calcium hydroxide depletion of cement paste. Crossed polarized light.

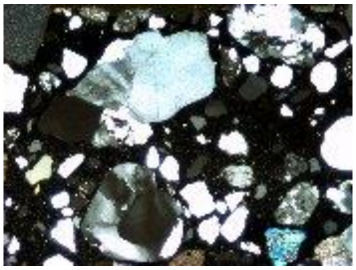
What is Acid Attack?

Concrete is susceptible to acid attack because of its alkaline nature. The components of the cement paste break down during contact with acids.

Most pronounced is the dissolution of calcium hydroxide which occurs according to the following reaction:

$2\ HX + Ca(OH)_2 \rightarrow CaX_2 + 2\ H_2O$
(X is the negative ion of the acid)

Exposed aggregate at concrete surface. Ordinary polarized light.



Exposed aggregate at concrete surface. Crossed polarized light.

The decomposition of the concrete depends on the porosity of the cement paste, on the concentration of the acid, the solubility of the acid calcium salts (CaX_2) and on the fluid transport through the concrete. Insoluble calcium salts may precipitate in the voids and can slow down the attack. Acids such as nitric acid, hydrochloric acid and acetic acid are very aggressive as their calcium salts are readily soluble and removed from the attack front. Other acids such as phosphoric acid and humic acid are less harmful as their calcium salt, due to their low solubility, inhibit the attack by blocking the pathways within the concrete such as interconnected cracks, voids and porosity. Sulphuric acid is very damaging to concrete as it combines an acid attack and a sulfate attack.

Microscopic appearance

An acid attack is diagnosed primarily by two main features:

- Absence of calcium hydroxide in the cement paste
- Surface dissolution of cement paste exposing aggregates

Please to not hesitate to contact CXI if you have some problems regarding acid attack or any other deterioration mechanisms.

TEMPERATURES AND THEIR CAUSES OF CONCRETE

Heat evolution in concrete is a very complex and extensively researched topic. To simplify this process, the heat evolution over time can be separated into five distinguished phases. The heat profile can change depending on the type of cement. Typical hydration for Type I cement is graphically represented in the figure below.

Table 1: Portland cement composition

Portland Cement Phases	Abbreviation (Chemical Formula)
Dicalcium silicate	C_2S
Tricalcium silicate	C_3S
Tricalcium aluminate	C_3A
Tetracalcium aluminoferrite	C_4AF
Calcium sulphate *	CaSO4, $CaSO_4 \cdot 2H_2O$ (gypsum), $CaSO_4 \cdot \frac{1}{2}H_2O$

*Calcium sulphate only represent ~10% of the cement mass. The other four phases are the principal compounds of the Portland cement and their individual mass fraction changes based on the type of cement.

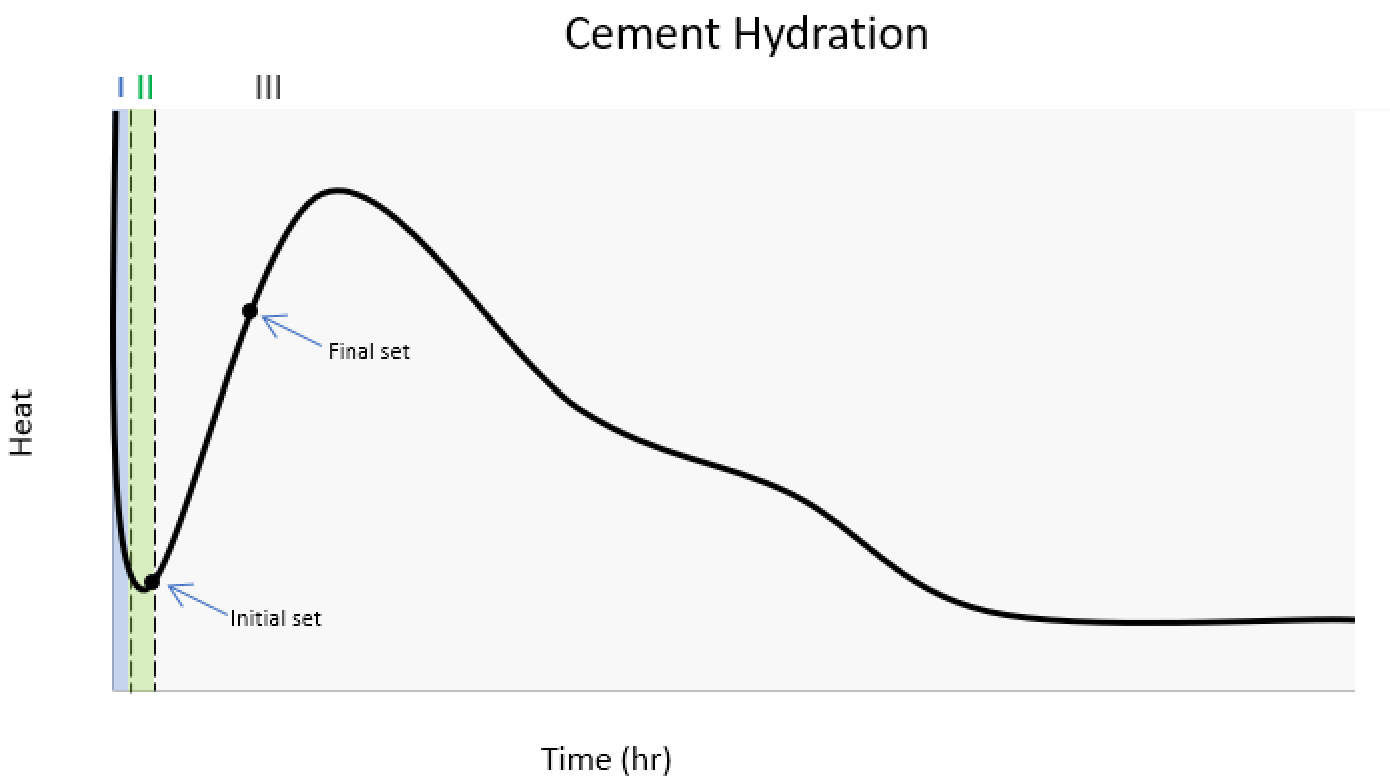


Figure 1: Heat of hydration for Type 1 cement

Phase I: Pre-Induction

A short time after the water comes into contact with the cement, there is a sharp increase in temperature, which happens very quickly (within a couple minutes). During this period, the primary reactive phases of the concrete are the aluminate phases (C_3A and C_4AF). The aluminate and ferrite phases react with the calcium and sulphate ions to produce ettringite, which precipitates on the surface of the cement particles. During this phase, at a lesser extent, the silicate phases (mainly C_3S) will also react in very small fractions compared to their total volume and form a very thin layer of calcium-silicate-hydrate (C-S-H).

Phase II: Dormant Period

This phase is also known as the induction phase. During this period, the rate of hydration is significantly slowed down. Traditionally, this is believed to be due to the precipitation of the aforementioned compounds on the surface of the cement particles, which leads to a diffusion barrier between cement particles and water. Nevertheless, there is significant debate on the physical and chemical reasons behind the occurrence of this stage and the methods to predict it.

This is the period at which the fresh concrete is being transported and placed since it has not yet hardened and is still workable (plastic and fluid). The length of the dormant period has been shown to vary depending on multiple factors (cement type, admixtures, w/cm). The end of the dormant period is typically characterized by the initial set.

Phase III and IV: Strength Gain

In this phase, the concrete starts to harden and gain strength. The heat generated during this phase can last for multiple hours and is caused mostly by the reaction of the calcium silicates (mainly C_3S and to a lesser extent C_2S). The reaction of the calcium silicate creates "second-stage" calcium silicate hydrate (C-S-H), which is the main reaction product that provides strength to the cement paste. Depending on the type of cement, it is also possible to observe a third, lower heat peak from the renewed activity of C_3A.

Phase V: Steady State

The temperature stabilizes with the ambient temperature. The hydration process will significantly slow down but will not completely stop. Hydration can continue for months, years, or even decades provided that there is sufficient water and free silicates to hydrate, but the strength gain will be minimal during such period of time.

Why Monitor Concrete Temperature?

In Phase II, the temperature of concrete can be measured as the concrete is poured. The temperature measurement is typically done to make sure the concrete is in compliance with certain specifications that define a certain allowable temperature range. Typical specifications require the temperature of the concrete during placement to be within a range of 10°C to 32°C (50°F to

90°F). However, different specified limits are provided depending on the element size and ambient conditions (ACI 301, 207). **The temperature the concrete exhibits during placement affects the temperature of concrete during the next hydration phase.**
Monitoring the temperature of the concrete during phase III and IV is a quality control component that is regularly being performed. The main reason behind this measurement is to ensure the concrete does not reach temperatures that are too high or too low to allow proper strength development and durability of the concrete. Another reason for monitoring concrete temperature during this phase is to evaluate the in-place strength, where the rate of hydration is the principal behind the maturity method (ASTM C 1074).

Cold-Weather Concreting

If the ambient temperature is too low, the hydration of the cement will significantly slow down or will completely stop until the temperature increases again. In other words, there will be a significant reduction or an end to the strength development. If the concrete temperature reaches freezing before reaching a certain strength (3.5 MPa/500 psi) (ACI 306), the concrete will have a reduced overall strength. This will also cause cracking as the concrete does not have sufficient strength to resist the expansion of water due to the formation of ice.

To ensure proper strength development and avoid cracking of the concrete, the general guidelines suggest that the concrete temperature must be maintained higher than a certain temperature for a specific amount of time (>5°C (40°F) for 48hrs) (ACI 306).

Hot-Weather Concreting

Generally, a limit of 70°C (160°F) is specified for the concrete temperature during hydration. If the temperature of the concrete during hydration is too high, it will cause the concrete to have high early strength but consequently gain less strength in the later stage and exhibit lower durability. Furthermore, it has been observed that such temperatures interfere with the formation of ettringite in the initial stage and subsequently its formation in the later stages is promoted; which causes an expansive reaction and subsequent cracking.

Additionally, high temperature issues are of concern, especially in mass concrete pours, where the core temperature can be very high due to the mass effect, while the surface temperature is lower. This causes a temperature gradient between the surface and the core, if the differential in temperature is too large it causes thermal cracking.

Mitigating Improper Concrete Hydration Temperatures

Multiple methods currently exist to mitigate the adverse effect of improper hydration temperatures. Two approaches, or a combination of both, can be taken to control the temperature during the dormant and strength-gain phase of the hydration process. One approach is to control the surrounding elements or mix constituents' temperature. The second approach is to optimize the mix design.

Concrete Temperature Control During Mixing and Curing

The temperature when the concrete is placed can be somewhat controlled by using cold water for the mix, cooling down aggregates using ice, or pouring at night when temperatures are naturally lower.

In cold weather, **the temperature of the concrete can be controlled** by providing appropriate curing conditions such as with the use of heating systems. High curing temperatures can also be controlled in the mass pour with cooling pipes.

Concrete Temperature Control During Mix Design

An effective approach to controlling heat generation during cement hydration is to have a mix design that is suited to the application and the ambient conditions. Here are some things to consider:

- Selecting the appropriate cement type changes the heat of hydration generated. Compared to Type I cement, Type III generates more heat while Type II generates moderate heat, and Type IV generates less than the others;
- Adjusting the finesse of the cement (a finer cement will generate more heat);

- Using supplementary cementitious materials (SCMs) is also an effective means of reducing the heat generated during hydration. Replacing a portion of the cement with, for instance, slag or fly ash, reduces the amount of reactive material in the early stages; in turn, this reduces the amount of heat generated and delays concrete strength gain; and

- Adding other types of admixtures such as retarders and accelerators (however, these mixtures will not typically affect heat generation; rather they will be used to control the length of the dormant period).
Keep in mind that appropriate curing is crucial to ensuring that the concrete has enough moisture to hydrate properly. Overall, the general contractor, engineer, and ready-mix supplier need to be in good communication with each other, test concrete temperatures regularly to avoid extremes during mixing, pouring, and curing, and have a plan in place in case temperatures do drop or exceed the recommended limits

Types of cracks in Concrete Structures

Types of cracks in concrete structures are structural cracks and non-structural cracks.

Structural Cracks in Concrete

Structural cracks are those which result from incorrect design, faulty construction or overloading and these may endanger the safety of a building and their inmates.

Non Structural Cracks in Concrete

Non Structural cracks occur mostly due to internally induced stresses in building materials. These cracks normally do not endanger the safety but may look unsightly, create an impression of faulty work or give a feeling of instability.

Cracks reappear over repaired surface as rust scales were not removed

Defects in Concrete

Concrete defects can be broadly classified into two categories

Macro Defects

If these defects are present, concrete has low strength and will rapidly deteriorate due to easy ingress of water and other chemicals. Invariably, structure will require repairs within a few years of its construction. Causes will have to be analysed and defects removed before doing any additional protective treatment.

Often, waterproofing of concrete slabs is carried out superficially and it fails to give the desired benefit because the defective concrete below this waterproofing layer has not been treated to seal the macro/micro defects which existed within the concrete slab.

The main causes of these defects are generally due to inadequacies in design and / or construction practices.

Micro Defects

These defects are not visible to the naked eye. They are usually very fine voids caused by large capillary pores resulting from the use of low grades (strength) of concrete with high water to cement ratio.

They could also occur due to addition of excess water or high water to cement ratio of concrete mix. Fine cracks are generally present in concrete and can occur due to various reasons. They do not pose a serious threat to concrete deterioration initially as they are generally not deep and are discontinuous.

With lapse of time due to variations in temperatures, changes in weather conditions, changes in loading conditions they increase in depth, length and width and combine with other fine cracks to create continuous passage for moisture, chlorides, sulphates and other chemicals from the environment to enter and start corrosion of steel in concrete and other deleterious reactions.

Corrosion of steel and spalling of concrete due to ingress of moisture

To conclude, macro defects and micro defects in concrete are both harmful to the health of buildings and can cause deterioration of concrete depending on the extent of their presence, environmental conditions around the building and maintenance done during its life cycle.

However macro defects by virtue of being larger can cause faster deterioration and more damage to the structure than the micro defects

Module 2

NON DESTRUCTIVE TESTING

Non-Destructive Testing of Concrete and its Methods

Non-destructive testing of concrete is a method to obtain the compressive strength and other properties of concrete from the existing structures. This test provides immediate results and actual strength and properties of concrete structure.

The standard method of evaluating the quality of concrete in buildings or structures is to test specimens cast simultaneously for compressive, flexural and tensile strengths.

The main disadvantages are that results are not obtained immediately; that concrete in specimens may differ from that in the actual structure as a result of different curing and compaction conditions; and that strength properties of a concrete specimen depend on its size and shape.

Although there can be no direct measurement of the strength properties of structural concrete for the simple reason that strength determination involves destructive stresses, several non- destructive methods of assessment have been developed.

These depend on the fact that certain physical properties of concrete can be related to strength and can be measured by non-destructive methods. Such properties include hardness, resistance to penetration by projectiles, rebound capacity and ability to transmit ultrasonic pulses and X- and Y-rays.

These non-destructive methods may be categorized as penetration tests, rebound tests, pull-out techniques, dynamic tests, radioactive tests, maturity concept. It is the purpose of this Digest to describe these methods briefly, outlining their advantages and disadvantages.

Methods of Non-Destructive Testing of Concrete

Following are different methods of NDT on concrete:

1. Penetration method
2. Rebound hammer method
3. Pull out test method
4. Ultrasonic pulse velocity method
5. Radioactive methods

Penetration Tests on Concrete

The Windsor probe is generally considered to be the best means of testing penetration. Equipment consists of a powder-actuated gun or driver, hardened alloy probes, loaded cartridges, a depth gauge for measuring penetration of probes and other related equipment.

A probe, diameter 0.25 in. (6.5 mm) and length 3.125 in. (8.0 cm), is driven into the concrete by means of a precision powder charge. Depth of penetration provides an indication of the compressive strength of the concrete.

Although calibration charts are provided by the manufacturer, the instrument should be calibrated for type of concrete and type and size of aggregate used.

Limitations and Advantages

The probe test produces quite variable results and should not be expected to give accurate values of concrete strength. It has, however, the potential for providing a quick means of checking quality and maturity of in situ concrete.

It also provides a means of assessing strength development with curing. The test is essentially non-destructive, since concrete and structural members can be tested in situ, with only minor patching of holes on exposed faces.

Rebound Hammer Method

The rebound hammer is a surface hardness tester for which an empirical correlation has been established between strength and rebound number.

The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer, which weighs about 4 lb (1.8 kg) and is suitable for both laboratory and field work. It consists of a spring-controlled hammer mass that slides on a plunger within a tubular housing.

The hammer is forced against the surface of the concrete by the spring and the distance of rebound is measured on a scale. The test surface can be horizontal, vertical or at any angle but the instrument must be calibrated in this position.

Calibration can be done with cylinders (6 by 12 in., 15 by 30 cm) of the same cement and aggregate as will be used on the job. The cylinders are capped and firmly held in a compression machine.

Several readings are taken, well distributed and reproducible, the average representing the rebound number for the cylinder. This procedure is repeated with several cylinders, after which compressive strengths are obtained.

Limitations and Advantages

The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength, but accuracy of ±15 to ±20 per cent is possible only for specimens cast cured and tested under conditions for which calibration curves have been established.

The results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate, and extent of carbonation of surface.

Pull-Out Tests on Concrete

A pull-out test measures, with a special ram, the force required to pull from the concrete a specially shaped steel rod whose enlarged end has been cast into the concrete to a depth of 3 in. (7.6 cm).

The concrete is simultaneously in tension and in shear, but the force required to pull the concrete out can be related to its compressive strength.

The pull-out technique can thus measure quantitatively the in-situ strength of concrete when proper correlations have been made. It has been found, over a wide range of strengths, that pull-out strengths have a coefficient of variation comparable to that of compressive strength.

Limitations and Advantages

Although pullout tests do not measure the interior strength of mass concrete, they do give information on the maturity and development of strength of a representative part of it. Such tests have the advantage of measuring quantitatively the strength of concrete in place.

Their main disadvantage is that they have to be planned in advance and pull-out assemblies set into the formwork before the concrete is placed. The pull-out, of course, creates some minor damage.

The test can be non-destructive, however, if a minimum pullout force is applied that stops short of failure but makes certain that a minimum strength has been reached. This is information of distinct value in determining when forms can be removed safely.

Dynamic Non Destructive Tests on Concrete

At present the **ultrasonic pulse velocity method** is the only one of this type that shows potential for testing concrete strength in situ. It measures the time of travel of an ultrasonic pulse passing through the concrete.

The fundamental design features of all commercially available units are very similar, consisting of a pulse generator and a pulse receiver.

Pulses are generated by shock-exciting piezo-electric crystals, with similar crystals used in the receiver. The time taken for the pulse to pass through the concrete is measured by electronic measuring circuits.

Pulse velocity tests can be carried out on both laboratory-sized specimens and completed concrete structures, but some factors affect measurement:

1. There must be smooth contact with the surface under test; a coupling medium such as a thin film of oil is mandatory.
2. It is desirable for path-lengths to be at least 12 in. (30 cm) in order to avoid any errors introduced by heterogeneity.
3. It must be recognized that there is an increase in pulse velocity at below-freezing temperature owing to freezing of water; from 5 to 30°C (41 – 86°F) pulse velocities are not temperature dependent.
4. The presence of reinforcing steel in concrete has an appreciable effect on pulse velocity. It is therefore desirable and often mandatory to choose pulse paths that avoid the influence of reinforcing steel or to make corrections if steel is in the pulse path.

Applications and Limitations

The **pulse velocity method** is an ideal tool for establishing whether concrete is uniform. It can be used on both existing structures and those under construction.

Usually, if large differences in pulse velocity are found within a structure for no apparent reason, there is strong reason to presume that defective or deteriorated concrete is present.

High pulse velocity readings are generally indicative of good quality concrete. A general relation between concrete quality and pulse velocity is given in Table.

Table: Quality of Concrete and Pulse Velocity

General Conditions	**Pulse Velocity ft/sec**
Excellent	Above 15,000
Good	12,000-15,000
Questionable	10,000-12,000
Poor	7,000-10,000
Very Poor	below 7,000

Fairly good correlation can be obtained between cube compressive strength and pulse velocity. These relations enable the strength of structural concrete to be predicted within ±20 per cent, provided the types of aggregate and mix proportions are constant.

The pulse velocity method has been used to study the effects on concrete of freeze-thaw action, sulphate attack, and acidic waters. Generally, the degree of damage is related to a reduction in pulse velocity. Cracks can also be detected.

Great care should be exercised, however, in using pulse velocity measurements for these purposes since it is often difficult to interpret results. Sometimes the pulse does not travel through the damaged portion of the concrete.

The pulse velocity method can also be used to estimate the rate of hardening and strength development of concrete in the early stages to determine when to remove formwork. Holes have to be cut in the formwork so that transducers can be in direct contact with the concrete surface.

As concrete ages, the rate of increase of pulse velocity slows down much more rapidly than the rate of development of strength, so that beyond a strength of 2,000 to 3,000 psi (13.6 to 20.4 MPa) accuracy in determining strength is less than ±20%.

Accuracy depends on careful calibration and use of the same concrete mix proportions and aggregate in the test samples used for calibration as in the structure.

In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

Radioactive Methods of NDT on Concrete

Radioactive methods of testing concrete can be used to detect the location of reinforcement, measure density and perhaps establish whether honeycombing has occurred in structural concrete units. Gamma radiography is increasingly accepted in England and Europe.

The equipment is quite simple and running costs are small, although the initial price can be high. Concrete up to 18 in. (45 cm) thick can be examined without difficulty.

Purpose of Non-Destructive Tests on Concrete

A variety of Non Destructive Testing (NDT) methods have been developed or are under development for investigating and evaluating concrete structures.

These methods are aimed at estimation of strength and other properties; monitoring and assessing corrosion; measuring crack siz e and cover; assessing grout quality; detecting defects and identifying relatively more vulnerable areas in concrete structures.

Many of NDT methods used for concrete testing have their origin to th e testing of more homogeneous, metallic system. These methods have a sound scientific basis, but heter ogeneity of concrete makes interpretation of results somewhat difficult.

There could be many parameters such as materials, mix, workmanship and environment, which influence the results of measurem ents.

Moreover, these test s measure some other property of concrete (e.g. hardness) and the results are interpreted to assess a different property of concrete e.g. strength, which is of primary interest.

Thus, interpretation of results is very important and difficult job where generalization is not possible. As such, operators can carry out tests but interpretation of results must be left to experts having experience and knowledge of application of such non-destructive tests.

Purposes of Non-destructive Tests are:

1. Estimating the in-situ compressive strength
2. Estimating the uniformity and homogeneity
3. Estimating the quality in relation to standard requirement
4. Identifying areas of lower integrity in comparison to other parts
5. Detection of presence of cracks, voids and other imperfections
6. Monitoring changes in the structure of the concrete which may occur with time
7. Identification of reinforcement profile and measurement of cover, bar diameter, etc.
8. Condition of prestressing/reinforcement steel with respect to corrosion
9. Chloride, sulphate, alkali contents or degree of carbonation
10. Measurement of Elastic Modulus
11. Condition of grouting in prestressing cable ducts

Types of Non Destructive Equipments

According to their use, non-destructive equipment can be grouped as under:

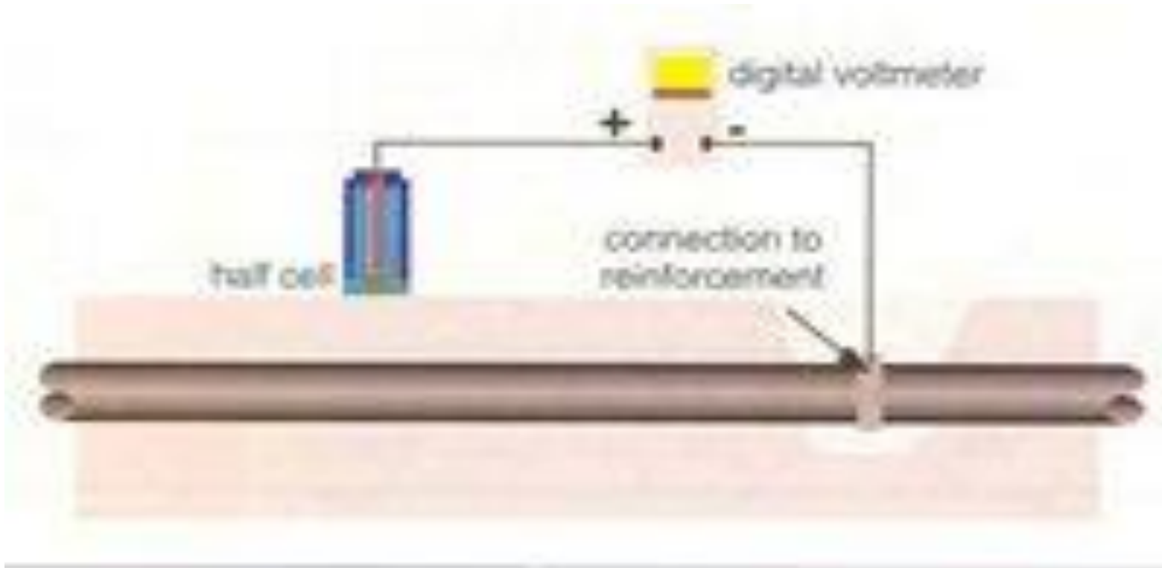
1. Strength estimation of concrete
2. Corrosion assessment and monitoring
3. Detecting defects in concrete structure
4. Laboratory tests

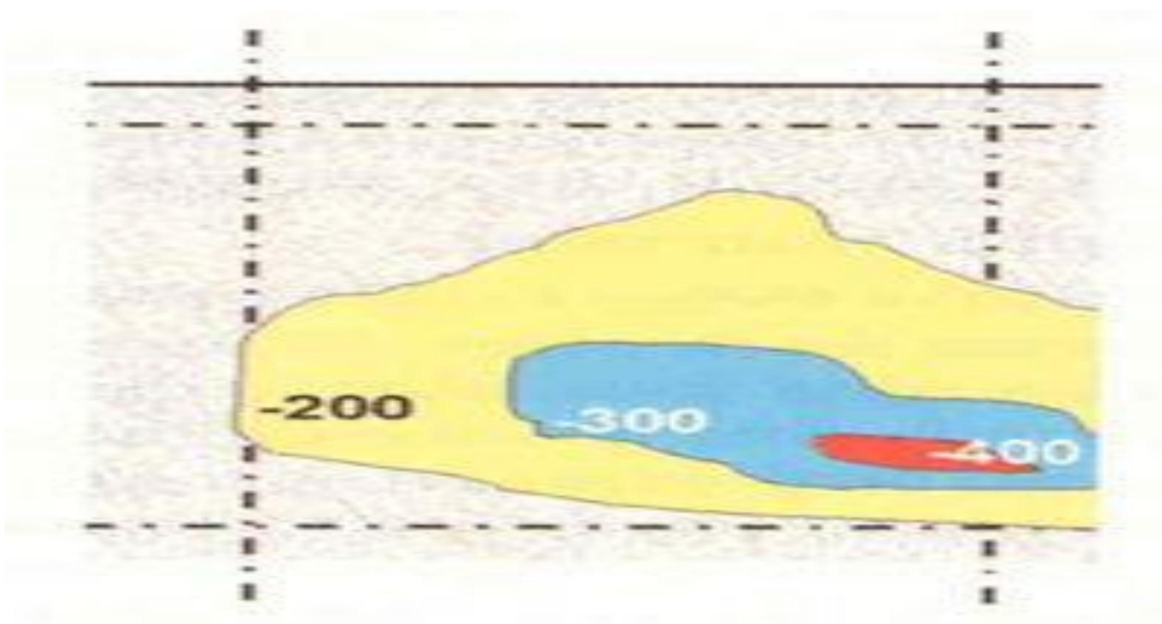
Half cell potential

Corrosion of reinforcing steel is an electro-chemical process and the behaviour of the steel can be characterised by measuring its half-cell potential. The greater the potential the higher the risk that corrosion is taking place. An electrode forms one half of the cell and the reinforcing steel in the concrete the other. The preferred reference electrode for site use is silver/silver chloride in potassium chloride solution although the copper/copper sulphate electrode is still widely used.

The survey procedure is firstly to locate the steel and determine the bar spacing using a covermeter. The cover concrete is removed locally over a suitable bar and an electrical connection made to the steel. It is necessary to check that the steel is electrically continuous by measuring the resistance between two widely separated points. The reinforcing bar is connected to the half-cell via a digital voltmeter, see diagram. Readings of half-cell potential are taken over a regular grid of points (say ½ m apart) to give a potential map of the area.

Contour lines may be plotted between points of equal potential to indicate those areas that have the greatest risk of corrosion. Locally exposing and inspecting the reinforcement in areas where both high and low risks of corrosion are indicated can be used to approximately calibrate the potential readings for the structure with respect to its present corrosion and the need for further investigation or repair.





HALF-CELL POTENTIAL TEST & RESISTIVITY TEST

Principle & Procedure

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 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 generally readings taken are at grid of 1 x 1 m for slabs, walls and at 0.5 m c/c for Column, beams

Reliability & Limitations

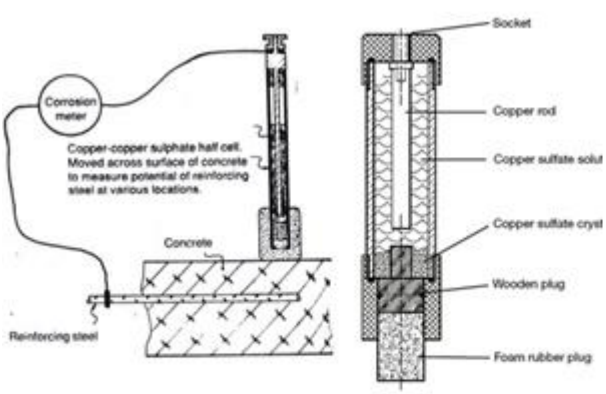
With this instruments a cover to reinforcement can be measured up to 70 – 150 mm with an accuracy of ± 15 % and Manufacturers claim accuracy of a bar diameter measurement to be less than 2 to 3 mm. But it has observed that, most of the available detectors do not accurately measure the bar diameter. Proper 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.

One end of Half-Cell connected to the reinforcement

Half-Cell Potential Test of Column

Marking of Slab and Pre-wetting for Half-Cell Potential Test

Half-Cell Potential Test of Slab



Working Diagram of Half-Cell Potential Test

Half – Cell Potentiometer

Half-Cell Potential Test

Half-Cell Potential Test of Overhead Water Tank Wall

An Equi-potential contour map can be plotted to get an overall picture of the member

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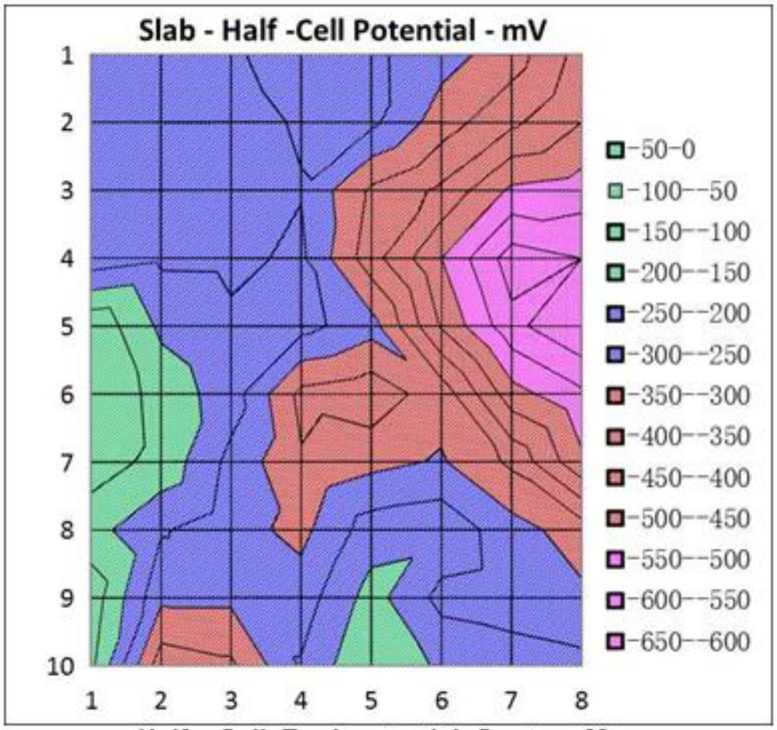


Half – Cell Equi-potential Contour Map

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

Significance and use

- This method may by 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 & Limitations

The test does not actual corrosion rate or whether corrosion activity has already started, but it indicates the probability of the corrosion activity depending upon the actual surrounding conditions and no information relating to corrosion kinetics can be obtained. 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 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.

Module 3

FAILURE OF BUILDINGS

UNIT – III [FAILURE OF BUILDINGS]

SYLLABUS: Definition of building failure-types of failures- Causes of Failures- Faulty Design, Accidental over Loading, Poor quality of material and Poor Construction practices- Fire damage- Methodology for investigation of failures-diagnostic testing methods and equipments-repair of cracks in concrete

Day 1

Topics to be covered: Definition of building failure-types of failures.

Q1. Define a building failure. List out different types of building failures.

Ans: Building failure occurs when the building loses its stability to perform its intended (design) function. Hence building failures can be categorized broadly into two groups.

1. Physical (Structural) failures
   Those are resulting in the loss of structural properties like strength.
2. Performance failures
   Those are resulting in the reduction of their function below an established acceptable limit.

Q2. Explain some of the causes of building failures.

Ans: Failure of a structure can occur from many types of problems, mostly unique to the type of structure or to the various industries.

- Due to the size, shape or the choice of material, the structure is not strong and tough enough to support the load. Failure can occur when the overstressed construction reaches a critical stress level.

- Instability, whether due to geometry, material or design, causing the structure to fail from fatigue or corrosion. These types of failures often occur at stress points, such as squared corners or from bolt holes from being too close to the material's edge, causing cracks to slowly form and then progress through cyclic loading conditions.
- Manufacturing errors, may be due to improper selection of materials, incorrect sizing, improper heat treating, failing to adhere to the design or shoddy workshop.

Causes of failures can also be categorized as manmade and natural.

Manmade causes:

- Most of the structural failures are associated with materials and are the consequence of human blunder involving a lack of know-how about materials or the combination of contrary materials.
- There are structural failures that can be endorsed to irregularity in materials. Although too much reliance is given on modern structural materials yet the manufacturing or production faults may exist even in the most dependable structural materials, such as standard structural steel or structurally blended concrete.

Natural causes:

- One of the major natural factors that result into building collapse is rainfall; others may include temperature, pressure etc.
- When there is a heavy downpour of rain, there is a possibility that one or more buildings (completed/ uncompleted), somewhere, would cave in.
- The fact remains that this is a natural factor that cannot be stopped, buildings therefore need to be constructed adequately bearing in mind such uncontrollable factors.

Building collapses are common in India due to:

- Substandard materials.
- Inadequate supervision in constructing multistory structures.
- The incidents have highlighted shoddy construction and violation of the building code, amid burgeoning demand for housing in many parts of India.

Home work:

1. Explain about different types of building failures.
2. What are the main causes of building failures.

Day 2

Topics to be covered: Causes of Failures - Accidental over Loading, Poor quality of material and Poor Construction practices

Q1. Explain about the problems of accidental over loading.

Ans: Most buildings are typically designed to meet minimum loading codes in order to save the buyer money in more heavy, structural materials, which also saves time and money in the construction process. Each room is typically designed for a certain purpose, such as living room in a residential home, garage and office in commercial/industrial buildings. Based on these room designations, the amount of minimum loading can vary from 5psf (lbs per sq. foot) to 250psf, or more.

If the designer viewed any part of the building as uninhabitable without storage, the typical loading capacity would be limited to 10psf. As soon as any storage is placed in that part, minimum code doubles to 20psf. Now this doesn't mean that one small box of toys will cause your entire attic system to collapse. However, by constantly loading that area (especially in just one location) with old furniture, heavy old televisions, and boxes of work tools, the existing structure could be compromised.

This accidental overloading can also be seen in roofing structures as well. The addition of solar panels, for example, is a good reason to have the roof structure analyzed. Although each panel is relatively light, the existing structure ought to be inspected to ensure that it can carry the additional weight.

Overloading forces may be due to

1. External (excessive wind/snow loads)
2. Internal (from heavy machinery etc.)

Overloading causes cracks in buildings. Overloading may occur in different ways.

- Overloading of the ground
- Overloading of the building itself
- Overloading of the building parts result in cracks

For example; Cracks under a floor due to overloading of slab.

Q2. Explain the effects of using poor quality material and poor construction practices.

Ans: Poor construction methods and workmanship is responsible for the failure of buildings and structure. The poor construction methods and workmanship is caused due to negligence and inadequate quality control at construction site. The effects of some of the poor construction methods are discussed below:

(a) Incorrect placement of steel

Incorrect placement of steel can result in insufficient cover, leading to corrosion of the reinforcement. If the bars are placed grossly out of position or in the wrong position, collapse can occur when the element is fully loaded.

(b) Inadequate cover to reinforcement

Inadequate cover to reinforcement permits ingress of moisture, gases and other substances and leads to corrosion of the reinforcement and cracking and spalling of the concrete.

(c) Incorrectly made construction joints

The main faults in construction joints are lack of preparation and poor compaction. The old concrete should be washed and a layer of rich concrete laid before pouring is continued. Poor joints allow ingress of moisture and staining of the concrete face.

(d) Grout leakage

Grout leakage occurs where formwork joints do not fit together properly. The result is a porous area of concrete that has little or no cement and fine aggregate. All formwork joints should be properly sealed.

(e) Poor compaction

If concrete is not properly compacted by ramming or vibration the result is a portion of porous honeycomb concrete. This part must be hacked out and recast. Complete compaction is essential to give a dense, impermeable concrete.

(f) Segregation

Segregation occurs when the mix ingredients become separated. It is the result of

1. Dropping the mix through too great a height in placing (chutes or pipes should be used in such cases)
2. Using a harsh mix with high coarse aggregate content
3. Large aggregate sinking due to over-vibration or use of too much plasticizer

Segregation results in uneven concrete texture, or porous concrete in some cases.

(g) Poor curing

A poor curing procedure can result in loss of water through evaporation. This can cause a reduction in strength if there is not sufficient water for complete hydration of the cement. Loss of water can cause shrinkage cracking. During curing the concrete should be kept damp and covered.

(h) Too high a water content

Excess water increases workability but decreases the strength and increases the porosity and permeability of the hardened concrete, which can lead to corrosion of the reinforcement. The correct water-to-cement ratio for the mix should be strictly enforced.

Home Work:

1. Explain about accidental over loading.
2. What are the effects of using poor quality material

Day 3

Q1: Explain different methods for the repair of cracks in concrete?
Ans: If we come across a crack in the concrete structure, a suitable method of concrete crack repair procedure should be selected. Successful repair procedures take into account the cause(s) of the cracking. For example, if the cracking was primarily due to drying shrinkage, then it is likely that after a period of time the cracks will stabilize. On the other hand, if the cracks are due to a continuing foundation settlement, repair will be of no use until the settlement problem is corrected.

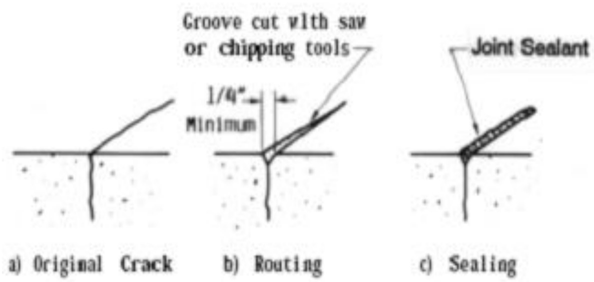
- **Routing and sealing**

Routing and sealing of cracks can be used in conditions requiring remedial repair and where structural repair is not necessary. This method involves enlarging the crack along its exposed face and filling and sealing it with a suitable joint sealant. This is a common technique for crack treatment and is relatively simple in comparison to the procedures and the training required for epoxy injection. The procedure is most applicable to approximately flat horizontal surfaces such as floors and pavements. However, routing and sealing can be accomplished on vertical surfaces (with a non-sag sealant) as well as on curved surfaces (pipes, piles and pole).

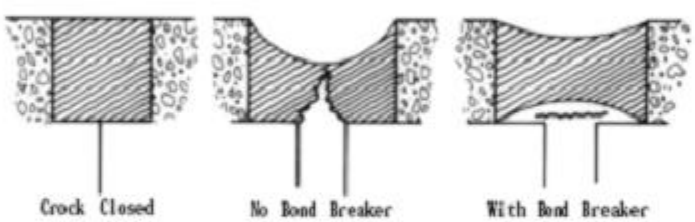
Routing and sealing is used to treat both fine pattern cracks and larger, isolated cracks. A common and effective use is for waterproofing by sealing cracks on the concrete surface where water stands, or where hydrostatic pressure is applied. This treatment reduces the ability of moisture to reach the reinforcing steel or pass through the concrete, causing surface stains or other problems.

The sealants may be any of several materials, including epoxies, urethanes, silicones, polysulfides, asphaltic materials, or polymer mortars. Cement grouts should be avoided due to the likelihood of cracking. For floors, the sealant should be sufficiently rigid to support the anticipated traffic. Satisfactory sealants should be able to withstand cyclic deformations and should not be brittle.

The procedure consists of preparing a groove at the surface ranging in depth, typically, from 1/4 to 1 in. (6 to 25 mm). A concrete saw, hand tools or pneumatic tools may be used. The groove is then cleaned by air blasting, sandblasting, or water blasting, and dried. A sealant is placed into the dry groove and allowed to cure. A bond breaker may be provided at the bottom of the groove to allow the sealant to change shape, without a concentration of stress on the bottom.



Repair of crack by sealing

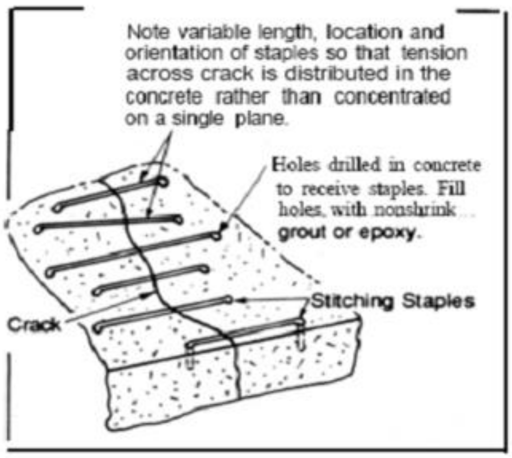


Repair using bond breaker

The bond breaker may be a polyethylene strip or tape which will not bond to the sealant. Careful attention should be applied when detailing the joint so that its width to depth aspect ratio will accommodate anticipated movement.

Stitching

Stitching involves drilling holes on both sides of the crack and grouting in U-shaped metal units with short legs (staples or stitching dogs) that span the crack as shown in Fig 3.3. Stitching may be used when tensile strength must be reestablished across major cracks. The stitching procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the staples in the holes, with either a non shrink grout or an epoxy resin-based bonding system.



- **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.

Gravity Filling

Low viscosity monomers and resins can be used to seal cracks with surface widths of 0.001 to 0.08 in. (0.03 to 2 mm) by gravity filling. High-molecular-weight methacrylates, urethanes, and some low viscosity epoxies have been used successfully. The lower the viscosity, the finer the cracks that can be filled. The typical procedure is to clean the surface by air blasting and/or water blasting. Wet surfaces should be permitted to dry several days to obtain the best crack filling.

Water blasting followed by a drying time may be effective in cleaning and preparing these cracks. Cores taken at cracks can be used to evaluate the effectiveness of the crack filling. The depth of penetration of the sealant can be measured. Shear (or tension) tests can be performed with the load applied in a direction parallel to the repaired cracks (as long as reinforcing steel is not present in the core in or near the failure area). For some polymers the failure crack will occur outside the repaired crack.

Drilling and plugging

Drilling and plugging a crack consists of drilling down the length of the crack and grouting it to form a key. This technique is only applicable when cracks run in reasonable straight lines and are accessible at one end. This method is most often used to repair vertical cracks in retaining walls. A hole [typically 2 to 3 in. (50 to 75 mm) in diameter] should be drilled, centered on and following the crack.

- **Pre-stressing steel**

  Post-tensioning is often the desirable solution when a major portion of a member must be strengthened or when the cracks that have formed must be closed (Fig. 3.5). This technique uses pre stressing strands or bars to apply a compressive force. Adequate anchorage must be provided for the pre stressing steel, and care is needed so that the problem will not merely migrate to another part of the structure.

Q2: Explain the procedure involved in Epoxy Injection method for the repair of cracks in concrete.

Ans: Epoxy injection

Cracks as narrow as 0.002 in. (0.05 mm) can be bonded by the injection of epoxy. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures. However, unless the cause of the cracking has been corrected, it will probably recur near the original crack. If the cause of the cracks cannot be removed, then two options are available.

One is to rout and seal the crack, thus treating it as a joint, or, establish a joint that will accommodate the movement and then inject the crack with epoxy or other suitable material. With the exception of certain moisture tolerant epoxies, this technique is not applicable if the cracks are actively leaking and cannot be dried out. Wet cracks can be injected using moisture tolerant materials, but contaminants in the cracks (including silt and water) can reduce the effectiveness of the epoxy to structurally repair the cracks.

The use of a low-modulus, flexible adhesive in a crack will not allow significant movement of the concrete structure. Epoxy injection requires a high degree of skill for satisfactory execution, and application of the technique may be limited by the ambient temperature.

- **Clean the cracks**: The first step is to clean the cracks that have been contaminated; to the extent this is possible and practical. Contaminants such as oil, grease, dirt, or fine particles of concrete prevent epoxy penetration and bonding, and reduce the effectiveness of repairs. Preferably, contamination should be removed by vacuuming or flushing with water or other specially effective cleaning solutions.
- **Seal the surfaces:** Surface cracks should be sealed to keep the epoxy from leaking out before it has gelled. Where the crack face cannot be reached, but where there is backfill, or where a slab-on-grade is being repaired, the backfill material or sub base material is sometimes an adequate seal. A surface can be sealed by applying an epoxy, polyester, or other appropriate sealing material to the surface of the crack and allowing it to harden. If a permanent glossy appearance along the crack is objectionable and if high injection pressure is not required, a strippable plastic surface sealer may be applied along the face of the crack. When the job is completed, the surface sealer can be stripped away to expose the gloss-free surface. Cementitious seals can also be used where appearance of the completed work is important. If extremely high injection pressures are needed, the crack can be cut out to a depth of 1/2 in. (13 mm) and width of about 3/4 in. (20 mm) in a V-shape, filled with an epoxy, and struck off flush with the surface.
- Install the entry and venting ports. Three methods are in general use:

1. **Fittings inserted into drilled holes:** This method was the first to be used, and is often used in conjunction with V-grooving of the cracks. The method entails drilling a hole into the crack, approximately 3/4 in. (20 mm) in diameter and 1/2 to 1 in. (13 to 25 mm) below the apex of the V grooved section.
2. **Bonded flush fitting:** When the cracks are not V grooved , a method frequently used to provide an entry port is to bond a fitting flush with the concrete face over the crack. The flush fitting has an opening at the top for the adhesive to enter and a flange at the bottom that is bonded to the concrete.
3. **Interruption in seal:** Another system of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

- **Mix the epoxy:** This is done either by batch or continuous methods. In batch mixing, the adhesive components are premixed according to the manufacturer's instructions, usually with the use of a mechanical stirrer, like a paint mixing paddle. Care must be taken to mix only the amount of adhesive that can be used prior to commencement of gelling of the material.

- **Inject the epoxy:** Hydraulic pumps, paint pressure pots, or air-actuated caulking guns may be used. The pressure used for injection must be selected carefully. Increased pressure often does little to accelerate the rate of injection. If the crack is vertical or inclined, the injection process should begin by pumping epoxy into the entry port at the lowest elevation until the epoxy level reaches the entry port above. For horizontal cracks, the injection should proceed from one end of the crack to the other in the same manner. The crack is full if the pressure can be maintained. If the pressure can not be maintained, the epoxy is still flowing into unfilled portions or leaking out of the crack.
- **Remove the surface seal:** After the injected epoxy has cured, the surface seal should be removed by grinding or other means as appropriate.

Home work:

1. Explain different methods for the repair of cracks in concrete?
2. Explain Epoxy injection process.

Day 4

Q1: Explain the ill effects of Fire Damage on concrete structures.

Ans: A crack is a complete or incomplete separation of concrete into two or more parts produced by breaking or fracturing. It destroys the wall's integrity, affects the structure safety even reduce the durability of structure. Cracks develop due to deterioration of concrete or corrosion or reinforcement bars due to poor construction or inappropriate selection of constituent material and by temperature and shrinkage effects. Cracking can occur in hardened and fresh, or plastic, concrete as a result of volume changes and repeated loading. Active cracks may require more complex repair procedures that may include eliminating the actual cause of the cracking in order to ensure a successful long-term repair. Failure to address the underlying cause may result in the crack's repair being short-term, making it necessary to go through the same process again. Cracks' sizes range from micro-cracks that expose the concrete to efflorescence to larger cracks caused by external loading conditions. Noting cracks' sizes shapes and locations can aid in determining their initial causes. The stress-strain response of concrete is closely associated with the formation of micro cracks, that is, cracks that form at coarseaggregate boundaries (bond cracks) and propagate through the surrounding mortar (mortar cracks). STRUCTURAL CRACKS These cracks occur due to incorrect design, faulty construction or overloading and these may endanger the safety of a building. Structural cracks are of important and have to be dealt more carefully because neglect to this leads to unsafe structure. Structural cracks are due to poor construction sites, swollen soil, poor soil bearing or overloading. For Example as we see in the ground floor of Block of A, in the western side of room no A001, structural cracks started to appear (Figure 1) these cracks are usually accompanied by other signs of foundation issues such as sticking doors and windows, slanted doors, sloping floors and cracks in porches. The common characteristics of structural cracks include: Continuous horizontal cracks along walls Vertical cracks that are wider at the top or bottom Stair-step cracks• Foundation wall cracks• Cracks in beams, foundation slabs• Angled cracks that form in the corners of walls with a horizontal crack in the center• Cracks wider than 1/8"• Cracks extending to the upper levels of the home• To control this, Rebar technique is adopted in stages, which is shown in Figure 3, Figure 4. Rebar also known as reinforcing steel, reinforcement steel, is a steel bar or mesh of steel wires used as a tension device in reinforced concrete and reinforced masonry structures to strengthen and hold the concrete in tension. Rebar's surface is often patterned to form a better bond with the concrete. Concrete is a material that is very strong in compression, but relatively weak in tension. To compensate for this imbalance in concrete's behavior, rebar is cast into it to carry the tensile loads. Most steel reinforcement is divided into primary and secondary reinforcement

NON-STRUCTURAL CRACKS Non Structural cracks occur mostly due to internally induced stresses in building materials. These cracks normally do not endanger the safety but may look unsightly, create an impression of faulty work or give a feeling of instability. These are mostly due to internally induced stresses in buildings materials and do not endanger safety of a building but may look unsightly, or may create an impression of faulty work or may give a feeling of instability. In some situations due to penetration of moisture through them non-structural cracks may spoil the internal finishes thus adding to the cost of maintenance, or corrode the reinforcement, thereby adversely affecting the stability of the Structure in long run. Non-structural cracks started to appear Controlling measures such as Portland cement grouting can be taken. 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 Drying shrinkage After hardening, concrete begins to shrink as water not consumed by cement hydration leaves the system. This is known as drying shrinkage. Water above that necessary to hydrate cement is required for proper workability and finish ability – the water is called "water of convenience." In general, the higher the additional water content, the higher the shrinkage potential. For small, unrestrained concrete specimens (prisms), a low ultimate shrinkage (strain) is considered to be less than 520 millionths (at 50 percentage relative humidity and [73 degrees Fahrenheit]). Typical concrete shrinkage has been measured at 520 to 780 millionths. However, for some mixtures, shrinkage exceeding 1,100 millionths has been documented. Using concrete with a higher drying shrinkage increases the risk of problems with the floor performance. Drying shrinkage cracks started to appear Controlling measures such as Dry packing can be chosen, Dry packing is the hand placement of a low water content mortar followed by tamping or ramming of the mortar into place, producing intimate contact between the mortar and the existing concrete. Because of the low water-cement ratio of the material, there is little shrinkage, and the patch remains tight and can have good quality with respect to durability, strength, and water tightness. To minimize shrinkage in place, the mortar should stand for 1/2 hour after mixing and then should be remixed prior to use. The mortar should be placed in layers about 3/8 in. (10 mm) thick. Each layer should be thoroughly compacted over the surface using a blunt stick or hammer, and each underlying layer should be scratched to facilitate bonding with the next layer. The repair should be cured by using either water or a curing compound. The simplest method of moist curing is to support a strip of folded wet burlap along the length of the crack

CRACK DUE TO THERMAL PROBLEMS External seasonal temperature variations In thicker sections, the internal temperature rises and drops slowly, while the surface cools rapidly to ambient temperature. Surface contraction due to cooling is restrained by the hotter interior concrete that doesn't contract as rapidly as the surface. This restraint creates tensile stresses that can crack the surface concrete as a result of this uncontrolled temperature difference across the cross section. In most cases thermal cracking occurs at early ages. In rare instances thermal cracking can occur when concrete surfaces are ex-posed to extreme temperature rapidly. External seasonal temperature variations cracks started to appear Remedial measures can be taken as Epoxy injection method. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures (ACI 503R). However, unless the cause of the cracking has been corrected, it will probably recur near the original crack.

CRACK DUE TO STRUCTURAL PROBLEMS Accidental overload The cross section of concrete is designed with both calculated and estimated loads, determined from building codes. Design includes such factors as the strength of the concrete, the number, sizing, and placement of reinforcing bars, and size and shape of the concrete cross section. When a structure is overloaded to the extent not covered in safety factors, concrete may be damaged or fail. Overloading may be in shear, flexure, or tension, or may be a result of fatigue or cyclic loading. Accidental overload cracks started to appear Remedial measures can be taken as Conventional reinforcement,cracked reinforced concrete have been successfully repaired by inserting reinforcing bars and bonding them in place with epoxy. This technique consists of sealing the crack, drilling holes that intersect the crack plane at approximately 90 degree, filling the hole and crack with injected epoxy and placing a reinforcing bar into the drilled hole. Typically, No. 4 or 5 (10 M or 15 M) bars are used, extending at least 18 in. (0.5 m) each side of the crack. The reinforcing bars can be spaced to suit the needs of the repair. They can be placed in any desired pattern, depending on the design criteria and the location of the in-place reinforcement.

CRACKS DUE TO PLASTIC PROBLEMS Plastic shrinkage Plastic shrinkage cracks typically occur on horizontal surfaces exposed to the atmosphere. These cracks are different from other early cracks becausethey are deeper and wider. Plastic shrinkage cracks are typically two to four inches deep and approximately one-eighth inch wide. They may also extend several feet in length adopting a crow's-foot pattern. These cracks form before any bond has developed between the aggregate particles and mortar. Therefore, the cracks tend to follow the edges of large aggregate particles or reinforcing bars and never break through the aggregate particles. Although plastic shrinkage cracks usually do not impair the structural performance of the slab, cracks in some building floors have been blamed for leakage. Plastic shrinkage cracks started to appear Remedial measures can be taken Epoxy injection method. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures (ACI 503R). However, unless the cause of the cracking has been corrected, it will probably recur near the original crack MICRO CRACKS They are usually very fine voids caused by large capillary pores resulting from the use of low grades (strength) of concrete with high water to cement ratio. They could also occur due to addition of excess water or high water to cement ratio of concrete mix. Fine cracks are generally present in concrete and can occur due to various reasons. They do not pose a serious threat to concrete deterioration initially as they are generally not deep and are discontinuous. With lapse of time due to variations in temperatures, changes in weather conditions, changes in loading conditions they increase in depth, length and width and combine with other fine cracks to create continuous passage for moisture, chlorides, sulphates and other chemicals from the environment to enter and start corrosion of steel in concrete and other deleterious reactions.

Micro cracks started to appear Remedial measures can be taken as surface treatments, Low solids and low-viscosity resin-based systems have been used to seal the concrete surfaces, including treatment of very fine cracks. They are most suited for surfaces not subject to significant wear. Bridge decks and parking structure slabs, as well as other interior slabs may be coated effectively after cracks are treated by injecting with epoxy or by routing and sealing. Materials such as urethanes, epoxies, polyesters, and acrylics have been applied in thickness of 0.04 to 2.0 in. (1 to 50 mm), depending on the material and purpose of the treatment.

Module 5

Repair Techniques

Module – V [Repair Techniques]

SYLLABUS: Grouting, Jacketing, Shotcreting, externally bondedplates, Nailing, Underpinning and under water repair; Materials, Equipments,Precautions and Processes.

Day 1

Q1: What is Grouting? Explain about different Grout materials.

Ans: Grout is a particularly fluid form of concrete used to fill gaps. Grout is generally a mixture of water, cement, and sand, and is employed in pressure grouting, embedding rebar in masonry walls, connecting sections of pre-cast concrete, filling voids, and sealing joints such as those between tiles. It is often color tinted when it will remain visible, and sometimes includes fine gravel when being used to fill large spaces such as the cores of concrete blocks). Unlike other structural pastes such as plaster or joint compound, correctly mixed and applied grout forms a waterproof seal.

The process of grouting of concrete cracks is repeated with other holes till all the holes are covered. On the day of grouting all the plugs are removed to drain out excess water and restored before commencing grouting. The same sequence as described above is adopted for injecting the cement grout.

Q2: What is Jacketing? Explain about different jacketing materials.

Ans: Jacketing is the process whereby a section of an existing structural member is restored to original dimensions or increased in size by encasement using suitable materials. A steel reinforcement cage or composite material wrap can be constructed around the damaged section onto which shotcrete or cast-in- place concrete is placed.

Collars are jackets that surround only for a part of a column or pier. These are usually used to provide increased support to the slab or beam at the top of the column. The form for the jacket consists of timber, corrugated metal, precast concrete, rubber, fiberglass, or special fabric; and may be permanent in some cases. The form must be provided with spacers to ensure equal clearance between it and the existing member. Materials, like conventional concrete and mortar, epoxy mortar, grout, and latex-modified mortar and concrete, are used as encasement materials. For jacketing, the void between the form and the existing member is filled using pumping, tremie, or preplaced aggregate concrete.

Jacketing is particularly used for the repair of deteriorated columns, piers, and piles and may easily be employed in underwater applications. The method is applicable for protecting concrete, steel, and timber sections against further deterioration and for strengthening. Permanent forms are preferred where protection against weathering, abrasion, and chemical pollution is desired. The collar provides increased shear capacity for the slab, and it decreases the effective length of the column. Architecturally collars are considered better than jacketing but performing the same structural function.

Before applying jackets or collars, all deteriorated concrete must be removed, cracks must be repaired, existing reinforcement must be cleaned, and surfaces must be prepared. The surface preparation improves the bond of the newly placed materials with the existing structure, which is difficult for underwater repairs. For underwater conditions, a plastic shell may be applied at the splash zone to help minimize abrasion. A drawback of jackets and collars is that they occupy space that was earlier available for other uses.

Home work:

1. Explain about different grout materials.
2. Explain how jacketing help repair concrete structures.

Day 2

Q1: Explain in detail about shotcreting.

Ans: Shotcrete is usually an all-inclusive term for both the wet-mix and dry-mix versions. In pool construction, however, the term "shotcrete" refers to wet-mix and "gunite" to dry-mix Fiber reinforcement (steel or synthetic) is also used for stabilization in applications such as slopes or tunneling. Cementitious binder and aggregates thoroughly mixed (central mixing, transit mixer, volumetric proportioning mixer or dry bagged premix) Water Added if necessary to bring shotcrete to “Earth Dry” consistency – 3 to 6% moisture content. Mix added to shotcrete delivery equipment or gunCompressed air conveys the shotcrete from the gun down the hose. Water introduced under pressure through a water ring at the nozzle. Shotcrete jetted from a nozzle at high speed onto a surface with the force of the impacting jet compacting the material.

Q2: Explain about nailing materials and their importance.

Ans: A nail consists of a metal rod or shank, pointed at one end and usually having a formed head at the other, that can be hammered into pieces of wood or other materials to fasten them together. A nail is usually made of steel, although it can be made of aluminum, brass, or many other metals. The surface can be coated or plated to improve its corrosion resistance, gripping strength, or decorative appearance. The head, shank, and point may have several shapes based on the intended function of the nail. Of the nearly 300 types of nails made in the United States today, most are used in residential housing construction. The average wood frame house uses between 20,000 and 30,000 nails of various types and sizes.

Nails are divided into three broad categories based on their length. In general nails under 1 inch (2.5 cm) in length are called tacks or brads. Nails 1-4 inches (2.5-10.2 cm) in length are called nails, while those over 4 inches (10.2 cm) are some-times called spikes. These categories are roughly defined, and there is considerable crossover between them.

The length of a nail is measured in a unit called the penny. This term comes from the use of nails in England in the late 1700s when it referred to the price of one hundred nails of that size. For example, a "ten penny nail" would have cost ten pennies per hundred. The symbol for penny is "d," as in 10d. This designation is believed to go back to the time of the Roman Empire when a similar form of measurement for hand-forged nails involved a common Roman coin known as the *denarius.* Today the term penny only defines the length of a nail and has nothing to do with the price. The shortest nail is 2d which is 1 inch (2.5 cm) long. A 10d nail is 3 inches (7.6 cm) long, and a 16d nail is 3.5 inches (8.9 cm) long. Between 2d and 10d the nail length increases 0.25 inch (0.64 cm) for each penny designation. Beyond 10d there is no logical progression to the lengths and designations.

Most nails are made of steel. Aluminum, copper, brass, bronze, stainless steel, nickelsilver, monel, zinc, and iron are also used. Galvanized nails are coated with zinc to give them added corrosion resistance. Blued steel nails are subjected to a flame to give them a bluish oxide finish that provides a certain amount of corrosion resistance. So-called cement-coated nails are actually coated with a plastic resin to improve their grip. Some brads are given a colored enamel coating to blend in with the color of the material they are fastening.

Process

Most nails are made from coils of metal wire. The wire is fed into a nail-making machine which can produce up to 700 nails per minute. The nails may then be further twisted or formed, cleaned, finished, and packaged.

The demand for mass-produced commodity nails is dependent on the fluctuations in the housing market, which varies with the economy. Demand for these nails is also subject to competition from foreign manufacturers, further reducing profits.

The demand for specialty nails, on the other hand, is expected to continue to grow and be profitable. New building materials, such as composite wood-fiber and cement-based siding and roofing, require new specialty nails. New corrosion-resistant coatings for nails are also being developed.

One unique new nail market is the result of the increase in building restoration and preservation efforts throughout the country. One nail factory in Massachusetts makes old-fashioned cut nails. They estimate that 20% of their work is in producing a variety of these nails for use in authentic building restoration projects.

Homework:

1. **Explain about shotcreting in concrete.**
2. **Explain about different types of nails used in concrete.**

Day 3

Q1: what is Underpinning and explain about it.

Ans: In construction or renovation, underpinning is the process of strengthening the foundation of an existing building or other structure. Underpinning may be necessary for a variety of reasons:

- The original foundation is simply not strong or stable enough.
- The usage of the structure has changed.
- The properties of the soil supporting the foundation may have changed (possibly through subsidence) or were mischaracterized during design.
- The construction of nearby structures necessitates the excavation of soil supporting existing foundations.
- To increase the depth or load capacity of existing foundations to support the addition of another storey to the building (above or below grade).

- It is more economical, due to land price or otherwise, to work on the present structure's foundation than to build a new one.
- Earthquake, flood, drought or other natural causes have caused the structure to move, thereby requiring stabilisation of foundation soils and/or footings.

Underpinning may be accomplished by extending the foundation in depth or in breadth so it either rests on a more supportive soil stratum or distributes its load across a greater area. Use of micropiles[1] and jet grouting are common methods in underpinning. An alternative to underpinning is the strengthening of the soil by the introduction of a grout, including expanding urethane-based engineered structural resins. Underpinning may be necessary where P class (problem) soils in certain areas of the site are encountered. Through semantic change the word underpinning has evolved to encompass all abstract concepts that serve as a foundation.

Underpinning With Screw Piles and Brackets

Underpinning with screw piles and brackets is normally used in certain instances where traditional underpinning process is not possible. Some buildings might require excavating to great depths or maybe is unfeasible to use a piling rig and the screw piles and brackets method is then selected. The screw piles and brackets can be installed by only a two man crew by hand or using small equipment such as a mini excavator. Screw piles can be installed in foundations having the capacity to work in tension and compression, withstand vertical and lateral wind forces, and vibration and shear forces. They are ideal when used with underpinning support brackets.

The structure can then be lifted back to a level position and the weight of the foundation transferred to the pier and bracket system.

Screw piles have many advantages over traditional pilings, such as the speed of installation, little noise and minimal vibration that may cause damage to the surrounding area.

Pile and Beam

Underpinning with pile and beams is another great and preferred method to alleviate footing. Using this system requires that a min-pile must be installed on either side of the affected wall. After the piles have been installed, then brickwork is removed below the wall and reinforced concrete needle beam is used to connect the piles and support the wall. Reducing the distance between needle beams can accommodate very high loads. The bearing capacity of the underlying strata will determine the number, diameter, depth and spacing of piles used. Augered piles or case driven piles can be used with this method of underpinning. The advantages of underpinning with pile and beams are:

- Suitable for restricted access
- Faster than traditional underpinning
- High load capability
- Less disruption, less spoil generated and completed quickly

Underpinning Using Piled Raft

Underpinning with a piled raft must be used when the whole structure needs to be underpinned. It is recommended when foundations are too deep for other underpinning methods or in areas where the soil is so hard that small equipment could not excavate up to require depth. Piles are placed at determined locations by loading conditions; then pockets below footings are broken and reinforced needle beams are placed to bear the wall's load.

A ring beam is then built to link all needles and the structure is poured with concrete.

Advantages of this system are:

- Provides lateral and traverse ties throughout the structure.
- Economical at depths greater than 1.5m.
- No need for external access.
- Reduces disruption to drainage systems.

Homework:

1. **What are the advantages of underpinning.**
2. **Explain about under water repair materials.**

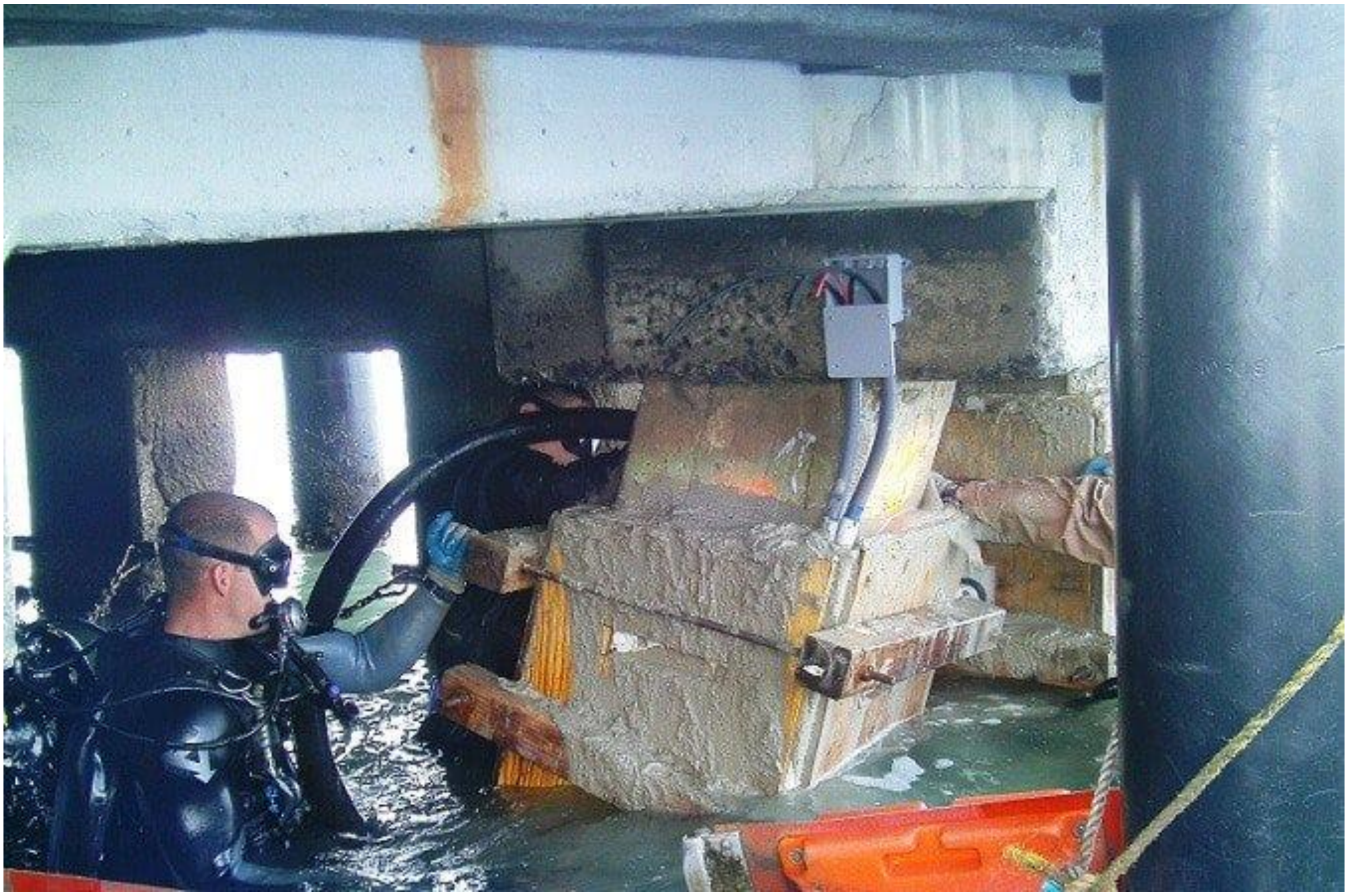
Day 4

Q1: Explain about different types of underwater repair materials and practices.

Ans: Repair of Underwater Concrete Structures – Methods and Procedure

Following are the different methods to repair underwater concrete structures:

- Surface spalling repair
- Large scale repair of underwater structural concrete
- Preplaced aggregate concrete
- Injection technique for restoring underwater concrete structure
- Guniting or shotcrete method to repair underwater concrete structure
- Steel sleeve repairing technique of underwater concrete



Surface Spalling Repair of Underwater Concrete Structures

Cover of underwater structural elements can spall off due to accidental damages. The damaged concrete cover must be replaced and repaired to prevent reinforcement corrosion in the future.

Slightly deteriorated regions will turn to more severe and dangerous damages in short time, especially in splash zones. The deteriorated area of underwater structure should be cleared from both marine growth and loose concrete before repairing procedures are began.

After that, based on the amount of damages, the boundary of spalled area should be saw-cut to a depth of 1.2-2 cm. In splash zones, cementitious mortar can be used for the damages region and water tolerant epoxy mortar may be employed in the case of small damage area.

For large repaired area, formworks might be used to hold the repairing material at its position. This could postpone enhancement work and prevent epoxy coat utilization because if it hardens it would produce smooth surface and consequently the bond will be weak.

Procedure of Surface Spalling Repair of Underwater Concrete

The basic procedures of surface spalling repair technique might include:

- Flush damaged region with fresh water completely.
- Apply a bonding coat.
- Apply the repair mortar before the coat is set.
- Apply a curing membrane to the applied repair mortar.
- Protect the repaired area against wave action until it hardened adequately.

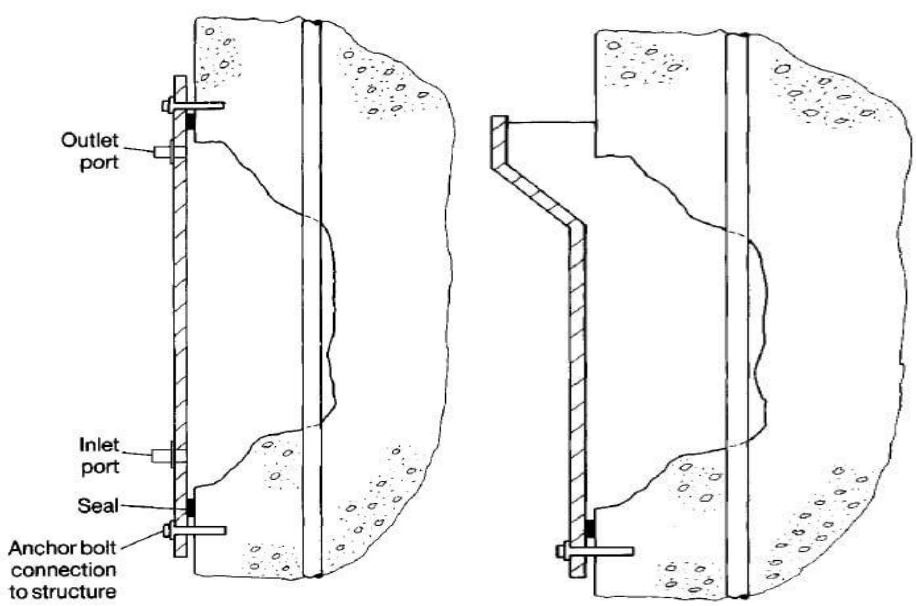


Fig. Formwork for Placement by Pumping

Fig. Bird's-Mouth Type Formwork for Surface Spalling Repair

Large Scale Repair of Underwater Concrete Structures

This technique is suitable option when damages caused by structural overloading, fire, ship impact, or reinforcement corrosion especially in the splash zone.

In the case where large areas are required to be restored, repair method and material selection is considerably important if shrinkage or bleeding lead to leakage path at the top of parent concrete and repair material interface.

When repairing materials have great thickness, thermal cracking may develop due to rise of temperature even though surrounding water decline the temperature rise.

Furthermore, repair of reinforcement is frequently needed because of distortion and considerable corrosion of reinforcement.

Procedure of Large Scale Repair of Underwater Concrete

The large-scale repair procedure is usually as follows:

- Prepare the damaged region
- Clean reinforcement adequately
- Determine formwork typed based on the placement method of repairing material
- Decrease concrete contamination with salts by flushing formwork with fresh concrete short period before pouring of repair concrete
- Pumping is used most of the time for placing repair material and it should start at the bottom of the formwork to push water out of the formwork from the bottom.

Preplaced Aggregate Concrete

After the installing the formwork at the area intended to be repaired, a well graded aggregate is placed and compacted in the formwork. It is recommended that, fresh water is employed to clean the aggregate prior to grout placement.

Then, appropriate grout is injected into the base of the well compacted aggregate in the formwork. In this process, water and voids are expelled out of the aggregate by the grout.

It is essential that the formwork is grout proof in order to prevent leaking from the formwork in addition to provide proper venting at the top to permit escaping voids and air.

It is substantially significant to sufficiently fill the formwork to the top of damage region with aggregate because when the grout is placed and aggregate is not present, the gout will shrink and cracks will develop.

It is advised that, vibration is not applied during injection to avoid washing out of grout.

Injection Technique for Restoring Underwater Concrete Structures

Similar to the steps used for repairing dry structures, injection of cementitious grout or resin can be employed to repair cracks and or voids in the concrete structure underwater.

Not only does the material selection is substantially based on void or crack size but also on possibility of anticipated movement of the member in the future.

Epoxy resin is appropriate for crack width of 0.1 mm whereas cement grout is suitable for crack width of greater than few millimeters and when crack width is smaller than 0.1 mm, the injection is not required.

Applied pressure and the time for which the pressure is kept prior to solidify repair material. There are two methods of injection that include pressure injection and gravity feed.

It is necessary to break the concrete to reinforcement if corrosion evidence can be seen and complete repairing should be suggested instead of injection method.

The procedures for injection technique are

- Prepare concrete surface along crack length
- Along crack length, fix inspection nipples at specific intervals
- Seal crack surface along the whole length of the crack
- Remove contamination using fresh water and be sure that injection path is open
- At one end of the crack, inject epoxy resin or cement grout into the crack through nipples

Guniting or Shotcrete Method to Repair Underwater Concrete Structures

This technique is the best option when large surface area or columns or beams are encased and usually dry process is used. In the dry method, dry mix is transferred by a hose and water is added to the dry mix at the nozzle.

Despite the fact that, Guniting method is not suitable for underwater repairing but it can be employed in splash or tidal zones if seriously rapid setting additives is introduced.

The success of this technique depends on nozzle-man skill and experience in adjusting water addition, pressure, and thickness uniformity. The maximum thickness of shotcrete should be restricted to fifty millimeter even though second layer can be employed if thicker layer is required.

Steel Sleeve Repairing Technique of Underwater Concrete

In this method, a steel sleeve is used around a pile or column after that the space between the sleeve and pile or column is filled with mortar or concrete. The sleeve could be designed to make rooms for further reinforcement corrosion.

The sleeve need to exceed top and bottom of the damaged length of the pile and withstand the force of the pile in the case that the bars are ineffective due to corrosion. Typical arrangement of steel sleeve is shown in Figure.

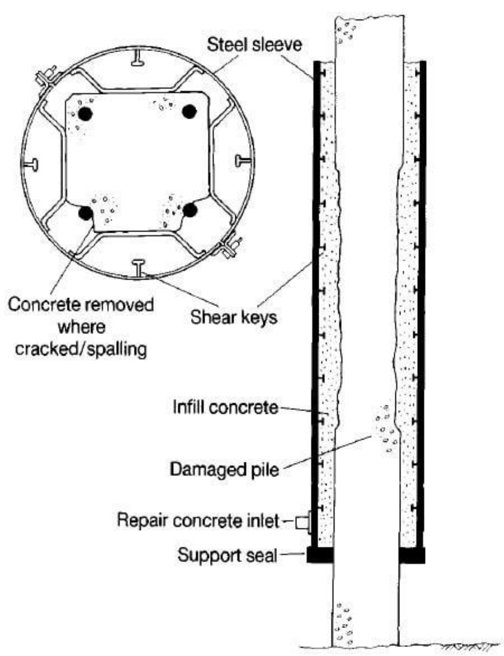


Fig. Arrangement of Steel Sleeve Repair

A steel sleeve repair technique procedure is as follows

- Prepare the damaged pile by loose concrete and marine growth
- Clamp a temporary support or sealing ring around the pile below the damages area
- Both the two semi circular sections of the sleeve
- Pump grout or cement at the bottom of the sleeve

- Remove the temporary support and employ corrosion protection to steel sleeve.

UNDERPINNING

In construction or renovation, **underpinning** is the process of strengthening the foundation of an existing building or other structure.

Underpinning may be necessary for a variety of reasons:

- The original foundation is not strong or stable enough.
- The usage of the structure has changed.
- The properties of the soil supporting the foundation may have changed (possibly through subsidence) or were mischaracterized during design.
- The construction of nearby structures necessitates the excavation of soil supporting existing foundations.
- To increase the depth or load capacity of existing foundations to support the addition of another storey to the building (above or below grade).
- It is more economical, due to land price or otherwise, to work on the present structure's foundation than to build a new one.
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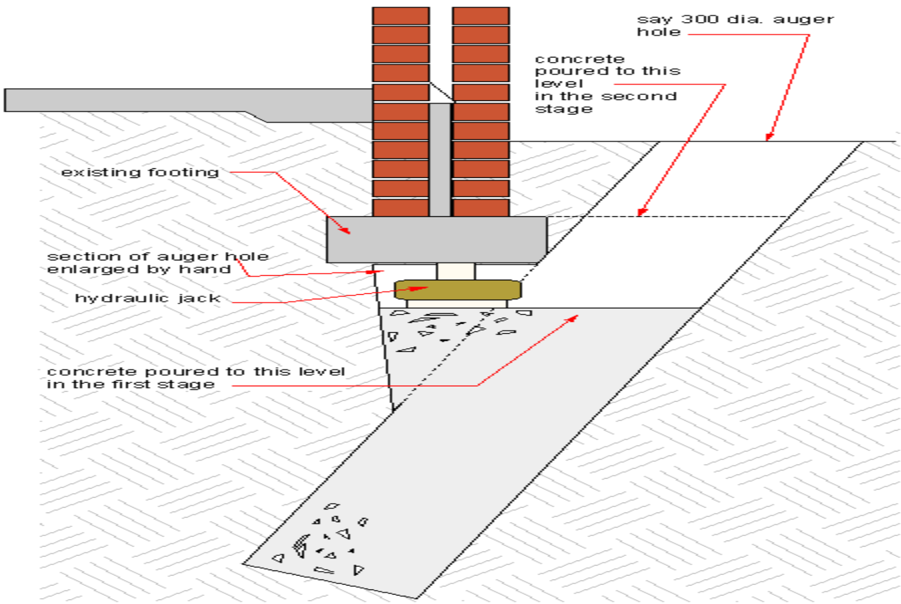
Underpinning may be accomplished by extending the foundation in depth or breadth so it either rests on a more supportive soil stratum or distributes its load across a greater area. Use of micropiles[1] and jet grouting are common methods in underpinning. An alternative to underpinning is the strengthening of the soil by the introduction of a grout, including expanding urethane-based engineered structural resins.

Underpinning may be necessary where P class (problem) soils in certain areas of the site are encountered.

Through semantic change the word underpinning has evolved to encompass all abstract concepts that serve as a foundation.



Mass Concrete Underpinning

'Traditional underpinning,' the mass concrete underpinning method is nearly 100 years in age, and the protocol has not changed. This underpinning method strengthens an existing structure's foundation by digging boxes by hand underneath and sequentially pouring concrete in a strategic order. The result is a foundation built underneath the existing foundation. This underpinning method is generally applied when the existing foundation is at a shallow depth, but works well up to fifty feet (fifteen meters) deep. The method has not changed since its inception with its use of utilitarian tools such as shovels and post hole diggers. Heavy machinery is not employed in this method due to the small size of the boxes being dug. There are several advantages to using this method of underpinning, including the simplicity of the engineering, the low cost of labor, and the continuity of the structure's use during construction.

Beam and base underpinning

The beam and base method of underpinning is a more technically advanced adaptation of traditional mass concrete underpinning. A reinforced concrete beam is constructed below, above or in replacement of the existing footing. The beam then transfers the load of the building to mass concrete bases, which are constructed at designed strategic locations. Base sizes and depths are dependent upon the prevailing ground conditions. Beam design is dependent upon the configuration of the building and the applied loads. Anti-heave precautions are often incorporated in schemes where potential expansion of clay soils may occur.[2]

Mini-piled underpinning

Mini-piles have the greatest use where ground conditions are variable, where access is restrictive, where environmental pollution aspects are significant, and where structural movements in service must be minimal. Mini-piled underpinning is generally used when the loads from the foundations need to be transferred to stable soils at considerable depths - usually in excess of 5 m (16 ft). Mini-piles may either be augured or driven steel cased, and are normally between 150 mm (5.9 in) and 300 mm (12 in) in diameter. Structural engineers will use rigs which are specifically designed to operate in environments with restricted headroom and limited space, and can gain access through a regular domestic doorway. They are capable of constructing piles to depths of up to 15 m (49 ft). The technique of minipiling was first applied in Italy in 1952, and has gone through many different names, reflecting worldwide acceptance and expiration of the original patents.[3]
The relatively small diameter of mini-piles is distinctive of this type of underpinning and generally uses anchoring or tie backs into an existing structure or rock. Conventional drilling and grouting methods are used for this method of underpinning. These mini-piles have a high slenderness ratio, feature substantial steel reinforcing elements and can sustain axial loading in both senses.[3] The working loads of mini-piles can sustain up to 1,000 kN (100 long tons-force; 110 short tons-force) loads.
In comparison to Mass Concrete Underpinning, the engineering aspect of mini-piles is somewhat more involved, including rudimentary engineering mechanics such as statics and strength of materials. These mini-piles must be designed to work in tension and compression, depending on the orientation and application of the design. In detail, attention with design must be paid analytically to settlement, bursting, buckling, cracking, and interface consideration, whereas, from a practical viewpoint, corrosion resistance, and compatibility with the existing ground and structure must be regarded.

Mini-piled underpinning schemes

Mini-piled underpinning schemes include pile and beam, cantilever pile-caps and piled raft systems. Cantilevered pile-caps are usually used to avoid disturbing the inside of a building, and require the construction of tension and compression piles to each cap. These are normally linked by a beam. The pile and beam system usually involves constructing pairs of piles on either side of the wall and linking them with a pile cap to support the wall. The pile caps are usually linked by reinforced concrete beams to support the entire length of the wall. Piled raft underpinning systems are commonly used when an entire building needs to be underpinned. The internal floors are completely removed, a grid of piles is installed, and a reinforced concrete raft is then constructed over the complete floor level, picking up and fully supporting all external and internal walls.

Underpinning by expanding resin injection

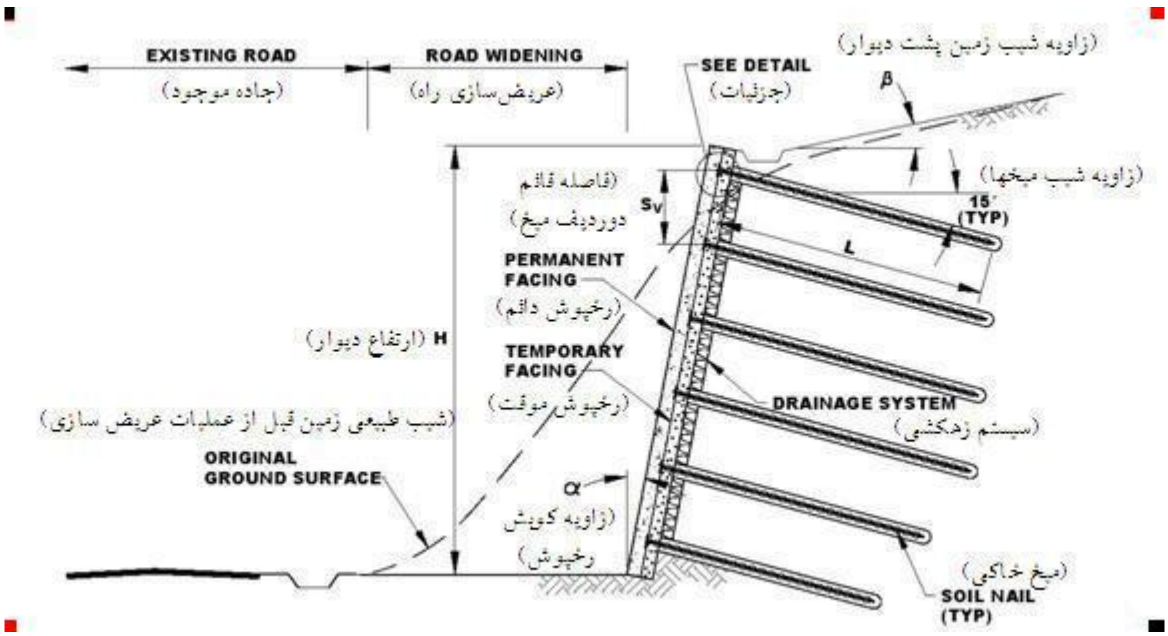
A mix of structural resins and hardener is injected into foundation ground beneath footings. On entering the ground the resin and hardener mix and expansion occurs due to a chemical reaction. The expanding structural resin mix fills any voids and crevices, compacts any weak soil and then, if the injection is continued, the structure above may be raised and re-levelled. This relatively new method of underpinning has been in existence for approximately 30 years, and because it does not involve any construction or excavation set-up, is known to be a clean, fast and non-disruptive underpinning method.

SOIL NAILING

Soil nailing is a construction remedial measure to treat unstable natural soil slopes or as a construction technique that allows the safe over-steepening of new or existing soil slopes. The technique involves the insertion of relatively slender reinforcing elements into the slope – often general purpose reinforcing bars (rebar) although proprietary solid or hollow-system bars are also available. Solid bars are usually installed into pre-drilled holes and then grouted into place using a separate grout line, whereas hollow bars may be drilled and grouted simultaneously by the use of a sacrificial drill bit and by pumping grout down the hollow bar as drilling progresses. Kinetic methods of firing relatively short bars into soil slopes have also been developed. Bars installed using drilling techniques are usually fully grouted and installed at a slight downward inclination with bars installed at regularly spaced points across the slope face. A rigid facing (often pneumatically applied concrete, otherwise known as shotcrete) or isolated soil nail head plates may be used at the surface.[1] Alternatively a flexible reinforcing mesh may be held against the soil face beneath the head plates. Rabbit proof wire mesh and environmental erosion control fabrics and may be used in conjunction with flexible mesh facing where environmental conditions dictate.

Soil nail components may also be used to stabilize retaining walls or existing fill slopes (embankments and levees); this is normally undertaken as a remedial measure.

Since its first application using modern techniques in Versailles in 1972,[2] soil nailing is now a well-established technique around the world. One of the first national guideline publications for soil nailing was produced in Japan in 1987.[citation needed] The U.S. Federal Highway Administration issued guideline publications in 1996[3] and 2003.[4]



Preliminary Analysis

Four main points to be considered in determining if soil nailing would be an effective retention technique are as follows. First, the existing ground conditions should be examined. Next, the advantages and disadvantages for a soil nail wall should be assessed for the particular application being considered. Then other systems should be considered for the particular application. Finally, cost of the soil nail wall should be considered.[4]:13-14 Soil nail walls can be used for a variety of soil types and conditions. The most favorable conditions for soil nailing are as follows: The soil should be able to stand unsupported one to two meters high for a minimum of two days when cut vertical or nearly vertical. Also all soil nails within a cross section should be located above the groundwater table. If the soil nails are not located above the groundwater table, the groundwater should not negatively affect the face of the excavation, the bond between the ground and the soil nail itself.[4]:14-15 Based upon these favorable conditions for soil nailing stiff to hard fine-grained soils which include stiff to hard clays, clayey silts, silty clays, sandy clays, and sandy silts are preferred soils. Sand and gravels which are dense to very dense soils with some apparent cohesion also work well for soil nailing. Weathered rock is also acceptable as long as the rock is weathered evenly throughout (meaning no weakness planes). Finally, glacial soils work well for soil nailing.

Inspection and performance monitoring

Inspection activities play a vital role in the production of high-quality soil nail walls because conformance to project plans and specifications should result in a soil nail wall that will perform its intended duty for its designed duration. Inspections usually involve evaluation of the following: conformance of system components to material specification, conformance of construction methods to execution specifications, conformance to short-term performance specifications, and long-term monitoring.[4]:156 Short-term performance specifications are checked with loads tests, which utilize hydraulic jacks and pumps to perform several load applications. Three common load tests for short-term performance are verification or ultimate load tests, proof tests and creep tests. Verification or ultimate load tests are conducted to verify the compliance of the soil nails with pullout capacity and strengths resulting from the contractor's installation method.[4]:163 Proof tests are intended to verify that the contractor's construction procedure has been consistent and that the nails have not been drilled and grouted in a soil zone not tested in the verification stage.[4]:163 Creep tests are performed to ensure that the nail design loads can be safely carried throughout the structure's service life

repair Techniques for Cracks in Concrete – Crack Repair

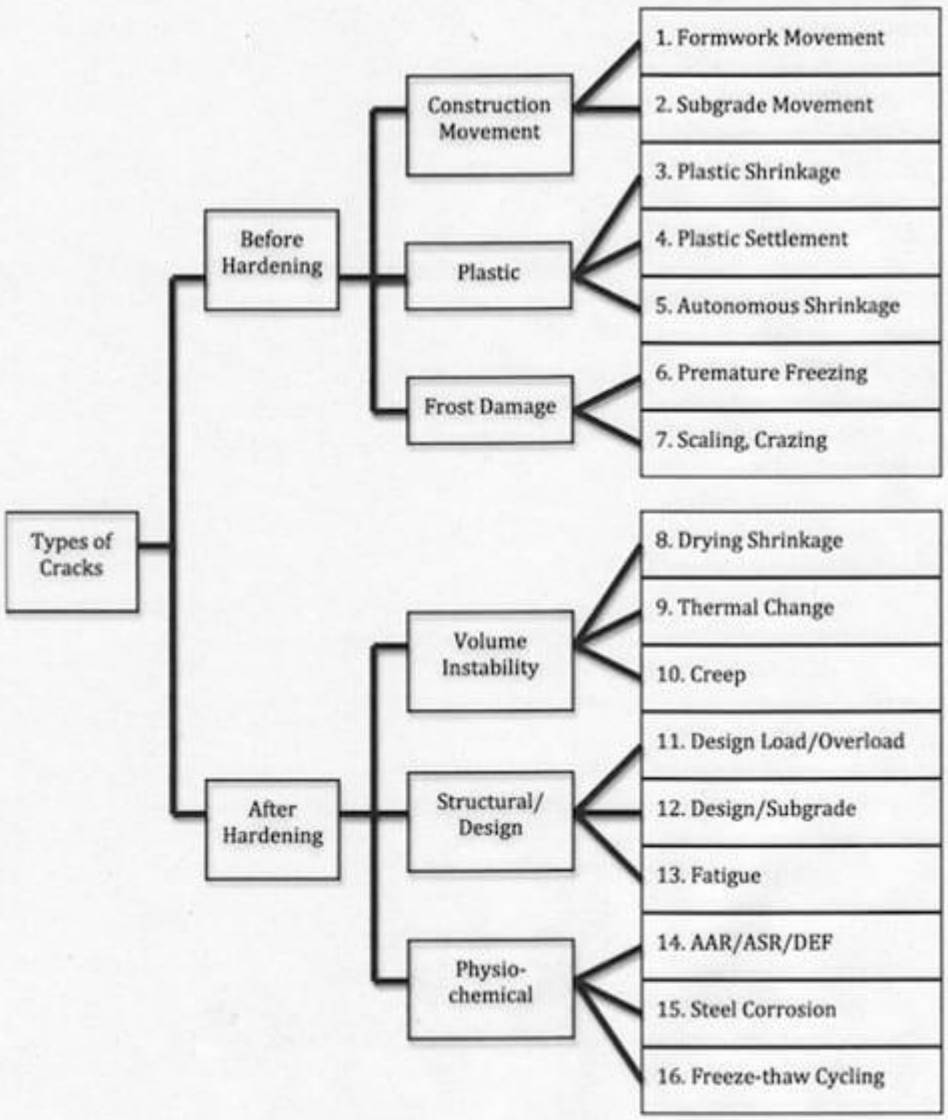
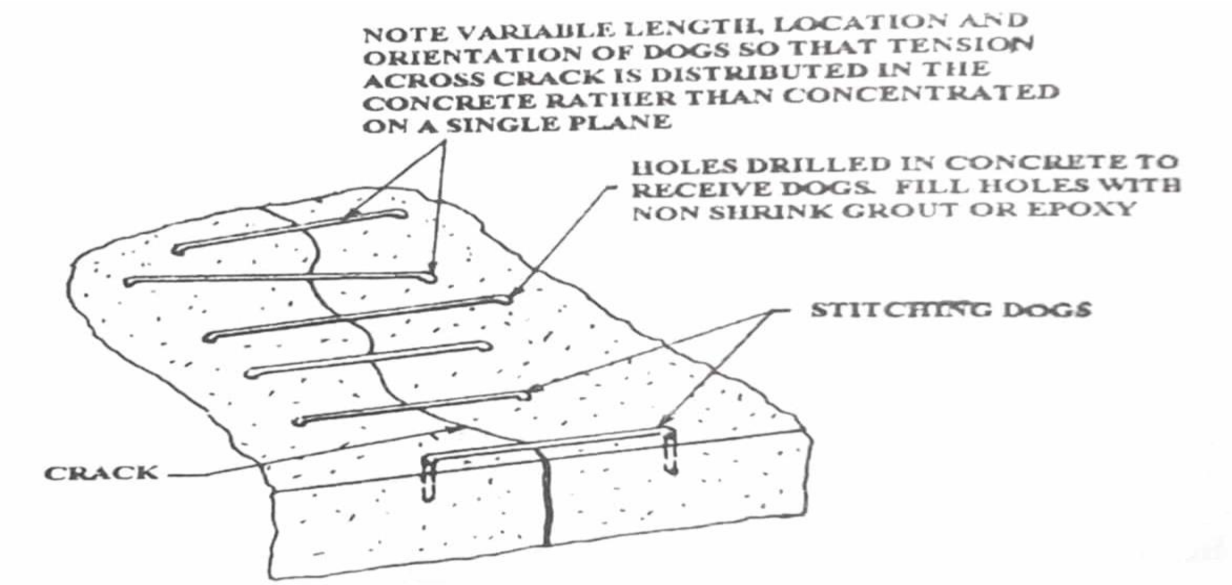


Figure Common causes of cracking in concrete structures

- Stitching
- Muting and sealing
- Resin injection
- Dry packing
- Polymer impregnation

- Vacuum impregnation
- Autogenous healing
- Flexible sealing
- Drilling and plugging
- Bandaging



Benefits Of Cracked Stitching

1. Quick, simple, effective and permanent.
2. The grout combination provides an excellent bond within the substrate.
3. Masonry remains flexible enough to accommodate natural building movement.
4. Non-disruptive structural stabilization with no additional stress

Muting And Sealing

This is the simplest and most common method of crack repair. It can be executed with relatively unskilled labor and can be used to seal both fine pattern cracks and larger isolated cracks. This involves enlarging the crack along its exposed face and sealing it with crack fillers. Care should be taken to ensure that the entire crack is routed and sealed.

Resin Injection

Epoxy resins are usually selected for crack injection because of their high mechanical strength and resistance to most chemical environments encountered by concrete. Epoxies are rigid and not suitable for active cracks. This method is used to restore structural soundness of members where cracks are dormant or can be prevented from further movements.

Underpinning

Underpinning is the process of strengthening and stabilizing the foundation of an existing building or other structure. Foundation underpinning is a means of transferring loads to deeper soils or bedrock.

Purpose Of Underpinning

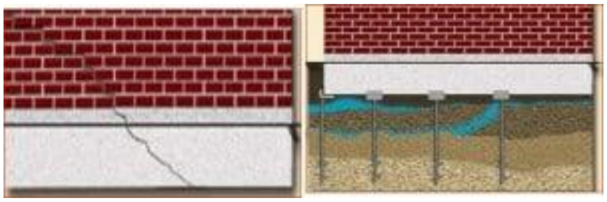
1. To obtain additional foundation capacity
2. To modify the existing foundation system
3. To create new foundations through which the existing load may be wholly or partially transferred into deeper soil
4. To arrest the excessive settlement
5. To improve the future performance of the existing foundations

When Underpinning Is Required?

- Construction of a new project with deeper foundation adjacent to an existing building.
- Change in the use of structure
- The properties of the soil supporting the foundation may have changed or was mischaracterized during planning.

To support a structure which is sinking or tilting due to ground subsidence or instability of the sup **Methods Used For Underpinning**

- Pit Underpinning
- Push Piers System
- Helical Pier System
- Pile Underpinning



Helical Pier System

- Other Methods
- Chemical Grouting
- Micro fine Grouting
- Micro piles

Fire Damage Repairs

- Timber structures may be repaired with new timbers or composites of steel and timber members.
- Steel structures are normally repaired with steel.
- Both concrete and masonry structural elements are frequently repaired with fiber reinforced polymers (FRP).
- Concrete structures are occasionally repaired with shortcrete

6)Time Table:

OFFLINE Classes Schedule

Time Table for III B.Tech CIVIL - I semester- (2021-22) wef 13/09/2021
Class Teacher - Mr.B.Sudheer Kumar(sudheerkumarb@diet.edu.in-8985687935)

TIMINGS / DAY	09:00 am-09.50 am	09.50am to 10.40am	10.40 am to 11.00 am	11:00 am-11:50 am	11:50 am-12:40 pm	12.40 pm to 1.30 pm	1:30pm-02:20 pm	02:20 pm-03:10 pm	03:10 pm-04:00 pm
MONDAY	WRE-I	SA	BREAK	CT	RRB	Lunch	RRS-ADD ON Course	PM	RRB
TUESDAY	SA	CT		RRB	CT		SFW-II LAB/ CT LAB		
WEDNESDAY	EE-II	WRE-I		EE-II	PM		SA	RRS-ADD ON Course	RRS-ADD ON Course
THURSDAY	CT	RRB		WRE-I	SA		RRS-ADD ON Course	EE-II	RRS-ADD ON Course
FRIDAY	WRE-I	RRB		EE-II	SA		CT LAB/SFW-II LAB		
SATURDAY	RRB	PM		WRE-I	CT		PM	RRS-ADD ON Course	RRS-ADD ON Course

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Phone: 9963981111, www.diet.edu.in, E-mail: info@diet.edu.in

Sl.No	**Sub Code**	**Subject Name**	**No of Periods**	**Name of the faculty**
THEORY				
1		Environmental Engineering-II(EE-II)	5	K.MANOHARINI
2		Water Resource Engineering-I(WRE-I)	6	B.SUDHEER KUMAR
3		Project Management(PM)	5	S.NAVEEN KUMAR
4		Concrete Technology(CT)	6	P.LAVANYA
5		Repair and Rehabilitation of Buildings(RRB)	6	MRVSG GUPTA
6		Structural Analysis(SA)	6	M.KEDARESWARI

LABARATORY				
7		Concrete Technology Laboratory (CT LAB)	3	P.LAVANYA
8		Survey Field Work-II(SFW-II)	3	B.SUDHEER KUMAR

9		Repair & Rehabilitation of Structures(RRS) - ADD ON Course	6	M RVSG Guptha

7) Photos

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8) Duration Of Course: 5 Weeks (40 Periods)

9) Exam paper:

NAME: M RVSG Gupta DEPARTMENT: CIVIL Batch: 2019-2023

YEAR/SEM:III/I Academic Year: 2021-22 Max Marks: 50

Question Paper for Assessment

SUBJECT: REPAIR AND REHABILITATION OF STRUCTURES (Add On Course)

Answer any one question from each chapter

(Weightage of Each Question 10 Marks)

UNIT-01 DETERIORATION OF STRUCTURES

1. What is meant by deterioration of structures and mention causes.
2. What is the process of deterioration like freezing and thawing.

UNIT-02 NON DESTRUCTING TESTING

1. Write a detail note about non destructive method for concrete structures
2. Explain the testing procedure of rebound hammer method clearly

UNIT-03 FAILURES OF BUILDING

1. Definition of building failures and types of failures for in concrete structures
2. What are the different types of failures in Distressed building.

UNIT-04 REPAIR TECHNIQUES

1. Explain concept of grouting technique for a cracked beam.
2. What is meant by jacking, short creating.

UNIT-05 INVESTIGATION OF STRUCTURES

1. Write down the case study for rehabilitation for bridges piers
2. Write down the case study for rehabilitation for dams

10) Course Completion Certificate

Dadi Institute of Engineering & Technology

Approved by AICTE & Permanently Affiliated to JNTUK

NAAC Accredited Institute & Inclusion under Section 2(f) & 12(B)of the UGC Act

Course Completion Certificate

THIS CERTIFICATE IS GIVEN TO

Paila Vinitha Devi

FOR SUCCESSFUL COMPLETION OF 5 WEEKS COURSE ON PHP REPAIR AND REHABILITATION OF STRUCTURES FROM 04/10/2021 TO 05/11/2020

M.RVSG Guptha
Coordinator

Prof. Dr. Ch. Narasimham
Principal

Sri Dadi Ratnakar
Chairman

VISAKHAPATNAM, ANDHRA PRADESH, DIET.EDU.IN