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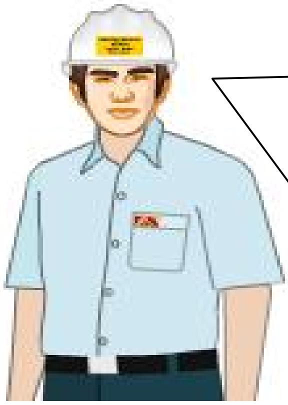
Tech Mailer



Dear Reader,

Welcome to the Technical Mailer from UltraTech Cement Ltd.

The development of cracks in concrete and their repair is a perpetual problem involving considerable cost and inconvenience to the occupants. The knowledge on types of cracks which are likely to occur, their causes and remedial measures as well as the role of construction materials, techniques etc., helps an Engineer to take preventive and remedial measures. Majority of cracks encountered during construction stage are related to one or the other form of Shrinkage. As the adage goes, "prevention is better than cure"; prevention of cracks in concrete is better than repair.

This issue presents you the information on **"Shrinkage Cracks – causes, preventive measures and repair methods".**

We hope you find the mailer informative and useful. Happy Reading!!

Issue Highlights

- *Various forms of Shrinkage*
- *Factors affecting Shrinkage*
- *Prevention of Shrinkage Cracks*
- *Repair of Shrinkage Cracks*

Introduction

Cracks in concrete are of common occurrence and these develop when stresses in the concrete exceed its strength. Cracks are classified as Structural and Non-Structural. Structural cracks, which are due to incorrect design, faulty construction and/or over loading, may endanger the safety and durability of a building. Non-Structural cracks are mostly caused by internally induced stresses in building materials and do not result in weakening of the structure. However, penetration of the moisture through the Non-Structural cracks and weathering action may result in corrosion of reinforcement, making the structure unsafe. They may also affect the aesthetics of the building. The internally induced stresses in concrete are due to the moisture changes, thermal movements, chemical actions etc. The stresses induce dimensional changes and cracking is found to occur whenever there is a restraint to the movement. The dimensional changes occur due to Shrinkage (Plastic, Drying, Autogenous, Carbonation etc.) or Expansion caused due to thermal movement or chemical actions. In cement concrete it is believed that one-third of shrinkage takes place in the first 10 days, half within one month and the remaining half in about a year. Shrinkage cracks in concrete may thus continue to occur and widen up to about a year.

In this article the various types of shrinkage, especially at early age, ensuing cracks and their prevention are discussed.

Various forms of Shrinkage

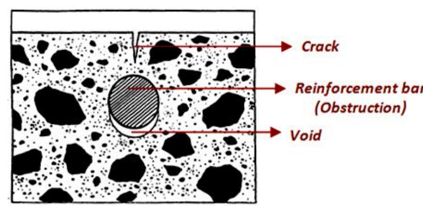
➢ Plastic Shrinkage

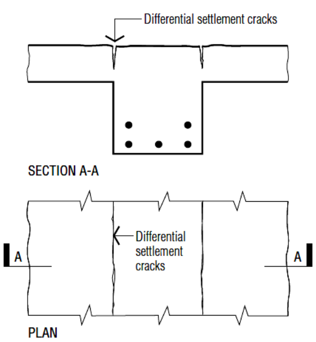
After the fresh concrete has been placed in forms, concrete undergoes a volumetric contraction while it is in plastic state (before the concrete has set). This is known as Plastic Shrinkage, Pre hardening or Pre-setting shrinkage. This Plastic shrinkage sometimes results in the formation of Cracks. This happens if concrete surface loses bleed water faster than the rate of bleeding. Quick drying of concrete at the surface results in shrinkage and as concrete in plastic state cannot resist any tension, short cracks develop. These cracks occur within a few hours (i.e. between one – two hours) of placing concrete, although often they may not be noticed until at least the next day.

These cracks usually are parallel to one another and are spaced 0.3m to 1m apart. These cracks may be as much as 5cm to 10cm in depth and upto 3mm in width. At the surface, the cracks are wider and taper down rapidly. They do not extend to free edges of the concrete, as there is no restraint to contractions there and hence no tensile stresses are developed in concrete.

➢ Plastic Settlement

The cracks due to Plastic Settlement are commonly mis-understood to be due to shrinkage. Plastic Settlement cracks occur when there is a relatively high amount of bleeding and some form of obstruction (e.g. reinforcement bars, tie bolts of formwork, large aggregate particles etc.,) to the downward settlement of the solids. These obstructions 'break the back of concrete' and generate voids under their 'belly' as shown. As a result, cracks are formed directly over formwork tie bolts or over the reinforcement near top of a section due to the arching of concrete over the obstacle causing tension in concrete. These cracks are typically found along the line of reinforcement or over obstacles. The amount of settlement tends to be proportional to the depth of concrete, i.e., the deeper the section, the greater the settlement. At lines of changes of section, e.g., at a beam/slab junction, the differential amount of settlement can lead to cracks forming at the surface.





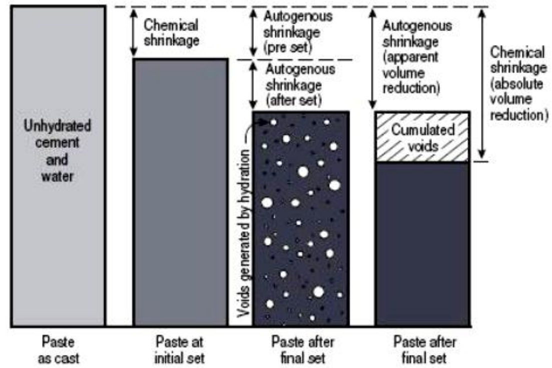
➢ Drying Shrinkage

After hardening, concrete starts drying. The excess water (not consumed for hydration) leaves the system causing contraction or shrinkage. This excess water, called water of convenience would have been added to get adequate workability and finishability. The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume. Under drying conditions, the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions. Cement paste shrinks more than mortar and mortar shrinks more than concrete. Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate. The magnitude of drying shrinkage is also a function of the fineness of gel. The finer the gel the more is the shrinkage.

The shrinkage that takes place after the concrete has set and hardened is called Drying Shrinkage and most of it takes place in the first few months. Any restraint to this contraction causes tensile stresses to develop in concrete causing cracks. A very small part of this shrinkage can be recovered on immersion of concrete in water. The rate of this shrinkage is time dependent. 15 – 30% of total shrinkage (after say 20 years) occurs in two weeks, 40 – 70% in three months and 66 – 80% in one year.

➢ Autogenous Shrinkage

Autogenous shrinkage is an important phenomenon in young concrete. This is found to occur even when no moisture movement from or into the paste is allowed. At low water/cement ratios, less than about 0.42, all the water is rapidly drawn into the hydration process and the demand for more water creates very fine capillaries. The surface tension within the capillaries causes Autogenous shrinkage (sometimes called chemical shrinkage or self-desiccation) which can lead to cracking. This is most often observed at a water-cement ratio below 0.30.Figure shows the reduction in volume due to this phenomenon.



The contribution of autogenous shrinkage has previously been viewed as "insignificant" in typical concrete mixtures due to the dominant role of drying shrinkage. In recent years the increasing use of high performance concretes has led to the re-introduction of autogenous concerns as the mixtures are using more "special" cements and multiple admixtures while reducing water. It is a problem often associated with high-strength concretes which typically contain high cement content and low water-cement ratio. This shrinkage occurs in the interior of large concrete mass and tends to increase at higher temperature. The magnitude of the shrinkage is found to further increase if silica fume has been used in the concrete mixture.

Autogenous shrinkage can be important when in situ concrete is placed over older concrete as in various forms of hybrid construction. Eurocode 2 states that autogenous shrinkage 'should be considered specifically when new concrete is cast against hardened concrete' and suggests that the shrinkage strain will be 2.5 (f_{ck} – 10) x 10^{-6}, where f_{ck} is the cylinder strength of the concrete.

Note that autogenous shrinkage is different from and additional to conventional drying shrinkage, which will start when water curing ceases.

➢ Thermal Shrinkage

Solids expand on heating and contract on cooling. The strain associated with temperature will depend on the co-efficient of the thermal expansion of the material and the magnitude of temperature drop or rise. Except under extreme climatic conditions, ordinary concrete structures suffer a little or no distress from changes in ambient temperature. However, in massive structures the combination of heat produced by cement hydration and relatively poor heat dissipation conditions results in a large rise in concrete temperature within a few days after placement. Subsequently, cooling to the ambient temperature often causes thermal shrinkage and may induce a tensile stress in the concrete resulting in cracks. Hence to ensure the concrete structures free of cracks, efforts are made to control the peak temperature through selection of proper materials mixed proportions, curing conditions and construction practice.

➢ Carbonation Shrinkage

Carbonation is the reaction of CO_2, which is present in the atmosphere with hydrated cement. The CO_2in presence of moisture forms carbonic acid that reacts with calcium hydroxide - $Ca(OH)_2$, a product of hydration to form Calcium Carbonate ($CaCO_3$). Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place. The carbonation proceeds from the surface of concrete inwards, but does so extremely slowly. The actual rate of carbonation depends on the permeability of the concrete, its moisture content and on the CO_2 content and relative humidity of the ambient medium. Concrete made with high water-cement ratio and inadequately cured will be more prone to carbonation i.e. there will be a greater depth of carbonation. The carbonation also results in increased strength and reduced permeability. However, it reduces the alkalinity of concrete that gives protective coating to the reinforcement against corrosion. If the depth of carbonation reaches upto the reinforcement, the reinforcement is liable to corrode. When the shrinkage is restrained partly or fully due to internal (i.e. aggregates or reinforcement) or external restraints, tensile stress are developed in concrete leading to the development of cracks. The extent of carbonation can be determined by treating a freshly broken surface with phenolphthalein. The carbonated portion is un-coloured, while the free calcium hydroxide turns to pink colour.

The ill effects of carbonation shrinkage can be mitigated by making the concrete denser and providing adequate cover to the reinforcement.

➢ Crazing

Crazing is the development of fine random cracks on the surface of the concrete caused by shrinkage of the surface layer. These cracks do not affect the structural integrity of concrete but may lead to subsequent deterioration of the concrete. The cracks are shaped like irregular hexagon and are typically not more than 50 to 100 mm across. They are rarely more than few millimeters deep and are more noticeable on steel troweled surfaces. They generally occur in the over floated or over troweled surface layers of concrete slabs and in the formed surfaces of concrete.

Generally craze cracks develop at an early age and are apparent the day after placement. The crazing is more prominently seen when the surface is wet.

The generally observed reasons for appearance of Crazing cracks are

- Poor or inadequate curing.
- Too wet a mix, excessive floating, the use of a jitterbug or any other procedure which depresses the coarse aggregate and produces an excessive concentration of cement paste and fines at the surface.
- Finishing while there is bleed water present on the surface or the use of steel trowel at a time when the smooth surface brings up too much water and cement fines. The use of a darby or bull float while bleed water is present will produce a high water-cement ratio at the surface, which makes the slab more susceptible to crazing
- Sprinkling cement on the surface to dry up bleed water. This concentrates fines on the surface.
- Occasionally carbonation of the surface can cause crazing.

Factors affecting Shrinkage

The initial shrinkage in concrete depends on number of factors, e.g. Cement and water content, size of aggregates and aggregate-cement ratio, excessive fines, use of admixtures, composition of cement, temperature, humidity and curing etc., which are described briefly below:

- **Cement Content:** The drying shrinkage is more with rich mixes having greater amount of cement. On the other hand, shrinkage is less when the concrete has large volume of aggregates.

- **Water Content:** The shrinkage is greater with the concrete having high water content (high water-cement ratio). It implies that dry mix has lesser shrinkage than a wet mix.

- **Aggregates:** By using the graded, largest possible maximum size of aggregates in concrete, the water required for the desired workability is reduced and such concretes exhibits lesser shrinkage because of reduction in porosity of hardened concrete. Shrinkage can be reduced by about 50% by increasing the volume of aggregates by 10%.

  For the same cement-aggregate ratio shrinkage of sand mortars is 2-3 times that of concrete using 20mm maximum size of aggregate and 3-4 times that of concrete using 40mm maximum size aggregate.

  Concretes having excessive fines will have greater shrinkage than those of having just adequate amount of fines needed for good grading. Over-sanded mixes of concrete exhibit higher shrinkage.

- **Presence of excessive Fines (Silt, Clay and dust):** Presence of silt, clay and dust in aggregates has significant effects on shrinkage of concrete. These finer particles increase the specific surface area of the aggregates and consequently the water requirement. IS 383-1970, lays more emphasis on cleanliness of aggregates and stipulates that the fines in aggregates should not exceed by 3% for Coarse as well as uncrushed fine aggregate.

- **Admixtures:** Admixtures that decrease the water requirement of concrete decrease the shrinkage of concrete and vice-versa. Use of Calcium chloride as accelerator in concrete appreciably increases the shrinkage upto 50% with 0.5 to 2% addition. When a part of cement is replaced with lime, shrinkage is reduced.
- **Composition of Cement:** The shrinkage is less for cements having greater proportions of Tri-Calcium Silicate and lower proportion of Alkalies like Sodium and Potassium oxides. Rapid Hardening cement has greater shrinkage than Ordinary Portland Cement.
- **Temperature and Humidity:** The temperature of fresh concrete influences the water requirement of the concrete and thus its shrinkage. For example, if the temperature of concrete gets lowered from 38^oC to 10^oC, the water requirement per m^3 of concrete for the same slump is reduced to the extent of about 25 liters per cubic meter of concrete. In a tropical country like India, concrete in mild winter months would have much less tendency for cracking than that done in hot summer months. In hot weather, use of warm aggregates and warm water should be avoided in order to keep the temperature of the fresh concrete low.

  The shrinkage is less in areas where the relative humidity of ambient air is high, e.g. Coastal areas. Low relative humidity may also cause Plastic shrinkage cracks.
- **Curing:** Curing plays an important part in limiting shrinkage. If proper curing is started as soon as initial set has taken place and is continued for at least 7-10 days, drying shrinkage can be comparatively reduced, because when concrete is hardening under moist environment initially there will be some expansion which offsets a part of subsequent shrinkage.

Prevention of Shrinkage Cracks

Plastic Shrinkage:

- The fresh concrete should be protected from direct sunrays and strong winds for at least 24 hours.
- Where feasible, carry out the concreting works during early hours of the day.
- Concrete should not be placed on dry subgrade. It should be made wet by sprinkling water before the concrete is placed.
- Avoid use of warm water and warm aggregates in order to keep the temperature of fresh concrete low.
- Dampen the subgrade and formwork, ensuring that any excess water is removed prior to placing concrete.
- Keep the aggregates under shade. In hot weather, lower the temperature of the fresh concrete by using chilled mixing water or replacing some of this water with crushed ice.
- The concrete should be placed and finished fast.
- Cover the freshly placed concrete with tarpaulins or plastic sheet to prevent evaporation of bleed water.
- Start curing as soon as possible after placing of concrete but before the surface water-sheen fully disappears.
- The use of sufficient proportions of synthetic or steel fibers in concrete can provide improved control of plastic cracking.

Plastic Settlement:

- Use mixes with lower bleeding characteristics e.g., lower slump and more cohesive mixes.
- Wet the subgrade before placing concrete to avoid excessive water loss from the base of the concrete.

- Increase the ratio of cover to reinforcing bar diameter, i.e., by increasing the cover or decreasing the size of the bars.
- Reduce obstruction to settlement.
- Avoiding the use of retarding admixtures is sometimes suggested as a way of minimizing plastic settlement cracking, but in hot weather the benefits of their use outweigh the disadvantages.
- Set all formwork accurately and rigidly so that it will not move during concrete placement.
- Place concrete in deep sections first (including columns) and let it settle prior to placing and compacting the top layers (ensuring that the two layers blend together).
- Fully compact the concrete.
- Cure the concrete promptly and properly.

Drying Shrinkage:

- Use minimum water content (consistent with placing and finishing requirements). To compensate for the reduction in workability, plasticizers can be used.
- Use the highest possible aggregate content and largest possible maximum aggregate size.
- Use concrete with workability as low as is compatible with ease of placing and achieving full compaction.
- Do not use admixtures known to increase drying shrinkage, e.g., those containing calcium chloride.
- Provide adequate and early curing to exposed surfaces, particularly on large flat areas.
- Eliminate external restraints as much as possible, particularly by providing movement joints wherever applicable.
- Provide reinforcement steel at closer spacing (generally 15cm in slabs) in order to control crack width.

Autogenous Shrinkage

- Consider a higher content of supplementary cementitious material like Fly ash and Ground granulated blast furnace Slag (GGBS) in the concrete mix
- Keep the surface of the concrete continuously wet; conventional curing by sealing the surface to prevent evaporation is not enough and water curing is essential.
- Consider addition of shrinkage-reducing admixtures more commonly used to control drying shrinkage,
- Consider addition of saturated lightweight fine aggregates

Crazing

- Start curing the concrete as soon as possible. The surface should be kept wet by either flooding with water or covering with wet burlap and keeping moist for a minimum of 3 days.
- Use of moderate slump (75mm to 125mm), air-entrained concrete. Higher slump (up to 150 to 180mm) can be used, provided the mixture is designed to produce the required strength without excessive bleeding and segregation.
- Air entrainment helps to reduce the rate of bleeding of fresh concrete and thereby reduces the chance of crazing.
- Never sprinkle or trowel dry cement or a mixture of cement and fine sand into the surface of the plastic concrete to absorb bleed water. Remove bleed water by dragging a hose pipe across the surface.
- DO NOT perform any finishing operation while bleed water is present on the surface.

Repair of Shrinkage Cracks:

Successful long-term repair procedures must address the causes of the cracks as well as the cracks themselves.

- **Before hardening of concrete**

  The Plastic shrinkage/Plastic Settlement may be repaired in plastic state by reworking the concrete surface using surface vibrators to close the cracks over their full depth and then completed by surface finishing. Careful timing is essential to ensure the concrete re-liquefies under the action of the vibrator and that the cracks close fully. If only re-trowelling is done, it may just form a skin (which can fracture with subsequent shrinkage, thermal or traffic impacts) over the cracks but not close them.

- **After hardening of concrete**

The key feature for successful crack repair is an understanding of the causes of cracking and also whether cracks are dormant or active.

→ **Dormant cracks –** are stable and future movements are not anticipated or in other words, unlikely to open, close or extend further. E.g., cracking caused by drying shrinkage and thermal shrinkage will be active cracks at the beginning but eventually stabilize and become dormant.

→ **Active (Live) cracks –** are expected to experience further movement and growth i.e., likely to open up. e.g., cracks resulting from continuing foundation settlement, cracks acting as contraction and expansion joints etc.

The first (and most important) step of repair is to prepare the surface to be repaired by cleaning it from loose particles, laitance, dirt, grease and paint, which interfere with the bonding. This can be done by wire brushing, grinding, sand blasting, water blasting etc.

The plastic shrinkage/settlement cracks after the concrete has hardened can be repaired by brushing cement grout into the cracks. This should be done as soon as possible after the concrete has hardened. Injecting low-viscosity polymers are preferable though not necessary.

Repair of Dormant Cracks:

Epoxy resins are most commonly used for injecting and sealing the dormant cracks. Some of these epoxy resins (monomers) can penetrate cracks as fine as 0.01mm. These materials provide an excellent adhesion to fresh and hardened concrete. Polyester resins and synthetic latex have also been used.

Cracks on horizontal surfaces can be sealed by opening a slight V on the upper surface and pouring the repair material into the crack, either starting at the middle and working towards the ends or starting at one end. Low viscosity urethanes, high-molecular-weight methacrylates (HMWA) and epoxies can be used to 'gravity fill' cracks with widths from 0.02mm-2mm. Lower viscosity materials are used to fill narrower cracks.

Polyurethane resins can be used to seal wet and leaking cracks as narrow as 0.05mm. This repair option is primarily used to stop water leaks and consists of injecting a reactive resin into cracks that combines with water to form an expanding gel that chokes off the leak and seals the crack. This repair option is a permanent repair and works with either active or dormant cracks.

Fine surface cracks in slabs and pavements can be repaired using bonded overlays or surface treatments if the cracks are dormant and not full-depth. Thin overlays consist of polymer-modified cement, silica fume mortars and surface treatments consisting of low solids and low viscosity resin-based systems.

Repair of Live Cracks:

These cracks should be treated as if they are the moving joints. They should cater for the anticipated potential movement. A suitable dimensioned recess should be cut along the line of the crack and then sealed with appropriate sealant materials such as mastics, thermoplastics and elastomers depending on the anticipated amount of movement.

Where there are large number of cracks, the most practical method of sealing surface is to treat the complete area with a membrane. Membranes can be applied either as liquids (such as bitumen or latex emulsions, resin coatings, including epoxy and polyurethane etc.) or preformed sheets (such as PVC, Butyl rubber, Bituminous plastic film carrier etc.). If no further cracking is anticipated, one of the liquid membrane treatments will often be adequate. If further cracking is anticipated, preformed sheets are advisable.

Conclusion:

Most of the building materials like Concrete, Mortar etc., expand on absorbing moisture and shrink on drying. These movements are reversible but some irreversible movement due to initial moisture changes e.g. shrinkage of cement and lime based materials is not uncommon. These cracks, although non-structural, do not endanger the safety, but affect the aesthetics of the structure. If left unattended, they may turn out to be a potential problem as they act as a gateway for the penetration of the deleterious materials into the concrete, thus affecting its strength and durability. Although the cracking cannot be eliminated totally, it can be minimized by understanding the reasons for such cracks. In this article, we have discussed the types of shrinkages, resultant cracks, preventive and repair methods. Most of these shrinkage problems are either due to the properties/quality of materials and workmanship viz. adequate water-cement ratio, compaction etc. The selection and use of suitable materials with good construction practices reduce the shrinkage and the resultant cracks thus enhancing the service life and reducing the life cycle cost.

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***Tech Mailer Team -* Dr. M R Kalgal, Prasad YTVV, Vaishnavi V**