Chapter-1 INTRODUCTION

1.1 DEFINITION:-

A Crack may be the first sign of a serious defect which may affect the serviceability or the stability of the building.

Fig. 1.1 CRACK

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 movements, moisture changes, chemical action, etc.

Most buildings crack at some time during their service life. The appearance of cracks is a symptom of distress within the fabric of the building. Often the cracking is of little consequence and once it is established as static, simple repair by filling or re-pointing is all that is required.

The appearance of cracks can also affect the value of the building, its insurability, the saleability and can be the subject of litigation. Therefore correctly assessing the significance of cracks is essential. However it is a far from a simple task and is often a subjective exercise. The implications of an incorrect assessment can lead to expensive and unnecessary remedial work. In some instances the remedial work may exacerbate the problem resulting in yet further and more extensive cracking.

1.2 ORIGIN OF CRACKS:-

- Cracks might develop due to –

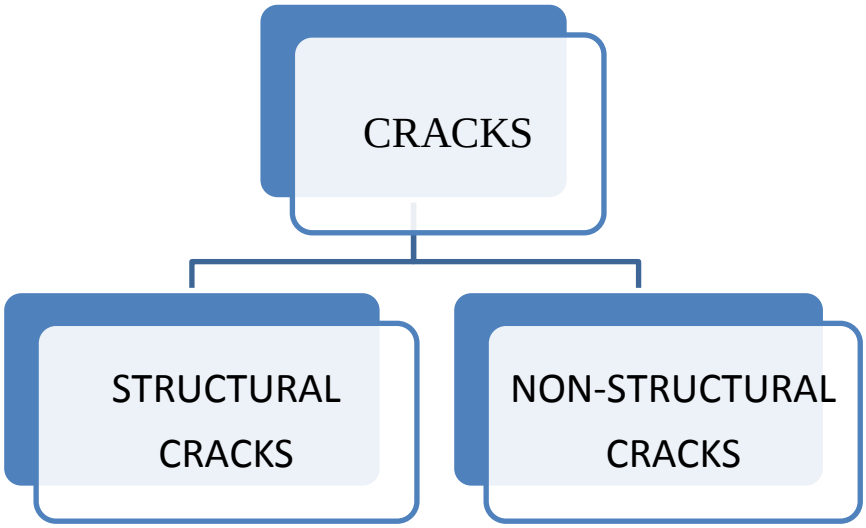
1. Deterioration of concrete or Corrosion of Rebar due to poor construction or Inappropriate selection of constituent materials.
2. Temperature and Shrinkage effects.
3. Settlement of supports

4. Natural Hazards, etc.

1.3 CLASSIFICATION:-

- Cracks could be classified as –

1. Structural Cracks and
2. Non-structural Cracks



-Due to Incorrect Design
-Faulty Construction
-Overloading

-Due to Internally Induced stress in Building Materials
-Penetration of Moisture

Fig.1.2 CLASSIFICATION CHART OF CRACKS

1.3.1 STRUCTURAL CRACKS:-

- Structural cracks are those which are due to incorrect design, Faulty construction or overloading. These may endanger the safety of a building.
- Extensive cracking of an RCC beam is an instance of structural cracking.

1.3.2. NON-STUCTURAL CRACKS:-

- Non-structural cracks are mostly due to internally induced stresses in building materials and these generally do not directly result in structural weakening.
- Sometimes non-structural cracks may, because of penetration of moisture through cracks or weathering action, result in corrosion of reinforcement and thus may render the structure unsafe.
- Some other types of cracks due to internal stresses. Internal stresses in building components could be compressive, tensile or shear. Most of the building materials

that are subject to cracking, namely, masonry, concrete, mortar, etc, are weak in tension and shear and thus forces of even small magnitude, when they cause tension or shear in a number, are able to cause cracking. It is possible to distinguish between tensile and shear cracks by closely examining their physical characteristics.

1.4 ALLOWABLE WIDTH OF CRACKS:-

- 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 than1 mm in width,

b) Medium–1 to 2 mm in width, and

c) Width- 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 maybe 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. Occurrence of closely spaced fine cracks at surface of a material is sometimes called ‘crazing’. Cracks from different causes have varying characteristics and it is by careful observation of these characteristics that one can correctly diagnose the cause or causes of cracking and adopt appropriate remedial measures.

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

a) Moisture changes
b) Thermal variations
c) Elastic deformation
d) Creep
e) Chemical reaction
f) Foundation movement and settlement of soil, and
g) Vegetation.
h) Shear Flexure
i) Bond and Disturbance

2.1 MOISTURE CHANGES:-

- As a general rule. Most of the building materials having pore in their structure in the form of intermolecular space, as for example. Concrete, mortar, burnt clay bricks, some stones, timber. Etc. expands on absorbing 'moisture' and shrinks on drying. These movements arc 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.

2.1.1 REVERSIBLE MOVEMENT:-

- From consideration of moisture movement of reversible nature, materials could be broadly classified as under:

I. Materials having very small moisture movement, as for example, burnt clay bricks, igneous rocks. Limestone, marble, gypsum plaster. Metals, etc. The use of these materials does not call for many precautions.

II. Materials having small to moderate moisture movement, as for example, concrete, sand-lime bricks, sandstones, cement and lime mortars, etc. In the use of these materials some precautions in design and construction are necessary.

III. Materials having large moisture movement, as for example, timber, block boards, plywood's, wood-cement products, fibrous boards, asbestos cement sheets, etc. For these materials, special techniques of treatment at joints and surrounds, and protective coats on surface are required.

- Based on research findings in UK, range of reversible moisture movement of some of the commonly used building materials is given in Table 2.1.

TABLE–2.1 MOISTURE MOVEMENTS OF SOME COMMONBUILDING MATERIALS

Sr. No.	MATERIALS	MOISTURE MOVEMENT (DRY TO SATURATION) PERCENT (%)
(1)	(2)	(3)
1.	Burnt clay bricks, Limestone	0.002 to 0.01
2.	Hollow clay bricks, Terra cotta	0.006 to 0.016
3.	Expanded clay concrete, Cinder concrete	0.017 to 0.04
4.	Sandstone, Sand-lime bricks, Concrete blocks	0.01 to 0.05
5.	Foam cellular concrete	0.04 to 0.05
6.	Cast-stone, dense concrete, cement lime mortars	0.02 to 0.06
7.	Auto-calved aerated concrete, clinker concrete	0.03 to 0.08
8.	Marble	Negligible
9.	Wood along grain	0.0008
10.	Wood across grain – tangential	5 to 15
11.	Wood across grain – radial	3 to 5

2.2THERMAL MOVEMENT:-

- 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. When there is some restraint to movement of a component of a structure, internal

stresses are set up in the component, resulting in cracks due to tensile or shear stresses.

- In extreme cases, stresses due to changes in temperature may exceed those due to loading; thermal movement is thus one of the most potent causes of cracking in buildings and calls for serious consideration.
- Extent of thermal movement in a component depends on a number of factors such as temperature variation, dimensions, co-efficient of expansion and some other physical properties of the materials.
- Coefficients of thermal expansion of some of the common building materials are given in Table 2.2.
- Expansion of brickwork in the vertical direction is reversible, but in the horizontal direction it is reversible only if the structure does not crack, since cracks generally get filled up with dust, etc. and do not close with drop in temperature. For a brick masonry wall of 10 m length. Variation in length between summer and winter could be of the order of 2 mm.
- Other factors which influence the thermal movement of component are: colour and surface characteristics, thermal conductivity. Provision of an insulating or protective layer and internally generated heat.
- Cracks due to thermal movement could be distinguished from those due to shrinkage or other causes from the criterion that the former open and close alternately with changes in temperature while the latter are not affected by such changes. When a concrete job has high drying shrinkage and is done in summer, that is when ambient temperature is high, contraction due to drop in temperature in winter and drying shrinkage acting units and there is a possibility of greater cracking.

TABLE-2.2 CO-EFFICIENT OF THERMAL EXPANSION OF SOME COMMON BUILDING MATERIALS

Sr No.	MATERIALS	CO-EFFICIENT OF THERMAL EXPANSION
(1)	(2)	(3)
1	Bricks and brickwork	5 to 7
2	Cement mortar and concrete	10 to 14
3	Sand-lime bricks	11 to 14
4	Stones :	
	a) Igneous rocks (granite etc.)	8 to 10
	b) Limestone's	2.4 to 9
	c) Marble	1.4 to 11
	d) Sandstone	7 to 16
	e) Slates	6 to 10
5	Metals :	
	a) Aluminium	25
	b) Bronze	17.6
	c) Copper	17.3
	d) Lead	29
	e) Steel and Iron	11 to 13
6	Wood	-

- The cracking of a typical structure due to thermal movement is given in fig.2.1.

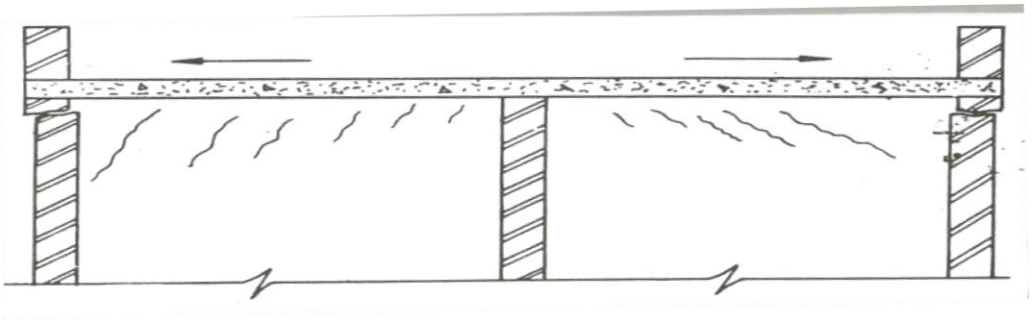
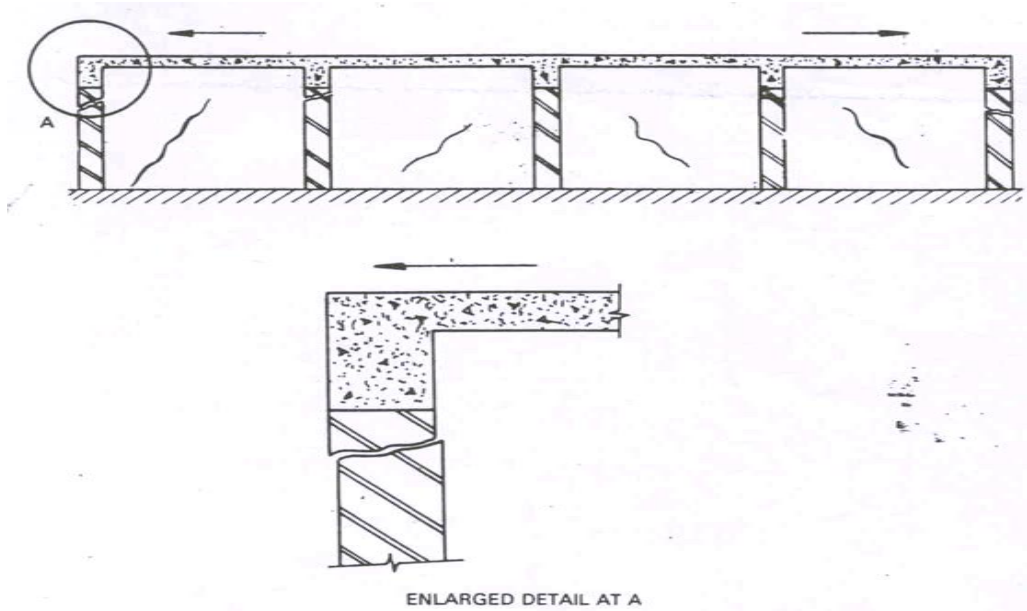
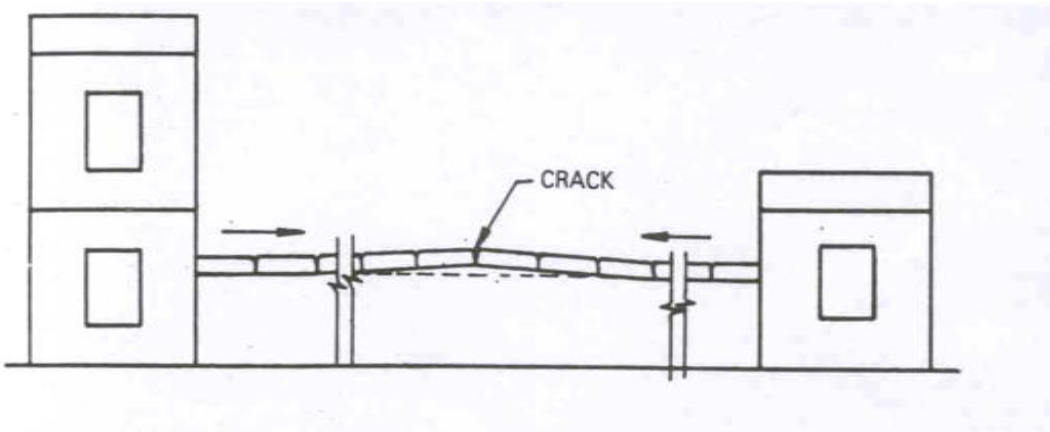


Fig.2.1 Cracking due to Thermal Movement

- In case of framed buildings due to thermal movement frames are distorted and cracks may appear as shown in fig.2.2.





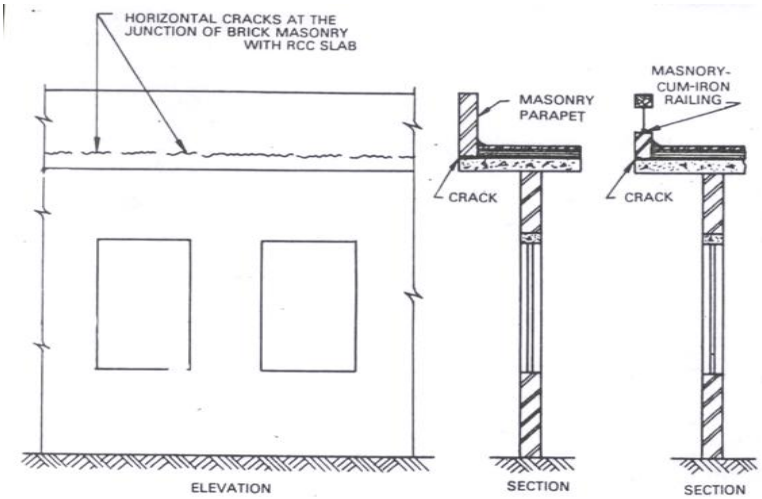


Fig.2.2 Framed Buildings due to Thermal Movement

2.3ELASTIC 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, dimensions magnitude of loading and of the components.
- This deformation, under circumstances such as those mentioned below, causes cracking in some portions:

a) When walls are unevenly loaded with wide variations in stress in different parts, excessive shear strain is developed which causes cracking in walls.

b) 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.

c) 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 in cracks at the junction.

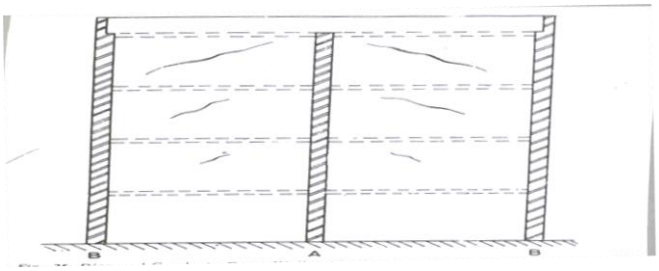


Fig.2.3 Cracking due to Elastic Deformation

2.4 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. This phenomenon known as creep.
- At low stress it is thought to be due to seepage and viscous flow and at high stress it may be due to inter-crystalline slip and micro-cracking.
- In concrete, extent of creep depends on a number of factors, such as water and cement content, water cement ratio, temperature, humidity, use of admixtures and pozzolanas, age of concrete at the time of loading, and size and shape of the component.
- Creep increases with increase in water and cement content, water cement ratio, and temperature; it decreases with increase in humidity of the surrounding atmosphere and age of material at the time of loading. Use of admixtures and pozzalanas in concrete increases creep.
- A high surface to volume ratio of concrete also increases creep because moisture in concrete can seep out at a faster rate without encountering much impedance. Thus, under similar circumstances, a small and thin component of concrete will undergo larger creep than a large and massive component.
- When stress in a material is less than two-third of the ultimate strength of the material, creep ceases after some time, total amount of creep depending upon the magnitude of stress.
- In brickwork, creep may cease after 4 months while in concrete it may continue up to about a year or so. However, in concrete, extent of creep is related to the process of hardening and thus most of the creep takes place in the first month and after that its pace slows down. That means creep strain can be reduced by deferring removal of cantering and application of external load.
- In steel under Tension, there is no creep up to yield point, but beyond the yield point up to point of failure, creep is quite substantial. Amount of creep in steel increases with rise in temperature.

- An important consequence of creep in concrete is the substantial increase in deformation of structural members, which may be 2 to 3 times the initial elastic deformation. This deformation sometimes results information of cracks in brick masonry of framed and load bearing structures.
- In some situations, creep has a beneficial effect on the performance of materials, as it tends to relieve shrinkage and thermal stresses.

2.5CHEMICAL 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, Corrosion of reinforcement in concrete and brickwork, and Alkali-aggregate reaction.

2.5.1SULPHATE ATTACK:-

- Soluble sulphates which are sometimes present in soil, ground water or clay bricks react with tricalcium aluminates content of cement and hydraulic lime in the presence oil moisture and form products which occupy much bigger volume than that of the original constituents.
- This expansive reaction results in weakening of masonry, concrete and plaster and formation of cracks. For such a reaction to take place, it is necessary that soluble sulphates, tricalcium aluminates and moisture-all the three are present.
- In buildings, the main components which are liable to sulphate attack are concrete and masonry in foundation and plinth, and masonry and plaster in superstructure. The chemical reaction proceeds very slowly and it may take about two or more years before the effect of this reaction becomes apparent.
- Movement and cracks due to this reaction in structures thus appear after about, two years and these thus could be distinguished from cracks due to other causes from consideration of age of structure at the time when cracks start appearing in a structure.
- Severity of sulphate attack in any situation depends upon:

a) Amount of soluble sulphates present;

b) Permeability of concrete and mortar;

c)Proportion of tri-calcium aluminates present in the cement used in concrete

d) Duration for which the building.

- Soluble sulphates normally found in a soil are those of sodium, potassium, magnesium and calcium. Strong and rich concrete and mortars can resist the sulphate attack better than weak and lean concretes and mortars.
- When sulphates are present, minimum cement content and maximum water-cement ratio are specified in order that concretes and mortars could resist sulphate attack.
- Percentage of tricalcium aluminates in ordinary Portland-cement varies between 8 and 13, and greater the percentage of this constituent, greater its susceptibility to sulphate attack.
- When water table is high, sulphates present in soil get dissolved in water and sulphates in solution attack the foundation concrete as well as cement mortar used in masonry in foundation and plinth. Similarly, continuous dampness in superstructure. Either due to leakage from water supply or drainage system or due to long spells of rain, beating against walls or leaking through roof will, in course of time, results in cracks in masonry as well as plaster.
- Sulphate attack on concrete and mortar of masonry in foundation and plinth would result in weakening of these components and may in course of time result in unequal settlement of foundation and cracks in the superstructure.

2.5.2CARBONATION:-

- When concrete hardens due to hydration of cement, some calcium hydroxide is liberated which sets up a protective alkaline medium inhibiting galvanic cell action and preventing corrosion: of steel. In course of time, free hydroxide in concrete reacts with atmospheric carbon-dioxide, forming calcium carbonate, resulting in shrinkage cracks. This reaction known as ‘Carbonation’ also lowers alkalinity of concrete and reduces its effectiveness as a protective medium.
- In good quality dense concrete, carbonation is confined mainly to surface layers of concrete and depth of carbonation may not exceed 20 mm in 50 years. In porous concrete, carbonation may reach a depth of 100 mm in 50 years.

- Carbonation is more rapid in a dry atmosphere but, since presence of moisture is necessary for galvanic action to take place, for corrosion of steel, an alternating dry and wet weather is more conducive to corrosion.
- In industrial towns, having higher percentage of carbon dioxide in the atmosphere because of pollution, cracking caused in concrete due to carbonation is comparatively much more. Such cracks can be avoided or minimized by ensuring use of dense and good quality concrete and limiting the width of elastic cracks in structural design to 0.30mm for protected internal members and to 0.20mm for unprotected external members.
- Occurrence of carbonation in case of masonry units of cellular or light-weight concrete is quite substantial, because carbon dioxide from atmosphere can penetrate to a considerable depth on account of porosity of the material. This reaction, therefore, accentuates shrinkage cracks in masonry employing these units. Curing of these units during manufacture with steam at atmospheric pressure causes pre-carbonation and considerably reduces subsequent shrinkage.

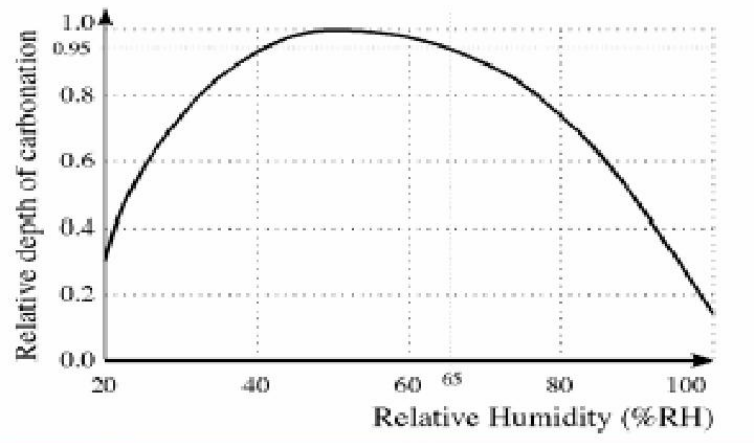


Fig.2.4 Carbonation

2.5.3CORROSION OF REINFORCEMENT:-

- Corrosion of reinforcement is an electro-chemical process and for that a necessary precondition is the formation of a galvanic cell which comprises(includes) two electrodes- anode and cathode, separated by an electrolyte and connected in an electrical circuit.

- Anode reaction of the cell involves dissolution of metal and its combination with oxygen to form iron oxide. Concrete always contains some moisture as such and acts as an electrolyte.
- Factors which lead to corrosion of reinforcement in concrete and reinforced brickwork are: Permeability of concrete, Carbonation, Corrosion cells, Electrolysis, Presence of Moisture and Soluble sulphates, Inadequacy of Cover, etc.
- As steel gets corroded, it increases in volume thus setting up internal stress in concrete. In course of time it first causes cracks in line with the direction of reinforcement and later causes spelling of concrete, dislodging cover of reinforcement from the body of the concrete, thus seriously damaging the structure.
- In reinforced brickwork, process of corrosion of reinforcement is similar to that in concrete, except that, it is more rapid and life expectancy of such work is much less.

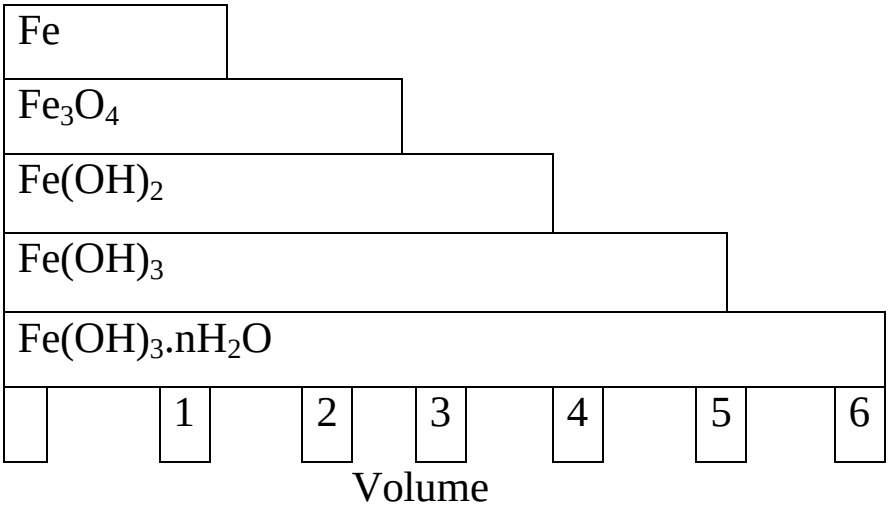


Fig.2.5 Process of Corrosion of Reinforcement

- There are mainly three types of Corrosion of Steel or Reinforcement :

A. Electrochemical Corrosion
B. Galvanic Corrosion
C. Atmospheric Corrosion

2.5.3.1Electrochemical Corrosion:-

- Iron reacts as :

  $Fe >> Fe^{++} + 2e^{-}$ (Anode Process)

- Water takes Oxygen from Atmosphere

  $2H_2O + O_2 + 2e^- >>> 4OH^-$ (Cathode Process)
- Fe^{++} and OH^- creates $Fe(OH)_2$
- $Fe(OH)_2$ is not stable, Oxidises to form $Fe(OH)_3$
- Takes water to form $Fe(OH)_3.nH_2O$ (Rust)

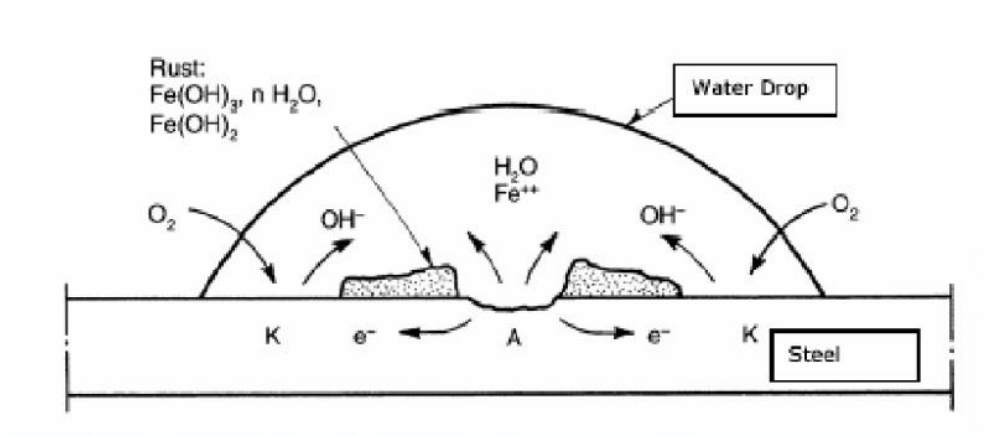


Fig.2.6 Electrochemical Corrosion

2.5.3.2Galvanic Corrosion:-

- More anodic metal releases Ions when two different metals are in Electrical contact in moist atmosphere.

2.5.3.3Atmospheric Corrosion:-

- It occurs due to High Humidity level (>65%), Air pollution such as SO_2 in air, etc.
- The corrosion velocity is doubled for every 10^0increase in temperature.

TABLE 2.3 DIFFERENCES BETWEEN ELECTROCHEMICAL AND GALVANIC SERIES

	Electrochemical series Thermodynamic series		Galvanic series Metals in sea water	
	Metal	Normal potential in volt at 25^0C against hydrogen electrode	Metal	Potential in volt at 20-25^0C against hydrogen electrode
Anodic	Mg/Mg^{++}	-2.34	Magnesium	-1.4
	Al/Al^{++}	-1.67	Zinc	-0.8
	Zn/Zn^{++}	-0.76	Al alloys	-0.8 to -0.5
	Cr/Cr^{++}	-0.74	Cadmium	-0.5
	Fe/Fe^{++}	-0.44	Steel , Cast iron	-0.5 to -0.4
	Cd/Cd^{++}	-0.40	Stainless steel, active	-0.3 to -0.1
	Ni/Ni^{++}	-0.25	Copper	-0.1
	Sn/Sn^{++}	-0.14	Tin	-0.1
	Pb/Pb^{++}	-0.13	Lead	0.0
	H/H^{+}	-0.00	H/H^{+}	0.00
Cathodic	Ag/Ag^{+}	+0.80	Silver	+0.1
	Pt/Pt^{++}	+1.12	Platinum	+0.4
	Au/Au^{++}	+1.68	Graphite	+0.4 to +0.5

2.5.4ALKALI-AGGREGATE REACTION:-

- If Alkali-aggregate reaction takes place, concrete is weakened and develops cracks and thus is no longer in a position to afford adequate protection to steel reinforcement.
  - In ordinary Portland cement alkalis namely, Sodium oxide (Na_2O) and Potassium oxide (K_2O) are present to some extent. These alkalis chemically react with certain siliceous mineral constituents of some aggregates and cause expansion, cracking and disintegration of concrete.
  - In case of RCC, cracking due to alkali-aggregate reaction gives rise to corrosion of reinforcement that may result in structural failure. Cracking due

to this cause is usually of map pattern and reaction being very slow; it takes a number of years for cracks to develop.

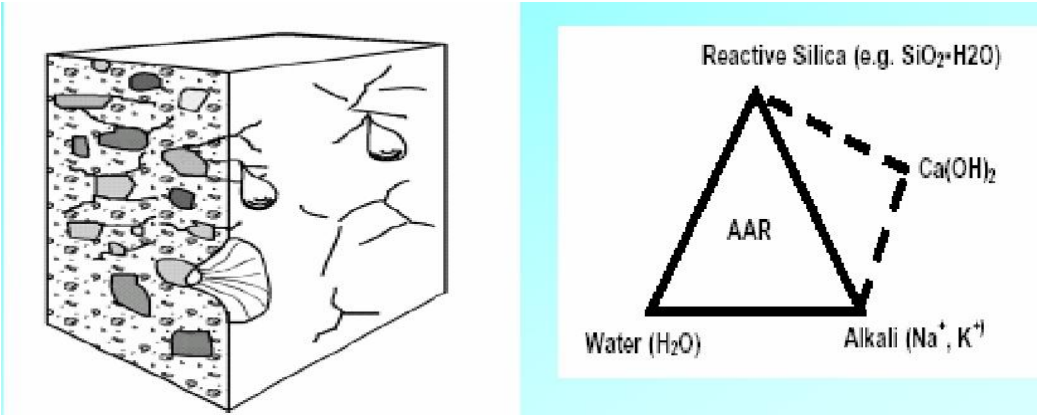
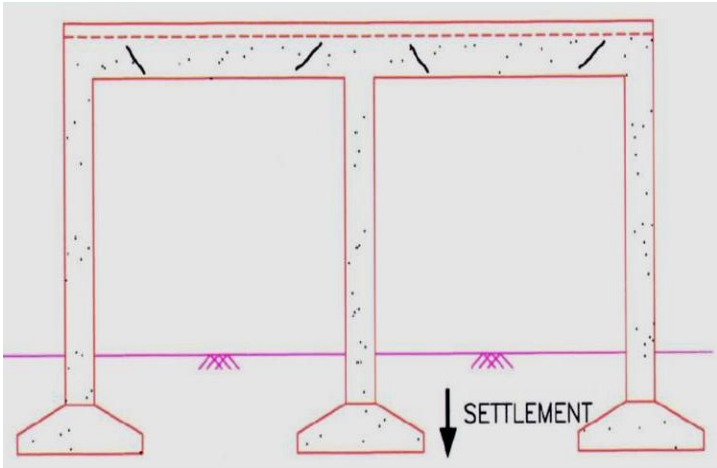


Fig.2.7Alkali-Aggregate Reaction

2.6 FOUNDATION MOVEMENT AND SETTLEMENT OF SOIL:-

- Buildings on expansion clays are extremely crack prone. The soil movement in such clay is more appreciable up to a depth of 1.5 to 2 m and this cause swelling and shrinkage and results in crack in the structure. The cracks due to settlement are usually diagonal in shape.
- 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.
- Sometimes, differential settlements in buildings occur when there are local variations in the nature of supporting soil and such variations are not detected and taken care of in the foundation design at the time of construction.
- Cracks that occur due to foundation movement of a corner on an end of a building are usually diagonal in shape. These cracks are wide at top and decrease in width downward. These cracks thus can be easily distinguished from those due to thermal or moisture movements.
- In case of a building built on soil which is not very compact, sometimes settlement starts when water due to unusually heavy rains or unexpected floods gets into the foundation and causes settlement in the soil under load of the structure.

- Such a settlement generally not being uniform in different parts, results in cracking Plinth protection around the building help to some extent in preventing seepage of rain and surface water into the foundation, thereby obviating the possibility of settlement cracks.
- Sometimes it becomes necessary to make a horizontal extension to an existing structure. Since foundation of a building generally undergoes some settlement as load comes on the foundation, it is necessary to ensure that new construction is not bonded with the old construction and the two parts (old and new) are separated by a slip or expansion joint right from bottom to the top, as otherwise when the newly constructed portion undergoes settlement, an unsightly crack may occur at the junction.
- Care should also be taken that in the vicinity of the old building; no excavation below the foundation level of that building is made.
- When plastering the new work a deep groove should be formed separating the new work from the old. If the existing structure is quite long (20 to 25 m), the old and new work should be separated by an expansion joint with a gap of about 25 to 40mm so as to allow some room for unhindered expansion of the two portions of the building.
- When it is intended to make horizontal extension to a framed-structure at some later date, it is necessary to provide twin columns at the junction with a combined footing for the foundation of the two columns.



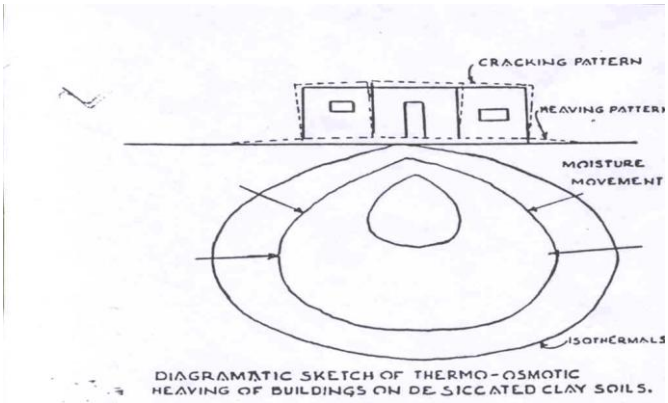


Fig.2.8 Cracks due to Settlement

2.7CRACKING 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.
- Sometimes plants take root and begin to grow in fissures of walls, because of seeds contained in bird droppings. If these plants are not removed well in time, these may in course of time develop and cause severe cracking of the wall.

- When soil under the foundation of a building happens to be shrinkable clay, cracking in walls and floors of the building can occur either due to dehydrating action of growing roots on the soil which may shrink and cause foundation settlement or due to upward thrust on a portion of the building, when old trees are cut off and the soil that had been dehydrated earlier by roots, swells up on getting moisture from some source, such as rain.
- A few examples of occurrence of cracks in structures, walls or floors due to vegetation are given below :

a) A case where roots of a tree growing under the foundation of a compound wall cause cracks in the wall. These cracks are wide at the base and narrow down as they pass upwards.
   - Sometimes thrust exerted by the growing roots may overturn a compound wall.

b) a case where trees growing close to a building founded on shrinkable soil cause shear cracks due to shrinkage of soil, and settlement of foundation. These cracks are wide at top and get narrow as they travel downwards.

c) A case where old trees growing in the vicinity of a structure are cut off in order to clear the surroundings. In course of time, soil under the foundation which had been dehydrated by the trees absorbs moisture from rain, etc, and swells up so as to exert upward thrust on the foundation. These cracks are wide at the base and get narrow as they travel upwards.

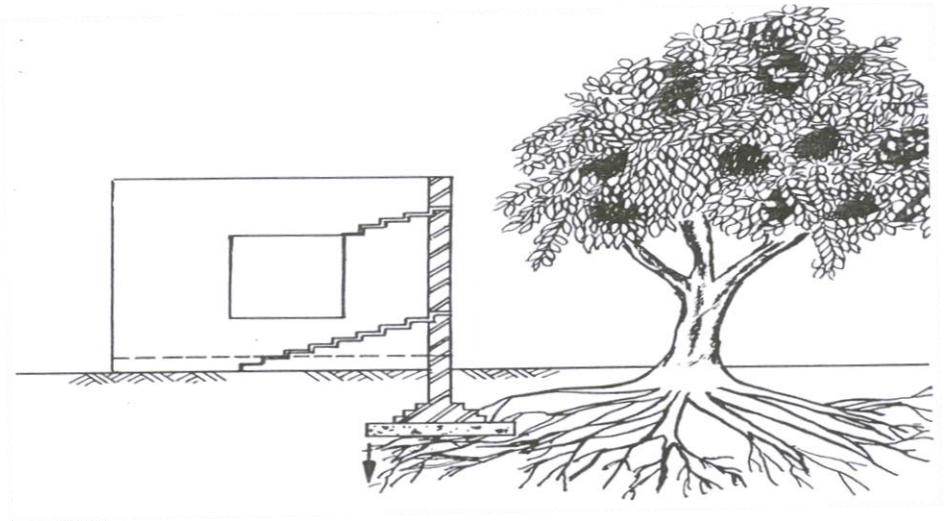


Fig. 2.9 Trees Growing close to a Building on Shrinkage Soil may Cause Cracks in the Walls

2.8 SHEAR FLEXURE CRACKS:-

- Cracks are commonly occurred in Structural members like Beams, Columns, and Slabs.

2.8.1 SHEAR FLEXURAL CRACKS IN BEAMS:-

- It occurs mainly due to combination of Shear and Moment, Shear strength Deficiency.
- These cracks occur at maximum Moment region, less moment of resistance, Inadequate Reinforcement and Insufficient section.
- It occurs either singly or Group.
- These Cracks affects to Structural Soundness.
- Such typical crack is shown in Fig.2.10.

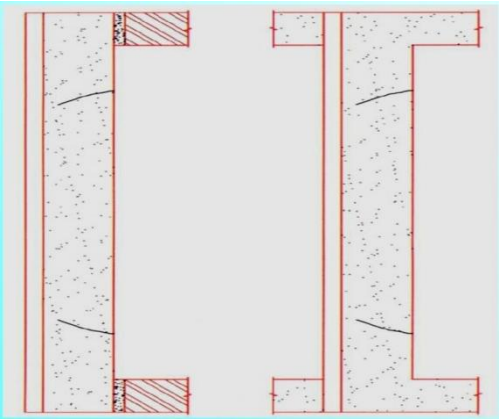


Fig. 2.10 SHEAR FLEXURE CRACKS IN BEAMS

2.8.2 SHEAR FLEXURAL CRACKS IN SLABS:-

- These cracks occurred mainly due to Inadequate Main Reinforcement and Distribution of Reinforcement not Continuous.
- These cracks also occurred due to Deficiency in Design, under assessment of loading, Overloading of section and Poor Quality of concrete.

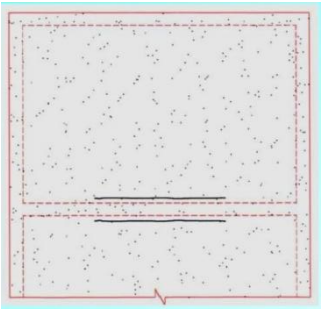


Fig.2.11 SHEAR FLEXURAL CRACKS IN SLABS

2.9 BOND CRACKS:-

- These cracks occurred due to Corrosion of Reinforcements, Inadequate cover and Poor quality of Concrete.
- Bond cracks are shown in Fig.2.12.

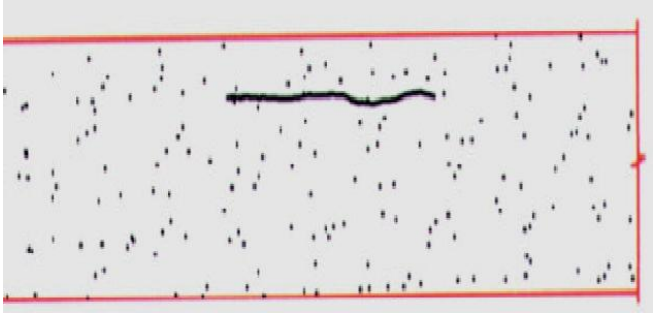


Fig. 2.12 BOND CRACKS

2.10 DISTURBANCE CRACKS:-

- In construction practices, these cracks occurred due to Removal/Stripping of Formwork or Shuttering of supporting members.
- Such type of crack is shown in Fig.2.13.

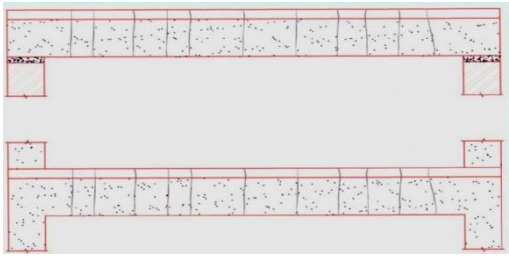


Fig. 2.13DISTURBANCE CRACKS

- Measures for prevention of cracks could be broadly classified under the following main sub-heads:

a) Choice of materials;
b) Specifications for mortar and concrete;
c) Architectural design of buildings;
d) Structural design;
e) Foundation design;
f) Construction practices and techniques; and
g) Environments.

3.1 CHOICE OF MATERIALS:-

- Certain properties of building materials have very vital influence on cracking which occur during construction or after the structure is completed and it is necessary for the engineer/ architect to have proper knowledge and understanding of these properties so that either use of such materials as may result in cracking could be avoided, if possible, or when use of such materials is inevitable, suitable precautions as would help in minimizing cracks could be taken.
- Properties of materials that influence cracking are: drying shrinkage, moisture movement, and thermal expansion, modulus of elasticity, porosity, creep, thermal conductivity, thermal insulation, thermal capacity, reflectivity and chemical composition.

3.1.1 MASONARY UNITS:-

a) Burnt clay bricks and other burnt clay products should not be used in masonry for a period of at' least two weeks in summer and three weeks in winter after these have been unloaded from kilns. These should be kept exposed to atmosphere during this period.
b) For use in masonry, bricks should be well burnt.
c) Use of burnt clay bricks containing excessive quantity of soluble sulphates should be avoided; if their use cannot be avoided, suitable fire cautions against sulphate attack should be taken.
d) When using units, having high values of drying shrinkage, for example, concrete blocks and sand-lime bricks, precautions should be taken.

e) For masonry work, use of such stones as are porous and are liable to shrink on drying, for example, sandstones, should be avoided.

3.1.2 FINE AGGREGATES:-

- Use of fine aggregate for mortar and concrete which is too fine or contains too much of clay or silt and is not well graded should be avoided. Percentage of clay and silt in fine aggregate (uncrushed) should not exceed 3 percent.

3.1.3 COARSE AGGREGATES:-

a) Coarse aggregate for concrete work should be well graded so as to obtain concrete of high density. Maximum size of coarse aggregate should be largest possible consistent with the job requirements.

b) Coarse aggregate for concrete should not be of stones that are porous and have high shrinkage coefficient.

c) Use of aggregate made from alkali reactive stone should be avoided. If it is not possible to avoid the use of such Aggregate, precautions should be taken.

d) When using brick aggregate for concrete in base course, use of aggregate containing excessive amount of soluble sulphates should be avoided.

e) Coarse aggregates should not contain fines exceeding 3 percent.

3.1.4 CEMENT:-

a) When use of alkali-reactive aggregate in concrete is unavoidable, alkali content of cement should not exceed 0.6 percent. If low-alkali cement is not economically available, use of pozzolanas should be made to check alkali-aggregate reaction.

b) When use of bricks containing excessive quantity of soluble sulphates is unavoidable, content of cement in mortar should be increased or special cements, namely, sulphate resisting Portland cement or super-sulphated cement should be used.

c) In massive structures, in order to limit heat of hydration. Use of low-heat cement should be made unless other methods are adopted to prevent rise in temperature of concrete.

3.1.5 TIMBER AND TIMBER PRODUCTS:-

a) Use of unseasoned, timber in wood-work and joinery should be avoided.

b) In large panels of joinery (say larger than 25 cm in width) use should be made of plywood or blackboard panels in place plain wood panels for internal work as the former have better dimensional stability.

3.1.6 STEEL REINFORCEMENT:-

- Use of steel as reinforcement in brick masonry in exposed situations should be avoided unless special precautions are taken to prevent rusting.

3.2 SPECIFICATION OF MORTAR AND CONCRETE:-

- Components or items in a building which are most prone to cracking are walls, floors, plasters and concrete work.
- Therefore, specifications of mortar and concrete have a very important role to play in regard to the incidence of cracking in buildings.
- Apart from strength and durability. Specifications for mortar and concrete should be decided on consideration of obtaining products with minimum of drying shrinkage and creep and with adequate resistance against sulphate attack.

3.2.1 MORTAR:-

a) MORTAR FOR MASONRY WORK:-

- Use of rich cement mortars which have high shrinkage should be avoided; composite cement-lime mortar should be preferred.
- When using concrete blocks of dense or light weight concrete or sand-lime bricks as masonry units in non-load bearing walls, use of rich cement mortars should be avoided. Mortar 1 cement: 2 lime: 9 sand for work done in summer and 1 cement: 1 lime: 6 sand for work done in winter would be adequate in most of the cases.

b) MORTAR FOR PLASTER WORK:-

- Use of rich cements plasters for plaster work should be avoided; composite cement lime mortars are less liable to shrinkage cracks; also plaster using mortar with coarse sand will crack less.

3.2.2 CEMENT CONCRETE:-

a) Aim should be to obtain strong and durable concrete by careful mix design, grading of aggregates. Control of water cement ratio, thorough mixing, proper compaction and adequate curing, etc. An over-sanded mix should be avoided.

b) Quantity of water used in concrete should be the minimum. Consistent with requirements for laying and proper compaction. This is one of the most important single factor which influences shrinkage and consequent cracking in concrete.

3.3 ARCHITECTURAL DESIGN OF BUILDINGS:-

- Factors ‘relating to architectural design of buildings which affect cracking are: large spans of rooms, provision of large windows in external walls, introduction of short

return walls in external elevation, etc. Door and window frames should not be placed flush with plaster surface and if that is unavoidable either the joints should be concealed with moulding strips or arrangement.

3.4 STRUCTURAL DESIGN OF BUILDINGS:-

- Factors in structural design which have an influence on cracking are:

a) Stress in different parts of masonry walls should be more or less uniform so as to avoid differential strain and consequent shear stresses and cracking.

b) Flexural members, namely, slabs and beams should have adequate stiffness so as to limit deflection.

c) Flexural cracks in concrete should be limited in width to 0.30 mm for protected internal members and 0.20 mm for unprotected external members.

d) In a rigid structure, such as rigid frames and shells, since movement joints are not feasible, thermal and shrinkage stresses should be taken care of in the design.

3.5 STRUCTURAL DESIGN OF FOUNDATION:-

a) Bearing pressure on foundation soil should be more or less uniform so as to avoid differential settlement.

b) Value of safe bearing pressure assumed for foundation design should be such as would keep overall settlement within reasonable limits for the type of structure in question.

c) When building on soil consisting of shrinkable clays, soil movements due to alternate wetting and drying and consequent swelling and shrinkage should be taken care of by providing special foundations, such as under-reamed piles, to avoid cracking. Also when necessary, water-proof apron should be provided all round the building to minimize moisture changes in soil under the building.

3.6 CONSTRUCTION PRACTICES AND TECHNIQUES:-

3.6.1 FILLING IN PLINTH:-

- Filling of soil in plinth should be done with good soil free from organic matter, brick-bats, and debris, etc.
- It should be laid in 25cm thick layers, well watered and compacted so that there may be no possibility of subsequent subsidence and cracking of floors.
- Special precautions are needed if filling is deep or flooring has to bear heavy loads as in grain. Godowns, warehouses and factory buildings.

3.6.2 MASONARY WORK:-

- Masonry work should proceed at a uniform level all round so as to avoid differential loading on the foundation.
- Mortar for masonry should not contain excessive water.
- Curing for masonry work should be done for a minimum period: of 7 to 10 days.
- Masonry work on RCC slabs and beams should not be started till at least 2 weeks have elapsed after striking of centring.

3.6.3 CONCRETE WORK:-

- As far as possible, concreting job should not be done when it is very hot, dry and windy.
- If unavoidable, precautions should be taken to keep down temperature of fresh concrete and to prevent quick drying.
- Curing should be done for a minimum period of 7 to 10 days.
- It should be terminated gradually so as to avoid quick drying.
- Water for mixing and curing of concrete should not contain impurities in excess of permissible limits.

3.6.4 RCC FRAMED CONSTRUCTION:-

- As far as possible, frame work should be completed before starting work of panel walls for cladding and partition walls.
- Work of construction of panel walls and partitions should be deferred as much as Possible and it should be proceeded with from top downward.
- Horizontal movement joints should be provided between top of panel walls and soffit of beam, and when structurally necessary, lateral support to the walls should be provided at top by using telescopic anchorages or similar restraints.
- When partition walls are to be supported on floor slab or beam, upward camber in the slab/ beam should be provided to forestall deflection.
- A horizontal expansion joint should be provided between top of a partition wall and soffit of slab/ beam, filling the gap with some compressible jointing material.

3.6.5 PLASTERING:-

- When plastering on concrete background, plastering should be done as soon as feasible after hacking and roughening the surface and applying cement slurry on the concrete surface to improve bond.

3.6.6 CONCRETE AND TERRAZO FLOOR:-

- When flooring is to be laid on RCC slabs, either a base course of lime-concrete should be provided between the RCC slab and the flooring or surface of slab should be well roughened, cleaned and primed with cement slurry before laying the concrete, terrazzo floors.

3.7 ENVIRONMENTS:-

3.7.1 VEGETATION:-

- Following precautions are necessary in regard to growing or removal of trees in the close vicinity of :-

a) When a building is founded on shrinkable soil, trees, particularly fast growing trees, should not be grown within a distance of expected height of trees.

b) If old trees exist close to an old building (within a distance of the height of the tree) these trees should not be removed all at once in one operation. If removal of trees is unavoidable, it should be done in stages.

c) When a site having shrinkable soil has been newly prepared for construction of buildings by clearing off existing trees and vegetation, construction work should not be started till the soil which had been desiccated by tree roots, has normalized in regard to its moisture content.

3.7.2 AMBIENT TEMPERATURE:-

a) Concrete work done in hot weather is highly crack prone due to high shrinkage.

b) It is, therefore, desirable to avoid concreting when ambient temperature is high or to take some special precautions.

3.7.3 DRY WEATHER:-

a) Concreting done in dry weather is likely to get dried quickly after laying, which would result in plastic cracking.

b) It is, therefore, necessary to take suitable precautions to prevent quick drying.

c) If windy conditions prevail and ambient. Temperature is high; damaging effect will be much more severe.

- Cracking in structures is of common occurrence and engineers are often required to look into their causes and to carry out suitable repairs and remedial measures. For repairs and remedies to be effective, it is essential that the engineer should have proper understanding of various causes of cracking.
- The underlying concepts in the three operations are stated below:-

4.1 REPAIRS:-

- The main purpose of repairs is to bring back the architectural shape of the building so that all services start working and the functioning of building is resumed quickly. Repair does not pretend to improve the structural strength of the building and can be very deceptive for meeting the strength requirements of the next earthquake.
- The actions will include the following:-

a) Patching up of defects such as cracks and fall of plaster.
b) Repairing doors, windows, replacement of glass panes.
c) Checking and repairing electric wiring.
d) Checking and repairing gas pipes, water pipes and plumbing services.
e) Re-building non-structural walls, smoke chimneys, boundary walls, etc.
f) Re-plastering of walls as required.
g) Rearranging disturbed roofing tiles.
h) Relaying cracked flooring at ground level.
i) Redecoration, whitewashing, painting, etc.

- The architectural repairs as stated above do not restore the original structural strength of cracked walls or columns and may sometimes be very illusive, since the redecorates building will hide all the weaknesses and the building will suffer even more severe damage if shaken again by an equal shock since the original energy absorbing capacity will not be available.

4.2 REPAIR MATERIALS:-

- The most common materials for damage repair works of various types are cement and steel. In many situations non-shrinking cement or an admixture like aluminium powder in the ordinary Portland cement will be admissible. Steel may be required in many forms, like bolts, rods, angles, channels, expanded metal and welded wire fabric.

- Special materials and techniques are available for best results in the repair and strengthening operations. They are described below:-

1) Shotcrete
2) Epoxy Injection
3) Routing and Sealing
4) Near-Surface Reinforcing and Sealing
5) Additional Reinforcement
6) Drilling and Plugging
7) Gravity Filling
8) Grouting
9) Dry Packing
10) Crack Arrest
11) Polymer Impregnation
12) Overlay and Surface Treatments
13) Autogenous Healing.

4.2.1 SHORTCRETE:-

- Shotcrete is a method of applying a combination of sand and Portland cement which mixed pneumatically and conveyed in dry state to the nozzle of a pressure gun, where water is mixed and hydration takes place just prior to expulsion. The material bonds perfectly to properly prepared surface of masonry and steel.
- In versatility of application to curved or irregular surfaces, its high strength after application and good physical characteristics, make for an ideal means to achieve added structural capability in walls and other elements. There are some minor restrictions of clearance, thickness, direction of application, etc.

4.2.2 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.
- If the cause of the cracks cannot be removed, then three options are available:

a) Rout and seal the crack, thus treating it as a joint;
b) Establish a joint that will accommodate the movement and then inject the crack with epoxy or other suitable material; and

c) Install additional support or reinforcement at the crack location to minimize movement.

- Epoxy materials used for structural repairs should conform to ASTM C 881 (Type IV). ACI 504R describes practices for sealing joints, including joint design, available materials, and methods of application.
- 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 that will cure and bond in the presence of moisture, but contaminants in the cracks (including silt and water) can reduce the effectiveness of the epoxy to structurally repair the cracks.
- Epoxy injection requires a high degree of skill for satisfactory execution, and use of the technique may be limited by the ambient temperature.
- The general procedures involved in epoxy injection are as follow:

4.2.2.1 CLEANING OF CRACKS:-

- The first step is to clean any 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 effective cleaning solutions. The solution is then flushed out using compressed air and a neutralizing agent or adequate time is provided for air drying. It is important, however, to recognize the practical limitations of accomplishing complete crack cleaning. A reasonable evaluation should be made of the extent, and necessity, of cleaning. Trial cleaning may be required.

4.2.2.2 SEALING THE SURFACES:-

- The crack face cannot be reached, but where there is backfill or where a slab-on-ground is being repaired, the backfill material or sub base material is sometimes an adequate seal; however, such a condition can rarely be determined in advance, and uncontrolled injection can cause damage such as plugging a drainage system.
- Extreme caution should be exercised when injecting cracks that are not visible on all surfaces. 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.
- If extremely high injection pressures are needed, alternate procedures should be followed:

❋ INSTALLING THE ENTRY AND VENTING PORTS:-

- Three methods are in general use:

1. **FITTING INSERTED INTO DRILLED HOLES:-**This 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, into which a fitting such as a pipe nipple or tire valve stem is usually bonded with an epoxy adhesive.
2. **BONDED FLUSH FITTING:-**An alternative method that is 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.

4.2.2.3 MIXING THE EPOXY:-

- Mixing is done 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.
- In the continuous mixing system, the two liquid adhesive components pass through metering and driving pumps before passing through an automatic mixing head.

4.2.2.4 INJECTING THE EPOXY:-

- Hydraulic pumps, paint pressure pots, or air-actuated caulking guns may be used.
- Increased pressure often does little to accelerate the rate of injection. In fact, the use of excessive pressure can propagate the existing cracks, causing additional damage.
- 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 a predetermined entry port above. The lower injection port is then capped, and the

process is repeated until the crack has been completely filled and all ports have been capped.

- For horizontal cracks, the injection should proceed from one end of the crack to the other in a similar manner.
- A low-pressure injection system is available that uses discrete capsules containing a premixed epoxy. The capsules are mounted on injection ports. A spring inside each capsule maintains a constant low pressure to dispense a low-viscosity, long-pot-life epoxy resin into a crack.

4.2.2.5 REMOVING THE SURFACE SEAL:-

- After the injected epoxy has cured, the surface seal should be removed by grinding or other means as appropriate.
- Another method involves the use of a vacuum or vacuum assist. There are two techniques. One technique is to entirely enclose the cracked member with a bag, introduce the liquid adhesive at the bottom, and apply a vacuum at the top. The other technique is to inject the cracks from one side and pull a vacuum from the other.
- Epoxy resins and injection procedures should be carefully selected when attempting to inject deliminations. Unless there is sufficient depth or anchorage to surrounding concrete, the injection process can be unsuccessful or increase the extent of delimination. Smith (1992) provides information on bridge decks observed for up to 7 years after injection. Smithson and Whiting (1992) describe epoxy injection as a method to rebond delaminated bridge deck overlays.

4.2.3 ROUTING & SEALING:-

- Routing and sealing of cracks can be used in conditions requiring repair 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.

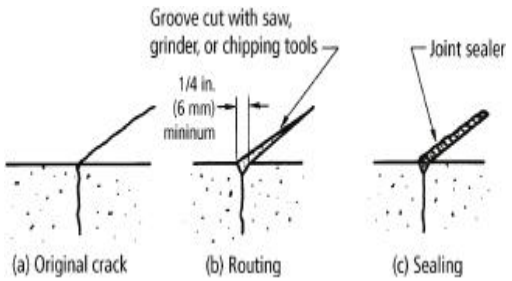


Fig.4.1 ***Repair of crack by routing and sealing***

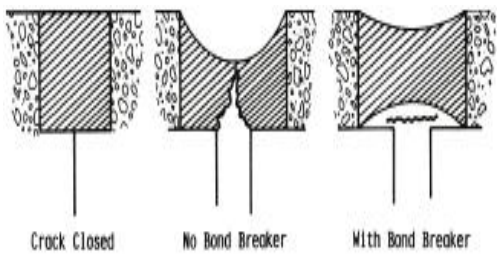


Fig.4.2 Effect of Bond Breaker

- Figure 4.1 shows the procedure for repairing a crack. This is a common technique for crack treatment and is relatively simple compared with the procedures and the training required for epoxy injection.

- The procedure is most applicable to approximately flat horizontal surfaces such as floors and pavements. Routing and sealing can be accomplished on vertical surfaces as well as on curved surfaces (pipes, piles, and poles).
- Routing and sealing is used to treat both narrow and wide 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, polysulphides, asphaltic materials, or polymer mortars. Cement grouts should be avoided due to the likelihood of cracking.
- Routing and sealing consists of preparing a vertical walled groove at the surface typically ranging in depth from 1/4 to 1 in. (6 to 25 mm). A concrete saw or right-angle grinder 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 (Fig. 4.1) and allowed to cure.
- Active cracks should be repaired using a bond breaker at the base of the routed channel (Fig. 4.2). A flexible sealant is then placed in the routed channel. It is important that the width-to-depth ratio of the channel is usually 2 or more. This permits the sealant to respond to movement of the crack with high extensibility.
- In some cases, over banding (strip coating) is used independently of or in conjunction with routing and sealing. This method is used to enhance protection from edge spalling and, for aesthetic reasons, to create a more uniform-appearing treatment.
- A typical procedure for over banding is to prepare an area approximately 1 to 3 in. (25 to 75 mm) on each side of the crack by sandblasting or other means of surface preparation, and applying a coating (such as urethane) 0.04 to 0.08 in. (1 to 2 mm) thick in a band over the crack.
- Cracks subject to minimal movement may be over banded, but if significant movement can take place, routing and sealing should be used in conjunction with over banding to ensure a waterproof repair.

4.2.4 NEAR-SURFACE REINFORCING AND PINNING:-

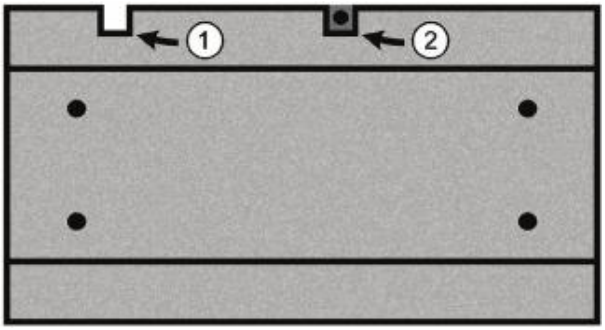


Fig.4.3 Repair using near-surface-mounted reinforcing:
(1) Saw cut 1/8 to 1/4 in. (3 to 6 mm) larger than bar diameter;
And (2) deformed bar or FRP bar bedded in epoxy resin.

- Near-surface reinforcing (NSR) is a method used to add tensile reinforcement perpendicular to the plane of the crack. As shown in Fig. 3.3, a slot is saw cut across the crack, and the slot is then cleaned. Typically, an epoxy resin is placed in the slot to act as a bonding agent and protective barrier to the bar that is subsequently placed. Both deformed steel reinforcing bars and procured fibre-reinforced polymer (FRP) bars are placed in the slot that is cut to approximately 0.125 in. (3 mm) wider and deeper than the diameter of the reinforcement to be installed. The reinforcing needs to be designed to increase the capacity beyond the tensile forces at the crack location.

4.2.5 ADDITIONAL REINFORCEMENT:-

4.2.5.1 CONVENTIONAL REINFORCEMENT:-

- Cracked reinforced concrete bridge girders have been successfully repaired by inserting reinforcing bars and bonding them in place with epoxy (Stratton et al. 1978; Stratton 1980; “Crack Repair Method: Conventional Reinforcement” 1985).
- This technique consists of sealing the crack, drilling holes that intersect the crack plane at approximately 90 degrees (Fig. 4.4), filling the hole and crack with injected epoxy, and placing a reinforcing bar into the drilled hole.

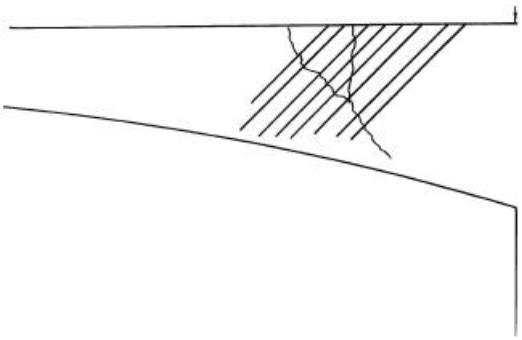


Fig. 4.4—reinforcing bar orientation

- 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. The epoxy bonds the bar to the walls of the hole, fills the crack plane, bonds the cracked concrete surfaces back together in one monolithic form, and thus reinforces the section.

4.2.5.2 PRESTRESSING 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. 4.5). This technique uses prestressing strands or bars to apply a compressive force.
- Adequate anchorage should be provided for the prestressing steel, and care is needed so that the problem will not merely migrate to another part of the structure. The effects of the tensioning force (including eccentricity) on the stress within the structure should be carefully analyzed.

4.2.6 DRILLING & PLUGGING:-

- Drilling and plugging a crack consists of drilling down the length of the crack and grouting it to form a key (Fig. 4.6).
- This technique is only applicable when cracks run in reasonably straight lines and are accessible at one end. This method is most often used to repair vertical cracks in retaining walls (“Selection of a Crack Repair Method” 1985).
- A hole (typically 2 to 3 in. [50 to 75 mm] in diameter) should be drilled, centered on and following the crack. The hole should be large enough to intersect the crack along its full length and provide enough repair material to structurally take the loads exerted on the key. The drilled hole should then be cleaned, made tight, and filled with grout.
- The grout key prevents transverse movements of the sections of concrete adjacent to the crack. The key will also reduce heavy leakage through the crack and loss of soil from behind a leaking wall.

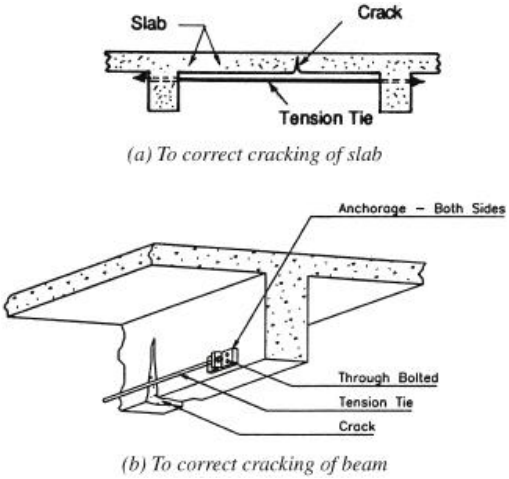


Fig. 4.5—Examples of external prestressing

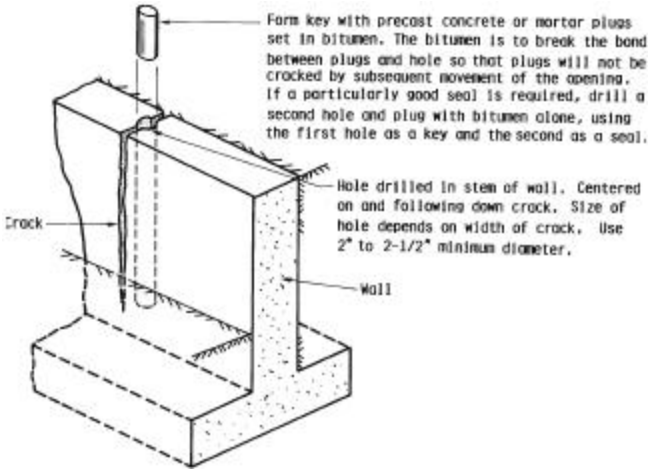


Fig. 4.6—Repair of crack by drilling and plugging

4.2.7 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 methacrylate, 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, water blasting, or both. Wet surfaces should be permitted to dry for several days to obtain the best crack filling. The monomer or resin can be poured onto the surface and spread with brooms, rollers, or squeegees.
- The material should be worked back and forth over the cracks to obtain maximum filling because the monomer or resin recedes slowly into the cracks. The use of this method on elevated slabs will require sealing of the cracks on the bottom of the slab to contain material from leaking through the crack.
- Excess material should be broomed off the surface to prevent slick, shining areas after curing. If surface friction is important, sand should be broadcast over the surface before the monomer or resin cures.
- Caution should be employed to avoid cutting existing reinforcement during the coring process. Cores can be tested to give an indication of the effectiveness of the repair method. The accuracy of the results may be limited, however, as a function of the crack orientation or due to the presence of reinforcing steel in the core. For some polymers, the failure crack will occur outside the repaired crack.

4.2.8 GROUTING:-

4.2.8.1 PORTLAND CEMENT GROUTING:-

- Wide cracks, particularly in gravity dams (Warner 2004) 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. The *w/cm*, however, 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 may be used. After the crack is filled, the pressure should be maintained for several minutes to ensure good penetration.

4.2.8.2 CHEMICAL GROUTING:-

- Chemical grouts, such as urethanes and acrylomides, are activated by catalysts or water to form a gel, a solid precipitate, or foam that will fill void space within concrete. The materials are primarily used for sealing cracks from water penetration.
- Bond strengths are typically low, so structural repairs are not made with chemical grouts. Cracks in concrete as narrow as 0.002 in. (0.05 mm) have been filled with chemical grout.
- The advantages of chemical grouts include applicability in moist environments (excess moisture available), wide limits of control of gel time, and their ability to be applied in very fine fractures.
- Disadvantages are the high degree of skill needed for satisfactory use, and lack of strength.

4.2.9 DRY PACKING:-

- 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 w/cm 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.

- Dry pack can be used for filling narrow slots cut for the repair of dormant cracks. The use of dry pack is not advisable for filling or repairing active cracks. Before a crack is repaired by dry packing, the portion adjacent to the surface should be widened to a slot about 1 in. (25 mm) wide and 1 in. (25 mm) deep.
- The slot should be undercut so that the base width is slightly greater than the surface width. After the slot is thoroughly cleaned and dried, a bond coat, consisting of cement slurry or equal quantities of cement and fine sand mixed with water to a fluid paste consistency, or an appropriate latex bonding compound, should be applied.
- Placing of the dry pack mortar should begin immediately. The mortar consists of one part cement, one to three parts sand passing a No. 16 (1.18 mm) sieve, and just enough water so that the mortar will stick together when moulded into a ball by hand.
- To minimize shrinkage in place, the mortar should stand for 1/2 hour after mixing, and then be remixed before 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 scratched to facilitate bonding with the next layer. There need be no time delays between layers.
- 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.

4.2.10 CRACK ARREST:-

- During construction of massive concrete structures, cracks due to surface cooling or other causes may develop and propagate into new concrete as construction progresses. Such cracks may be arrested by blocking the crack and spreading the tensile stress over a larger area.
- A piece of bond breaking membrane or a grid of steel mat may be placed over the crack as concreting continues. A semicircular pipe placed over the crack may also be used (Fig.4.7).

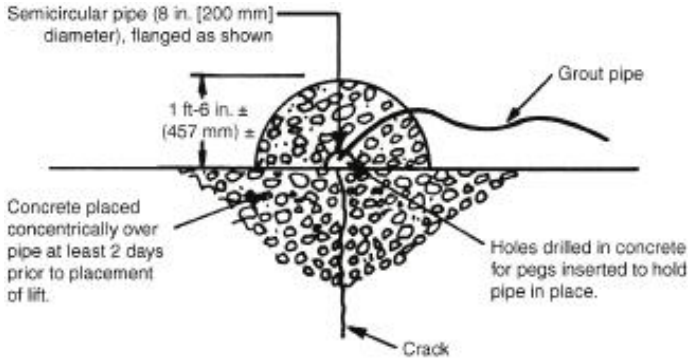


Fig. 4.7—Crack arrest method of crack repair

- A description of installation procedures for semicircular pipes used during the construction of a massive concrete structure follows:

1. The semicircular pipe is made by splitting an 8 in. (200 mm), 16 gauge pipe and bending it to a semicircular section with an approximately 3 in. (75 mm) flange on each side.
2. The area in the vicinity of the crack is cleaned
3. The pipe is placed in sections so as to remain centered on the crack
4. The sections are then welded together
5. Holes are cut in the top of the pipe to receive grout pipes; and
6. After setting the grout pipes, the installation is covered with concrete placed concentrically over the pipe by hand. The installed grout pipes are used for grouting the crack at a later date.

4.2.11 POLYMER IMPREGNATION:-

- This method is used to repair cracks by impregnation with a very low-viscosity monomer that is then polymerized in place. A monomer system is a liquid consisting of monomers that will polymerize into a solid. Suitable monomers have varying degrees of volatility, toxicity, and flammability, and they do not mix with water. They are very low in viscosity, and will soak into dry concrete and fill the cracks.
- The most common monomer used for this purpose is methyl methacrylate. Monomer systems used for impregnation contain a catalyst or initiator plus the basic monomer (or combination of monomers). They may also contain a cross-linking agent. When heated, the monomers join together, or polymerize, creating a tough, strong, durable plastic that greatly enhances a number of concrete properties.
- If a cracked concrete surface is dried, flooded with the monomer, and polymerized in place, some of the cracks will be filled and structurally repaired.

- If the cracks contain moisture, however, the monomer will not soak into the concrete at each crack face; consequently, the repair will be unsatisfactory. If a volatile monomer evaporates before polymerization, it will be ineffective. Polymer impregnation has not been used successfully to repair fine cracks. Polymer impregnation has primarily been used to provide more durable, impermeable surface.

4.2.12 OVERLAY & SURFACE TREATMENTS:-

- Cracks in structural slabs and pavements may be covered by using either a bonded or unbonded overlay or surface treatment. These methods do not repair cracks, but rather hide or obscure the cracks, unless a sufficiently reinforced overlay is installed that can handle the design loads and not allow reflective cracking.

4.2.13 AUTOGENOUS HEALING:-

- A natural process of crack repair known as autogenous healing can occur in concrete in the presence of moisture and the absence of tensile stress. It has practical application for closing dormant cracks in a moist environment, such as in mass concrete structures.
- Healing occurs by formation of calcium carbonate within cracks. Calcium carbonate forms by exposure of calcium hydroxide, which is a by-product of cement hydration, to carbon dioxide in air and water. The calcium carbonate that slowly precipitates is a hard, strong material. It not only fills void space within cracks, but also bonds crack surfaces and restores strength to the concrete.
- Healing will not occur if the crack is subjected to movement during the healing period. Healing will also not occur if there is a positive flow of water through the crack. Saturation of the crack and the adjacent concrete with water during the healing process is essential for developing any substantial strength. Submergence of the cracked section is desirable.
- Alternatively, water may be ponded on the concrete surface so that the crack is saturated. The saturation should be continuous for the entire period of healing. A single cycle of drying and reimmersion will produce a drastic reduction in the amount of healing strength. Procedures to facilitate healing should begin as soon as possible after the crack appears. Delayed healing results in less restoration of strength than does immediate correction.

4.3 RESTORATION:-

- It is the restitution of the strength the building had before the damage occurred. This type of action must be undertaken when there is evidence that the structural damage can be attributed to exceptional phenomena that are not likely to happen again and that the original strength provides an adequate level of safety.
- The main purpose of restoration is to carry out structural repairs to load bearing elements. It may involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored. The process may involve inserting temporary supports, underpinning, etc.
- Some of the approaches are stated below:

a) Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of no shrinking mortar will be preferable.

b) Addition of reinforcing mesh on both -faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it suitably. Several alternatives have been used.

c) Injecting epoxy like material, which is strong in tension, into the cracks in walls, columns, beams, etc.

4.4 STRENTHENING:-

- Strengthening is an improvement over the original strength when the evaluation of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future quakes.
- Commonly, strengthening procedures should aim at one or more of the following objectives:

a) Increasing the lateral strength in one or both directions, by reinforcement or by increasing wall areas or the number of walls and columns.

b) Giving unity to the structure by providing a proper connection between its resisting elements, in such a way that inertia forces generated by the vibration of the building can be transmitted to the members that have the ability to resist them. Typical important aspects are the connections between roofs or floors and walls, between intersecting walls and between walls and foundations.

c) Eliminating features that are sources of weakness or that produce concentrations of stresses in some members. Asymmetrical plan distribution of resisting members, abrupt changes of stiffness from one floor to the other, concentration of large masses,

large openings in walls without a proper peripheral reinforcement are examples of defect of this kind.

d) Avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members. Since its cost may go to as high as 50 to 60% of the cost of rebuilding, the justification of such strengthening must be fully considered.

- A case study for causes, prevention and repair of cracks of the buildings will be presented. This chapter includes the following:

1. Background
2. Investigation
3. Implementation of Case Study.

5.1 BACKGROUND:-

- The afflicted structures form Vaheguru Apartment & Hans raj Complex at Bhavnagar. The buildings were designed for Commercial as well as Residential. The buildings are five storeys.
- Fig. 5.1 & Fig. 5.2 show the Side view and Elevation of the buildings.
- The buildings were already constructed. Attention was drawn towards the Beams, Columns, Slabs, Walls, Compound walls and Joints where structural distress in the form of flexural, shear, corrosion of reinforcement and joints cracking had been observed.
- Cracking has been noticed since five years.
- Cracks are commonly occurred in Structural members like Beams, Columns, Slabs, Joints, Walls and Compound walls.

Fig.(a) Vaheguru Apartment

Fig.(b) Hans raj Complex

Fig. 5.1 Elevation of the buildings

Fig.(c) Vaheguru Apartment **Fig.(d) Hans raj Complex**

Fig. 5.2 Side view of the Buildings

5.2 INVESTIGATION:-

- An investigation process was carried out in order to determine the causes of cracks. The investigation process basically consists of reviewing technical information, condition survey of the site for visual inspection, specific field tests to check for strength, reinforcement details, etc.
- The investigation process carried out in order to determine the causes of cracks of Building components were included the following phases:

5.2.1 VISUAL INSPECTION:-

- The first signs of deterioration in concrete buildings are usually fine cracks and rust stains which may be accompanied by spalling of concrete. Visual Inspection is the first step to be taken in order to prepare a complete investigation to determine the cause, nature and extent of deterioration.
- We show various types of cracks in Vaheguru Apartment and Hans raj Complex which are both commercial as well as Residential.
- After the some investigation, we knows that these buildings are more than 20 years old, which visualises various types of cracks in components of buildings such as Beam, Columns, Slabs, Plastering, etc.

5.2.2 FIELD INVESTIGATION:-

- The purpose of this investigation was to determine the strength and structural adequacy of concrete in the structure, as a result of visible cracks and doubt in the quality of concrete.
- On the visit of Vaheguru Apartment and Hans raj Complex, we show various cracks and take snapshots of same. Then the study of these, we reached the situation that

these cracks with the help of various references how they occurred and which type of material is used to prevent and repair these cracks.

5.2.3 STRUCTURAL DESIGN REVIEW:-

- As part of the investigation. The structural designs for the cracked beams were reviewed. The analysis has revealed that, based on the original design strength of the concrete, 20 N/mm^2 the beams, columns and slabs are safe under expected loading conditions.
- Using the in-situ strength of the concrete, 14 N/ mm^2, as a basis for checks, the analysis reveals that the ultimate moment capacity of the beams is exceeded.
- The calculations showed that the moment capacity is reduced for the beams. Thus, leading to reduction in the overall factor of safety of the system.

5.3 IMPLEMENTATION OF CASE STUDY:-

- We went on the site and show various types of cracks. Various types of cracks may be defined by us who consists of how these cracks occurred in the building components. Then how to repair and which type of materials applied to repair the cracks.
- All the cracks with its causes, prevention and which type of materials used in repair the cracks described as following:

5.3.1 CORROSION OF REINFORCEMENT:-

5.3.1.1 CAUSES:-

- Corrosion of reinforcement is the main cause of damage to concrete structures.
- Corrosion creates expansive corrosion products, which crack and subsequently spall off the concrete cover; eventually corrosion will reduce bar diameters to unsafe values and collapse cannot be excluded.
- The occurrence of corrosion in concrete structures shows an extremely wide distribution. This wide distribution is due to strong variations in cover depth, concrete quality, environmental aggressiveness, level of routine maintenance and several other factors.
- In the first period, aggressive substances such as chloride ions or carbon dioxide penetrate the cover and ultimately reach the steel, which causes the onset of corrosion, called depassivation or corrosion initiation.

- In the second stage, actual corrosion takes place and the expansion due to corrosion products being formed builds up tensile stresses in the concrete cover until it cracks. This cracking produces the first visible signs of corrosion, although in some cases, rust stains at the concrete surface may show before cracking.
- In the next stage, expansion due to corrosion proceeds until parts of the concrete cover completely detach and spall off constituting a potential danger for users of the structure or the general public.
- In the fourth and final stage, reinforcing bar diameter loss becomes as severe as to approach the minimum required for structural stability; eventually, collapse cannot be ruled out.
- It is an accepted fact that permeability is the gateway of corrosion. It is clearly seen that permeability of concrete contributes to corrosion and corrosion induces cracking and cracking further promotes permeability and this cycles continues till concrete is completely destroyed.

Fig. 5.3(a) Corrosion of Reinforcement in Beams

Fig. 5.3(b) Corrosion of Reinforcement in Columns

Fig. 5.3(c) Corrosion of reinforcement in slabs

5.3.1.2 PREVENTION:-

- Proper management of structures will aim at preventing corrosion damage or taking measures to repair damage and re-install corrosion protection well before serious danger occurs.
- Permeability of concrete was reduced.

5.3.1.3 REPAIR:-

- Epoxy based thin coating has been found to be extremely effective except few drawbacks. The innovative method of corrosion protection is the development of a two component anti-corrosive coating of rebars which has all the positive features of epoxy coating excluding all the short comings of the same.
- For corrosion not to occur it is necessary that the alkalinity around the rebar is high. Specific reactive fillers reduce the permeability of protective coating over rebar. Selective polymer in the formulation increases the bond between coatings and rebar and also makes the coating denser to polluting gas.

- In carrying out repair we attempt to create a bond between old structure and new repair materials which will restrict the shrinkage in repair material.
- **MATERIALS** used for repair are as follows:

A. **Cementone:** Cemproof liquid, Cemproof Powder.

B. Dr. Fixit: New coat.

C. Fosroc^{R}: Epoxy-Resin, Nitobond SBR, Nitoprime Zincrich plus.

5.3.2 FOUNDATION MOVEMENT AND SETTLEMENT OF SOIL:-

5.3.2.1 CAUSES:-

- 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.
- Differential settlements in buildings occur when there are local variations in the nature of supporting soil and such variations are not detected.

5.3.2.2 PREVENTION:-

- To avoid settlement cracks in buildings, it is essential that designs for their foundations are based on sound engineering principles and good practice.
- Bearing pressure on foundation soil should be more or less uniform so as to avoid differential settlement. When building on soil consisting of shrinkable clays, soil movements due to alternate wetting and drying and consequent swelling and shrinkage should be taken care of by providing special foundations, such as under-reamed piles to avoid cracking.

Fig. 5.4 Foundation Movement and Settlement of Soil

5.3.2.3 REPAIR:-

- To provide a 2 m wide flexible water-proof apron all-round the building at a depth of about 0.5m below the ground level.
- **MATERIALS** used for repair are as follows:

A. **Fosroc^{R}:** Rendroc Plug, Deck guard E2000.

5.3.3 MOISTURE MOVEMENT:-

5.3.3.1 CAUSES:-

- Most of the building materials with pores in their structure in the form of intermolecular space expand on absorbing moisture and shrink on drying. These movements are cyclic in nature and are caused by increase or decrease in inter pore pressure with moisture changes.
- Initial shrinkage occurs in all building materials that are cement/lime based such as concrete, mortar, masonry and plasters. Generally heavy aggregate concrete shows less shrinkage than light weight aggregate concrete.

5.3.3.2 PREVENTION:-

- 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 undergone most of its initial shrinkage. In case of structural concrete shrinkage cracks are controlled by using temperature reinforcement.
- Plaster with coarse well graded sand or stone chip will suffer less from shrinkage cracks and is preferred for plastering for external face of walls.
- Considering the building as a whole, an effective method of controlling shrinkage cracks is the provision of movement joints. The work done in cold weather will be less liable to shrinkage cracks than that in hot weather since movement due to thermal expansion of materials will be opposite to that of drying shrinkage.

Fig. 5.5 Moisture Movement

5.3.3.3 REPAIR:-

- Materials used for repair of such type of crack are:

A. Cementone: Cemproof Liquid, Cemplas,

B. **Fosroc^{R}:** Nitobond SBR.

5.3.4 PLASTERING:-

5.3.4.1 CAUSES:-

- Cracks occurred in plastering due to Temperature changes, Weather conditions, Disturbance, Inadequate Materials, etc.

5.3.4.2 PREVENTION:-

- Plastering work should be done after masonry has been properly cured and allowed to dry so as to undergo initial shrinkage before taking up plaster work.
- When plastering on concrete background, plastering should be done as soon as feasible after hacking and roughening the surface and applying cement slurry on the concrete surface to improve bond.

5.3.4.3 REPAIR:-

- Materials used for repair of such type of crack are:

A. Cementone: Cemplas,

B. Dr. Fixit: Bathseal Grout, Pidiproof LWT, Pidigrout 5M

C. Fosroc^{R}: Deckguard Elastic.

Fig. 5.6 Plastering

5.3.5 JOINT CRACKS:-

5.3.5.1 CAUSES:-

- Movement joints in structures are introduced so that unduly high stresses are not set up in any part of a structure, and it may not develop unsightly cracks. When a joint permits expansion as well as contraction it is termed as ‘expansion joint’; when it allows only contraction, it is termed as ‘control joint’ and when the joint permits sliding movement of one component over another it is termed as ‘slip joint’.

Fig. 5.7 Joint Cracks

5.3.5.2 PREVENTION:-

- Lime concrete terrace over roof slab- Provide 10 to 15 mm wick dummy joint & 4 to 6 m apart; fill the joints with some mastic compound.
- Masonry partitions- Provide horizontal expansion joints.

5.3.5.3 REPAIRS:-

- Materials used for repair of such type of crack are:

A. Dr. Fixit: Roft Rainbow Tile Mate, Roft RTM Epoxy.

B. Fosroc^{R}: Deckguard Elastic, Nitomortar PE.

5.3.6 CRACKS DUE TO VEGETATION:-

5.3.6.1 CAUSES:-

- Large trees growing in the vicinity of buildings cause damage in all type of soil conditions.
- 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.

5.3.6.2 PREVENTION:-

- When a building is founded on shrinkable soil, trees, particularly fast growing trees, should not be grown within a distance of expected height of trees. If old trees exist close to an old building these trees should not be removed all at once in one operation. If removal of trees is unavoidable, it should be done in stages.

Fig. 5.8 Cracks due to Vegetation

5.3.6.3 REPAIR:-

- Materials used for repair of such type of crack are:

Fosroc^{R}: Deckguard E2000, Deckguard Elastic.

5.3.7 CRACKS IN WALLS:-

5.3.7.1 CAUSES:-

- This will happen if the wall is built between two heavy structures which act as rigid restraints and no expansion joints have been provided in building.

5.3.7.2 PREVENTION:-

- Remedy for this defect lies in relaying the affected portion of coping and providing expansion joints at suitable intervals.

Fig.5.9 Cracks in Walls

5.3.7.3 REPAIR:-

- Materials used for repair of such type of crack are:

  Fosroc^{R}: Rendoroc DS, Renderoc SC, Renderoc 252, Deck guard Clear.

5.3.8 THERMAL CRACKS:-

5.3.8.1 CAUSES:-

- It is the formation of horizontal cracks at the support of a brick parapet wall. Parapet masonry is very much exposed and are subject to wide range of temperature variations. Parapet does not have much self-weight to resist horizontal shear force at its support caused by differential thermal movement.

5.3.8.2 PREVENTION:-

- Mortar for parapet masonry should severity of cracking could be much is 1 cement: 1 lime: 6 sand and a good bond should be ensured between masonry and concrete.
- It may be necessary to introduce expansion joints at closer intervals as same as Compound wall.

5.3.8.3 REPAIR:-

- Materials used for repair of such type of crack are:

  Fosroc^{R}: Deck guard Clear, Nitomortar PE, Deck guard E2000.

Fig. 5.10 Thermal Cracks

5.3.9 CRACKS DUE TO DISTURBANCE:-

5.3.9.1 CAUSES:-

- In construction practices, these cracks occurred due to Removal/Stripping of Formwork or Shuttering of supporting members.

5.3.9.2 PREVENTION:-

- It is necessity that supporting members should have to taking care during Removal/Stripping of Formwork or Shuttering.

Fig. 5.11 Cracks due to Disturbance

5.3.9.3 REPAIR:-

- Materials used for repair of such type of crack are:

  Fosroc^{R}: Deck guard E2000, Deck guard Elastic**.**

Chapter-6 CONCLUSION

- After the study of whole project, we reached following conclusion :
- The Individual Cracks in R.C. members are unique by themselves. They are versatile diagnostic devices, clearly indicating the specific problems in the concerned R.C. members.
- In addition, they also indicate the degree of seriousness of the problem. So The Cracks are the penalty for showing carelessness in the Structural designs, construction quality and workmanship.

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