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Study on control of cracks in a Structure through Visual Identification & Inspection

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Abstract: *Structural Cracks are a common occurrence in all types of buildings. To ensure the longevity of the structure, engineers are often required to look into their causes and carry out suitable repairs and remedial measures. For repairs and remedies to be effective, it is essential that the engineer should have a proper understanding of various causes of occurrence of cracks. For investigating the causes it is necessary to observe carefully the location, shape, size, depth, behavior and other characteristics of the cracks, and to collect information about specifications of the job and time of construction. It is also necessary for the engineer to keep track of when the cracks first came to notice. This paper talks about how visual inspection of cracks can be helpful in order to identify and categorize them with respect to various parameters by taking case study of an institutional building.*
Keywords : *Cracks, Shrinkage, Structural Failure, Stresses, Grouting*

I. INTRODUCTION AND BACKGROUND STUDY

Modern structures are comparatively tall and slender, have thin walls, are designed for higher stresses and are built at a fast pace. These structures are, therefore, more crack-prone as compared with old structures which used to be low, had thick walls, were lightly stressed and were built at a slow pace. Moreover, moisture from rain can easily reach the inside and spoil the finish of a modern building which has thin walls. Thus measures for control of cracks in buildings have assumed much greater importance on account of the present trends in construction. (Shetty, 2005)

Cracks in buildings are of common occurrence. A building component develops cracks whenever stress in the component exceeds its strength. Stress in a building component could be caused by externally applied forces, such as dead, live, wind or seismic loads, or foundation settlement or it could be induced internally due to thermal variations, moisture changes, chemical action, etc.

Cracks could be broadly classified as Structural and Non-Structural. Structural cracks which are due to incorrect design, faulty construction or overloading and Non-structural cracks are mostly due to internally induced stresses in building materials and these generally do not directly result in structural weakening. These are due to penetration of moisture or thermal variation. Cracks may appreciably vary in width from very thin hair cracks barely visible to naked eye (about 0.01 mm in width) to gaping cracks 5 mm or more in width. A commonly known classification of cracks, based on their width is:

(a) Thin— less than 1 mm in width,
(b) Medium — 1 to 2 mm in width, and
(c) Wide — more than 2 mm in width.

Cracks may be of uniform width throughout or may be narrow at one end, gradually widening at the other. Cracks may be straight, toothed, stepped, map pattern or random and may be vertical, horizontal or diagonal. Cracks may be only at the surface or may extend to more than one layer of materials. (Gambhir, 2005)

II. LITERATURE REVIEW

Principal causes of occurrence of cracks in buildings are as follows:

1. Moisture changes,
2. Thermal variations,
3. Elastic deformation,
4. Creep,
5. Chemical reaction,
6. Foundation movement and settlement of soil, and
7. Vegetation.

1. Moisture Changes

As a general rule, most of the building materials having pores in their mortar, burnt clay bricks, some stones, timber, etc. Expand on absorbing moisture and shrink on drying. These movements are reversible, that is

Cyclic in nature and is caused by increase or decrease in the inter-pore pressure with moisture changes, extent of movement depending on molecular structure and porosity of a material. The various effects of moisture changes:-

- Reversible Movement
- Initial Shrinkage

The various causes of initial shrinkage are:-

- *Cement Content*
- *Water content*
- *Aggregates*
- *Use of accelerators*
- *Curing*
- *Presence of excessive fines*
- *Humidity*
- *Composition of cement*
- *Temperature* (Gambhir, 2005)

***2.* Movement due to Thermal Variations**

It is a well-known phenomenon of science that all materials, more or less, expand on heating and contract on cooling. Magnitude of movement, however, varies for different materials depending on their molecular structure and other properties.

Factors affecting the thermal movement are:

- *Color and Surface Characteristics*
- *Thermal Conductivity*
- *Provision of an Insulating or Protective Layer.*
- *Internally Generated Heat*

***3.* Movement due to Elastic Deformation**

Structural components of a building such as walls, columns, beams and slabs, generally consisting of materials like masonry, concrete, steel, etc, undergo elastic deformation due to load in accordance with Hook's law, the amount of deformation depending upon elastic modulus of the material, magnitude of loading and dimensions of the components. This deformation, under circumstances such as those mentioned below, causes cracking in some portions:

- When walls are unevenly loaded with wide variations in stress in different parts, excessive shear strain is developed which causes cracking in walls.
- When a beam or slab of large span undergoes excessive deflection and there is not much vertical load above the supports, ends of beam/slab curl up causing cracks in supporting masonry.
- When two materials, having widely different elastic properties, are built side by side, under the effect of load, shear stress is set up at the interface of the two materials, resulting in cracks at the junction. (institution, Design and installation of joints in buildings, 1968)

***4.* Movement due to creep**

Some building items, such as concrete, brickwork and timber, when subjected to sustained loads not only undergo instantaneous elastic deformation, but also exhibit a gradual and slow time-dependent deformation known as creep or plastic strain. The latter is made up of delayed elastic strain which recovers when load is removed, and viscous strain which appears as permanent set and remains after removal of load. (institution, Code of practice for plain and reinforced concrete, 2000)

***5.* Movement due to chemical reaction**

Certain chemical reactions in building materials result in appreciable increase in volume of materials, and internal stresses are set up which may result in outward thrust and formation of cracks. The materials involved in reaction also get- weakened in strength. Commonly occurring instances of this phenomenon are: sulphate attack on cement products, carbonation in cement-based materials, and corrosion of reinforcement in concrete and brickwork, and alkali-aggregate reaction.

***6.* Foundation movement and settlement of soil**

Shear cracks in buildings occur when there is large differential settlement of foundation either due to unequal bearing pressure under different parts of the structure or due to bearing pressure on soil being in excess of safe bearing strength of the soil or due to low factor of safety in the design of foundation. Buildings constructed on shrinkable clays (also sometimes called expansive soils) which swell on absorbing moisture and shrink or drying as a result of change in moisture content of the soil, are extremely crack prone and special measures are necessary to prevent cracks in such cases. (CBRI, Roorkee) (Mughieda, 2007)

7. **Cracking due to vegetation**

Existence of vegetation, such as fast growing trees in the vicinity of compound walls can sometimes cause cracks in walls due to expansive action of roots growing under the foundation. Roots of a tree generally spread horizontally on all sides to the extent of height of the tree above the ground and when trees are located close to a wall; these should always be viewed with suspicion.

III. CASE STUDY

For a better and thorough understanding a case study was carried out at O.P. Jindal Institute of Technology, Raigarh Chhattisgarh. OPJIT although being a fairly new institution having started in 2008, Most of the structure already have started showing deep cracks at various locations all across the campus which will lead to the decrease in the durability of structure. Most of the structures in the campus including institutional building, Hostel, etc are composite structures where columns are of structural steel slabs being RCC. This combination has led to occurrence of cracks at all the major juncture points of steel and concrete. The use of improper design mix, Improper curing along with many other reasons has led to different structural and Non-structural cracks. For the cracks all the prominent cracks were identified and classified on its possible causes. Subsequently remedial measures for each of those cracks have been identified and listed. In the month of July 2014, the main building of the college and as well as all the internal rooms were inspected carefully and each type of cracks were photographed and recorded for further observations. The cracks have been categorized on the basis of:-

(a) Thin— less than 1 mm in width,
(b) Medium — 1 to 2 mm in width, and
(c) Wide — more than 2 mm in width.

Fig. 1: Cracks below window sill level

Width: - Above 3mm

Type: - Wide crack

Probable causes: -Settlement of soil, Shrinkage or Overloading

Fig. 2: Cracks at Juncture of slab and steel beam

Width:-above 2mm

Type:-Non-structural, Wide crack

Probable causes: - Due to joint, Contraction occur between two walls

Fig. 3: Cracks at juncture of brickwork & steel column
Width:-Below 1mm,
Type:-Thin crack, Non-structural
Probable causes: - Less bonding between cement and steel, Improper Curing, Shrinkage of slab & thermal variation

Fig. 4: Vertical cracks in wall
Width:-Between 1mm to 2mm
Type:-Non-structural, Medium
Probable causes: - Temperature Variation, Shrinkage, & Moisture Changes

Fig. 5: Cracks at corner of sunshade
Width:-Above 5mm,
Type:-Gap crack
Probable causes: - Improper cantilevering, Due to joint, & Heavy exposure to water

Fig. 6: Cracks below a beam
Width:-Above 2mm
Type:-Structural, Medium cracks
Probable causes: - Due to Overloading, & Improper Design

Fig.7: Cracks above window
Width:-more than 2mm
Type:-Non-structural, Gap crack
Probable causes: - Thermal variation, Moisture & Overloading (Kashyzadeh, 1990)

IV. TREATMENT MEASURES

The aim of crack repair has to be established a prior and achieved by proper selection of repair material and methodology. The goal of all crack repairs is to achieve one or more objectives such as:

- Restore and increase the strength of cracked components
- Restore and increase the stiffness of cracked components
- Improve functional performance of the structural members
- Prevent liquid penetration
- Improve the appearance of the concrete surface
- Improve durability; and prevent development of a corrosive environment at the reinforcement.

Materials for nonstructural crack repair of dormant nature should be a rigid material. Cementitious, polymer modified cementitious grouts of acrylic, styrene-acrylic and styrene-butadiene should be used for wider cracks. However polyester and epoxy resins should be used for injection of dormant cracks. For live cracks flexible material of polysulphide or polyurethane should be used.

Before repair of any non-structural cracks the factors have to be considered are:

- Whether the crack is dormant or live;
- The width and depth of the crack;
- Whether or not sealing against pressure is required, and, if so, from which side of the crack will the pressure be exerted and
- Whether or not appearance is a factor.

A. Repair of Dormant cracks

Dormant cracks may range in width from 0.05 mm or less (crazing) to 6 mm or more. The width of the crack has a considerable influence on the materials and methods to be chosen for its repair. The fine cracks are repaired by low viscous epoxy resin and other synthetic resin by injecting. Wide cracks on a vertical surface are also repaired by injection methods. Cracks on horizontal surface can be repaired by injection or by crack filling by gravity.

Dormant cracks, where the repair does not have to perform a structural role, can be repaired by enlarging the crack along the external face and filling and sealing it with a suitable joint sealer.

This method is commonly used to prevent water penetration to cracked areas. The method is suitable for sealing both fine pattern cracks and larger isolated defects. Various materials are used such as including epoxies, urethanes, silicones, polysulphides, asphaltic materials and polymer mortars. Polymer mortars are used for wider cracks. The crack is routed out, cleaned and flushed out before the sealant is placed. It should be ensured that the crack is filled completely. Where ever a cementitious material is being used, dry or moist crack edges must be wetted thoroughly.

B. Cementitious Grouts

It is used for repair of cracks that are greater in width. It is a mixture of cementitious material and water that is proportioned to produce a pourable consistency. Cement-based grouts are available in a wide range of consistencies; therefore, the methods of application are diverse. These materials are the most economical of the choices available for repair. They do not require unusual skill or special equipment to apply, and are reasonably safe to handle. These materials tend to have similar properties to the parent concrete & mortar, and have the ability to undergo autogenous healing due to subsequent hydration of cementitious materials at fracture surfaces. Shrinkage is a concern in such type of grouts. These are not suitable for structural repairs of active cracks.

For application of cementitious grouts generally, some form of routing and surface preparation, such as removal of loose debris are needed. Pre-wetting should be done to achieve a Saturated-Surface-Dry (SSD) condition. Grouts are generally to be mixed to a pourable consistency by using a drill and paddle mixer, and the consistency may be adjusted thereafter. Application should be done by hand troweling or dry packing into vertical and overhead cracks to fill all pores and voids .Finally, a suitable coating to be applied on the repaired surfaces.

C. Epoxy Resin Grouts

This is most common polymer material used for gravity feed crack repairs. It should be formulated to have a very thin consistency (low viscosity) and low surface tension to enable the resin to easily penetrate fine cracks by gravity alone. Viscosities below 200 centipoise (cps) should be a minimum requirement.

The horizontal concrete elements such as bridge and parking decks, floor slabs, plaza decks, and similar surfaces can be repaired with gravity feed resin. The cracks should be cleaned and free from dust. If required some routing may be required to facilitate pouring of resin. The surface should be cleaned with a compressed air. If water is used during cleaning then it should be dried for 24hr because the moisture present inside the crack may obstruct the flow of resin. The resin has to be mixed in a bucket with a paddle mixer. Small cans or squeeze bottles can be used for pouring into individual cracks. Before pouring of resin the underside of cracks should be sealed temporarily to avoid any leakage. The pouring should continue till the cracks go on absorbing after which the excess resin should be removed with a flat rubber squeegee.

D. Application of Epoxy Injection

1) Surface preparation

The cracks should be cut and cleaned properly. Any contamination should be removed by flushing with water or some especially effective solvent. Then the solvent should be blown out with compressed air, or adequate time should be given for air drying. The surfaces should be sealed. This keeps the epoxy from leaking out before it gelled. A surface can be sealed by brushing an epoxy over the surface of the crack and allowing it to harden. If extremely high injection pressures are needed, then the crack should be cut into a V-shape, filled with an epoxy, and should be stroke off flush with the surface. The entry ports should be installed thereafter.

2) Fixing of injection ports/nozzles

There are three ways to do this. Fitting of nozzles to be inserted in drilled holes should be made by drilling a hole into the crack for 8 mm dia injection packers @ 200 to 300 mm c/c, penetrating below the bottom of the V-grooved section. A fitting such as a pipe nipple should be inserted or tire valve stem should be inserted into the hole and bonded with an epoxy adhesive.

A vacuum chuck and bit will help to keep the cracks from being plugged with drilling dust. The second method is by bonded flush fitting. When the cracks are not V-grooved, a common method of providing an entry port is to bond a fitting flush with the concrete face over the crack.

Last method is by interruption in seal. Another way to allow entry is to omit the seal from part of the crack. This method uses special gasket devices that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack.

3) Mixing

Mixing the two components of epoxy injection grout of base and hardener should be done in a suitable container with heavy duty slow speed drilling machine with paddle attachment. Mixing should be made for 2 to 3 minutes to obtain a uniform color.

4) Injection of Epoxy

For smaller area or isolated crack a hand pump may be used for injection. Hydraulic pumps, paint pressure pots, or air-actuated caulking guns can be used for larger cracked areas. The pressure should be selected carefully, because too much pressure can extend the existing cracks and cause more damage. If cracks are clearly visible, injection ports can be installed at appropriate interval by drilling directly into the crack surface. The surface of the crack between ports is allowed to cure. For vertical cracks, pumping of epoxy into the entry port should start at the lowest elevation until the epoxy level reaches the entry port above. Then the lower injection port is caped and the process is repeated at successively higher ports until the crack has been completely filled in. For horizontal cracks, injection starts from one end of the crack to the other in the same way. When the pressure is maintained, the crack is filled completely. For injection from underside of ceiling of flat roof a lot of pressure is being exerted. Hence care should be taken while injecting from underside. (Hosein, 1980)

5) Removal of the Surface Seal

After the injected epoxy has cured, the surface seal is being removed by grinding or some other appropriate means.

V. CONTROLLING MEASURES

A. Measures for controlling cracks due to shrinkage

- To avoid cracks in brickwork on account of initial expansion, a minimum period varying from 1 week to 2 weeks is recommended by authorities for storage of bricks after these are removed from Kilns.
- Shrinkage cracks in masonry could be minimized by avoiding use of rich cement mortar in masonry and by delaying plaster work till masonry has dried after proper curing and has undergone most of its initial shrinkage.
- Use of precast tiles in case of terrazo flooring is an example of this measure. In case of in-situ/terrazo flooring, cracks are controlled by laying the floor in small alternate panels or by introducing strips of glass, aluminum or some plastic material at close intervals in a grid pattern, so as to render the shrinkage cracks imperceptibly small.

- In case of structural concrete, shrinkage cracks are controlled by use of reinforcement, commonly termed as 'temperature reinforcement'. This reinforcement is intended to control shrinkage as well as temperature effect in concrete and is more effective if bars are small in diameter and are thus closely spaced, so that, only thin cracks which are less perceptible, occur.
- To minimize shrinkage cracks in rendering/plastering, mortar for plaster should not be richer than what is necessary from consideration of resistance to abrasion and durability

B. Measures for controlling cracks due to thermal variations

- Wherever feasible, provision should be made in the design and construction of structures for unrestrained movement of parts, by introducing movement joints of various types, namely, expansion joints, control joints and slip joints.
- Even when joints for movement are provided in various parts of a structure, some amount of restraint to movement due to bond, friction and shear is unavoidable. Concrete, being strong in compression, can stand expansion but, being weak in tension, it tends to develop cracks due to contraction and shrinkage, unless it is provided with adequate reinforcement for this purpose. . Members in question could thus develop cracks on account of contraction and shrinkage in the latter direction. It is, therefore, necessary to provide some reinforcement called 'temperature reinforcement" in that direction.
- Over flat roof slabs, a layer of some insulating material or some other material having good heat insulation capacity, preferably along with a high reflectivity finish, should be provided so as to reduce heat load on the roof slab.
- In case of massive concrete structures, rise in temperature due to heat of hydration of cement should be controlled.
- Provision of joints in structure.

Note: - For seismic Zones III, IV & V, expansion joints have to be much wider for which IS: 4326-1976 'Code of practice for earthquake resistant design and construction of buildings (first revision) should be referred 19.

C. Measures for prevention of cracks due to creep

Though it may not be possible to eliminate cracking altogether, following measures will considerably help in minimization of cracks due to elastic strain, creep and shrinkage:

- Use concrete which has low shrinkage and low slump.
- Do not adopt a very fast pace of construction.
- Do not provide brickwork over a flexural RCC member (beam or slab) before removal of centering, and allow a time interval of at least 2 weeks between removal of centering and construction of partition or panel wall over it.
- When brick masonry is to be laid abutting an RCC column, defer brickwork as much as possible.
- When RCC and brickwork occur in combination and are to be plastered over, allow sufficient time (at least one month) to RCC and- brickwork to undergo initial shrinkage and creep before taking up plaster work. Also, either provide a groove in the plaster at the junction or fix a 10 cm wide strip of metal mesh or lathing over the junction to act as reinforcement for the plaster. (Central Building Research Institute, 1984)
- In case of RCC members which are liable to deflect appreciably under load, for example, cantilevered beams and slabs, removal of centering and imposition of load should be deferred as much as possible (at least one month) so that concrete attains-sufficient strength, before it bears the load.

D. General measures for chemical attack

- In case of structural concrete in foundation, if sulphate content in soil exceeds 0.2 percent or in ground water exceed 300 ppm, use very dense concrete and either increase richness of mix to 1:1/5:3 or use sulphate resisting Portland cement/super-sulphated cement or adopt a combination of the two methods depending upon the sulphate content of the soil.
- For superstructure masonry, avoid use of bricks containing too much of soluble sulphates (more than 1 percent in exposed situations, such as parapets, free standing walls and masonry in contact with damp soil as in foundation and retaining walls; and more than 3 percent in case of walls in less exposed locations) and if use of such bricks cannot be avoided, use rich cement mortar (1:1/2:4.5 or 1:1/4 :3) for masonry as well as plaster or use special cements mentioned earlier and take all possible precautions to prevent dampness in masonry.
- To prevent cracking due to corrosion in reinforcement and premature deterioration, it is desirable to specify concrete of richer mix (say 1:1/5:3) for thin sections in exposed locations and to take special

care about grading, slump, compaction and curing of concrete. (Chand, October 2008) (CBRI, Roorkee)

VI. CONCLUSIONS

From the above case study we have concluded that some preventions could be taken care of during the construction process itself. Any lack of attentiveness can lead to a cause for damage in the building in its future, which can also lead to the failure of structure.

Cracks may occur due to various reasons, as discussed earlier. The occurrence of cracks cannot be stopped but particular measures can be taken to restrict them to reduce the level and degree of consequences.

Generally speaking, for causes and prevention of cracks in any particular case it is necessary to make careful observations and to collect detailed information in the form of a checklist with regards to the following aspects as may be relevant to a particular case:

1. What is the past history of the structure with respect to year of completion of construction, the life span of the structure and so on.
2. Has there been any subsequent additions and alterations, major repairs, etc?
3. What are the specifications of that part of the structure where cracks have occurred?
4. When did the cracks first appear? Have the cracks since widened or extended? If the cracks are in walls, should the cracks be monitored continuously?
5. Do the cracks open and close with change in temperature during the course of a day?
6. Are the cracks superficial or deep, and if deep, what is the depth of cracking?
   A fine steel wire may be used as a probe to measure the depth of a crack and where necessary, a small patch of the affected part may be removed to determine the depth of a crack. In case of walls, it should be ascertained whether the crack are through or not, by examining both sides of the wall.
7. What are the starting and ending points of the cracks? Are these crack positions related with the openings and weak sections in the buildings? Do the cracks start above the damp proof course (DPC) or do these pass through DPC and extend to the foundation?
8. What are the geometries of the cracks, i.e. whether these are horizontal, vertical, diagonal or random, whether straight, toothed, stepped and whether of uniform width or tapering, etc.?
   In case of vertical and diagonal cracks in walls, if cracks are straight, masonry units would also have cracked while toothed and stepped cracks would follow the course of vertical and horizontal joints in masonry. In case of tapering cracks, it should be observed as to which end of the crack is wider, that is, upper or lower.
9. Do the cracks follow any set pattern in regard to direction and spacing?
   As an example, vertical cracks may occur in a long compound wall at more or less uniform spacing of say 4 to 6 m all along the length, or in a building, diagonal cracks may occur over most of the door openings similarly situated, starting from the lintels and travelling upward in a direction away from the opening. In concrete floors, cracks may occur in most of the panels more or less in the middle, or diagonal cracks may occur at the corners.
10. Is there any level difference on both sides of a crack?
    This could be determined by moving tip of a finger across a crack or by putting a straight edge across the crack. By this check, tensile cracks could be distinguished from shear cracks and also bowing or curving of walls could be detected.
11. Do the cracks have sharp or rounded edges?
    This could be found out by visual examination either with the naked eye or with the help of a magnifying glass. Rounded edges of cracks will mean alternate compressive and tensile forces as in case of thermal movements.
12. Are the cracks accompanied by a bow in the member, if so, what is the extent of bow?
    A bow will indicate buckling of the -member due to compressive force.
13. Are there any signs of continuous dampness in the area affected by cracks? Is the area subjected to severe exposure to rain? Are there any indications of leakage of water from any source, such as water supply lines, storage stands, drains, rain, etc.?
14. Are there any signs of general or local subsidence around the building? Is the building built on shrinkable clay soil? Does it have shallow foundation? Are there any special features about the growth of vegetation around the structure?
15. Do the bricks used in the-job contain excessive quantities of soluble sulphates?
16. Does the soil or ground water under the structure contain excessive quantities of soluble sulphates?

Some guidance has also been given for diagnosing causes of cracks that may have occurred in a structure and suitable remedial measures, where feasible, have been suggested.

There are so many structures which have failed due to occurrence of cracks and these failure caused a huge loss of life and property so if cracks get identified suitable remedial measures should be taken as soon as possible.

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