ACKNOWLEDGEMENT

Prior to all; First and For most; I thank the almighty God, for giving me the opportunity to re-join the university and helping me go through all the course works and this research case study with special enthusiasm and courage.

I am greatly thankful to Ethiopian Road Authority for their sponsorship of the MSc. program and support during all times with work in partnership course carried out as part of agreements signed between Ethiopian Roads Authority and Jimma University. I also would like to thank our lecturers who teach us very well Associate Prof. Dr.-Engineer Esayas Alemayehu, Asser mallari, prophesier Emer, Engr. Romano A. Gabrillo, Engr. Elmer C. Agon and others. My special gratitude should also go to my advisor Eng. Josilito (Associate Professor), who supported me in providing related references that would essentially help in shaping the previous proposal in such a beautiful manner.

Last but not least, my special compliment goes to my family for their continuous support and prayer during this work.

ABSTRACT

One of the wide ranging problems that the construction industry is facing is the quality problem. This major problem is spread over most of the construction projects, among this condominium buildings are critically affected. Moreover the projects' performances are also affected against time, cost and quality. This case study is about investigating assessment of cracks in building, in the case of Addis Ababa city summit condominium chirkos site from the quality perspective. The study concepts will be developed through literature review that enables to find out the previously stated facts about the issue. Project case studies are used to assess the problem on construction site. Recommendations that would reduce adverse effects of building cracks will be forwarded. Finally, based on the analysis of the results, recommendations for Addis Ababa city housing development Agency will be proposed that enables to minimize the adverse effect of cracks on building and favours the construction industry for better performances.

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LIST OF SYMBOLS

W_k - Characteristic crack width.

W_m - Mean crack width.

S_M - Average distance between crack

ϵ_M - Mean strain of the reinforcement.

$\emptyset$ - Bar diameter.

ϵ - Concrete strain.

f_{yd}- Design strength of steel.

f_{yk}- Characteristic tensile strength of steel

f_{cd}- Design strength of concrete.

F_{ck}- Characteristic compressive strength of concrete.

ρ_r – ratio of area of reinforcement to area of concrete.

ACRONYM

ACI - American Concrete Institute

CRM- Crack Repair Method

EBCS-Ethiopian Building Code Standards

ER-Epoxy Resin

FRP -Fiber Reinforced Polymer

MPA - Mega Pascal

NSR- Near Surface Reaction

PU-Poly Urethane

RCC- Reinforced Concrete

UV-Ultra Violate

1. INTRODUCTION

1.1 GENERAL

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.

Internally induced stresses in building components lead to dimensional changes and whenever there is a restraint to movement as is generally the case, cracking occurs. Due to dimensional changes caused by moisture or heat, building components tend to move away from stiff portions of the building which act as fixed points. In case of symmetrical structures, the centre of the structure acts as a fixed point and movement takes place away from the centre. A building as a whole can easily move in the vertical direction, but in the horizontal direction, sub-structure and foundation exert a restraining action on the movement of the superstructure. 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.

The construction industry is not complete without the element of concrete. Concrete is the world’s most common construction material, used primarily for its durability and versatility. With the wide spread of use of this construction material, it is important knowledge that concrete cracks. Cracks in buildings are of common occurrence.

Concrete is a quasi-brittle material with a low capacity for deformation under tensile stress. Mechanical loading, deleterious reactions, and environment loading can result in the development of tensile stresses in concrete. These tensile stresses all too frequently result in cracking that can adversely affect the performance of concrete and the building as a whole.

The age-old axiom in concrete construction is that concrete cracks. Cracks in concrete have many causes. They may affect appearance only, or they may indicate significant structural distress or a lack of durability. Cracks may represent the total extent of the damage, or they may point to problems of greater magnitude. Their significance depends on the type of structure, as well as the nature of the cracking. While cracks may develop in concrete for a variety of causes, the underlying principle is the relatively low tensile strength of concrete.

Visible cracking occurs when the tensile stresses exceed the tensile strength of the material. Visible cracking is frequently a concern since these cracks provide easy access for the infiltration of aggressive solutions into the concrete and reach the reinforcing steel or, other components of the structure leading to deterioration.[Principle of modern building, 1961, volume 1, Her Majesty's stationary office, London.]

Cracks could be broadly classified as structural or non-structural. Structural cracks are those which are due to incorrect design, faulty construction or overloading and these may endanger the safety of a building. Extensive cracking of an RCC beam is an instance of structural cracking. Non-structural cracks are mostly due to internally induced stresses in building materials and these generally do not directly result in structural weakening. In course of time, however, sometime 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. .[Principle of modern building, 1961, volume 1, Her Majesty's stationary office, London.]

Cracks may be only at the surface or may extend to more than one layer of materials. As a general rule, thin cracks, even though closely spaced and greater in number, are less damaging to the structure and are not so objectionable from aesthetic and other considerations as a fewer number of wide cracks.

The crack developed in the building has to be maintained. It can be achieved by proper selection of repair material and methodology. The goal of all crack repairs is to restore and increase the strength of cracked component; 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

1.2 STATEMENT OF THE PROBLEM

Crack may represent the total extent of damage, or they may be worse condition in structure. Crack may affect appearance of the structure, increase vibration and failures of building, decrease durability and service life of the building. The variable types of crack in structure are not easily understood by the owners of building and maintenance side. Most cracks in buildings appear in almost all the walls and other structural elements such as columns and beams, and they are of different patterns. Generally speaking, cracks in building are a serious problem and it should take remedial measure.

The appearance of cracks can also affect the value of the building, its insurability, the sale ability 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.

Generally, the appearance of crack in a building affects the safety and performance of the building. So in order to tackle this problem proper crack repair method should be developed. The proper repair of cracks depend on knowing the causes and selecting repair procedures that take this causes into account, otherwise, the repair may only be temporary.

1.3 OBJECTIVE

1.3.1 General objective:

To identify different types of cracks on buildings and assesse the possible causes of the cracks, and indicating the necessary repair mechanism..

1.3.2 Specific objectives:

- To identify the types of cracks on buildings at summit condominium.
- To identify the cause of cracks on buildings.
- Indicate methods to minimize cracks on building structure.
- Indicate mechanism of repair for cracked buildings.

1.4 scope of the research/ case study

This thesis research focused on

- Assessment of cracks on building structures.
- The type, cause and prevention of cracks in the residence building of summit condominium.

Select summit condominium residence building of chirkos site to obtain the relevant data for my case study.

1.5 METHODOLOGY

The process involves studying literature review for information sources; identify potential issues to finding research problem, site reconnaissance survey and building inspection. Summaries of the process will be explained in flow chart below:

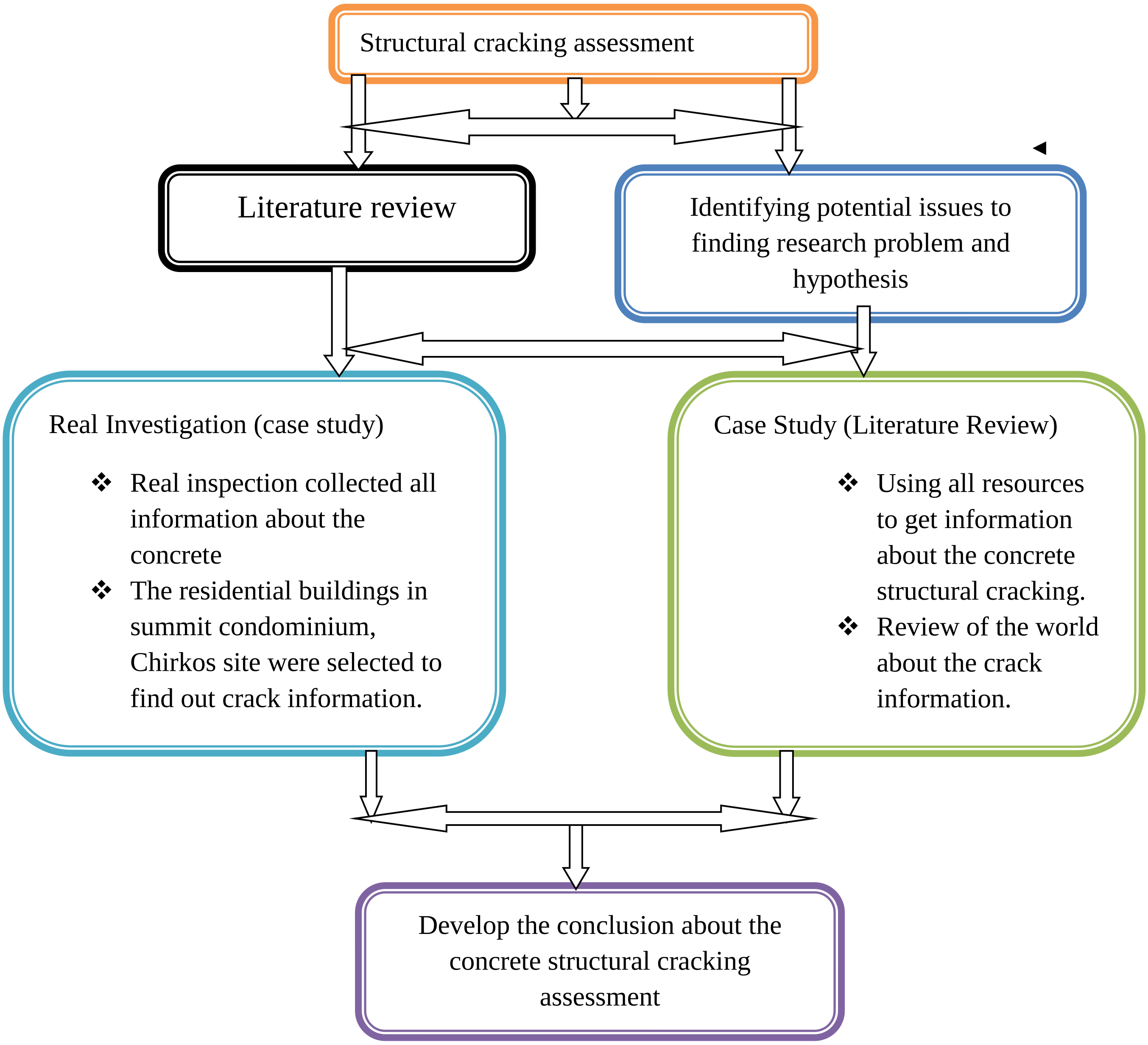


Chart: Tentative Research Flow Chart.

2. LITERATURE REVIEW

2.1 INTRODUCTION

There are three main parties in the construction industry, the contractor who is in charge of providing and placing the concrete, the designer who is responsible for designing the structures to hold the proposed load and accommodate intended use of the structure, and the owner who is responsible for the use and maintenance of the structure after construction. Each of these parties in the construction business will be at one point fully responsible for the concrete structure during or after its construction. In order to be able to prevent or to minimize occurrence of cracks, it is necessary to understand basic causes of cracking and to have knowledge about certain properties of building materials. [Concrete Slab Surface Defects: Cause, Prevention and Repair, IS177, Portland Cement Association, Skokie, IL.]

Cracks can be classified by direction, width and depth, namely longitudinal, transverse, vertical, diagonal and random. With regard to direction at the surface, there are two main kinds: map cracks or pattern cracks. These are rather uniformly distributed short cracks running in all directions roughly in hexagonal patterns. They indicate restraint of the surface layer by the inner concrete or backing. The other kind is the single continuous cracks which run in rather definite directions, often in parallel at definite intervals; they indicate restraint in the direction perpendicular to them. In most cases, cracks that appear and continue to develop after the concrete has hardened are considered active. Cracking is called dormant when it is caused by a factor that is not expected to occur again. [Concrete Slab Surface Defects: Cause, Prevention and Repair, IS177, Portland Cement Association, Skokie, IL.]

Cracks are also classified into two broad categories including those that occur before and those observed after hardening. Cracks may be of uniform width or may be narrow at one end. Cracks could be straight, toothed, stepped, map pattern or random and also may be vertical, horizontal or diagonal.

2.2 LIMIT STATE OF CRACKING FOR CONCRETE MEMBERS

For reinforced concrete two limit states of cracking are described. These are the limit state of crack formation and limit state of crack widths. The particular limit state to be checked is chosen on the basis of the requirements for durability and appearance. The requirements for durability depends on the condition of exposure and the sensitivity of the reinforcement to corrosion. [EBCS 2, 1995]

2.2.1 Limit state of crack formation

1. The maximum tensile stresses in the concrete are calculated under the action of design loads appropriate to a serviceability limit state and on the basis of the geometrical properties of the transformed un cracked concrete cross section.

2. The calculated stress shall not exceed the following value

a) Flexure σ_{ct}=1.70$f_{ctk.}$

b) Direct tension σ_{ct}=$f_{ctk.}$

c) In addition to the above, minimum reinforcement shall be provided for control of cracking.

2.2.2 Limit state of crack widths

If crack widths have to be calculated, the following approximate may be used in the absence of more accurate methods.

$$W_k = 1.7W_m$$

$$W_m = S_M \epsilon_M$$

Where W_k is the characteristic crack width

W_m Is the mean crack width

S_M is the average distance between cracks

ϵ_M is the mean strain of the reinforcement considering the contribution of concrete in tension.

The average distance between cracks may be obtained from

$Sm=50+0.25k1k2\emptyset/\rho r$

Where $\emptyset$ is the bar diameter

K1 is coefficient which characterizes the bond properties

k1 = 0.8 for deformed bars

K1 = 1.6 for plain bars

K2 is a coefficient representing the influence of the form

k2 = 0.5 for bending

K2 =1.00 for pure tension

K2= $(\epsilon 1 + \epsilon 2)/2\epsilon 1$ for bending with tension

$\epsilon 1, \epsilon 2$ are the larger and the smaller concrete strains, respectively below the neutral axis of cracked section

Adequate protection against corrosion may be assumed provided that the minimum concrete cover are compiled and provided further that the characteristic crack width do not exceed the limiting values given in table 1 appropriate to the different conditions of exposure.[EBCS 2 ,1995 page 57]

Table 1 characteristic crack width for concrete members

Type of exposure	Dry environment: interior of buildings of normal habitation or offices (MILD)	Humid environment: interior components (e.g.laundaries); exterior components; components in non-aggressive soil and /or water (MODERATE)	Seawater and/or aggressive chemical environment: components completely or partially submerged in sea water; components in saturated salt air; aggressive industrial sphere (SEVERE)
Characteristic crack width in mm	0.4	0.2	0.1

2.2.3 Crack width

Design codes [e.g. EBCS 2 1991] give guidelines for calculating the crack width on the outer concrete surface. The variation of crack width within the cover depends on the bond between reinforcement and concrete as well as on the deformation of the concrete cover itself. Bond between concrete and reinforcement ensures the force transfer mechanism between reinforcement and surrounding concrete cover and the load bearing capacity of the composite material. Without bond the reinforcement and concrete could not work together.

2.3 SIZE OF CRACKS ON WALLS

Using the width of the crack as an indication of its severity, cracks might be categorized into five groupings [inform guide structural cracks, historic Scotland].

a) Negligible

It can be generally assumed that hair line cracks, with a dimension of less than a millimetre in width, are of little concern apart from the aesthetic and nuisance they create. Simple redecoration is enough to deal with the problem.

b) slight

Over a period of time, if the structural movement has stopped and stabilized, are cracks that are between 1 and 5 mm in width. They can normally be dealt with through filling the voids and carrying out redecoration on the interior of the building.

c) Moderate

These cracks category is extending in range between 5 and 15 mm in width. They require some builder work to remedy related circumstances.

d) Severe

Are cracks extending in width up to 25 mm and they indicate that extensive structural repair works will be required.

e) very severe

Are cracks having width greater than 25 mm and they indicate very severe structural damage. They normally require major repair work.

2.4 CAUSE OF CRACKS IN MEMBERS OF BUILDING

The cracks in buildings can be classified as structural cracks and non-structural cracks [Min, 2006, kashyzadeh and kosher, 2012]. Causes of structural and non-structural cracks are described briefly.

2.4.1 Non-structural cracks

Non-structural cracks appear due to internally induced stresses in building materials and these generally do not directly result in structural weakening. In course of time, however, some time 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. Non-structural cracks results in environmental effects and restraints to these effects and do not endanger the safety of the structure. These inevitable non-structural or intrinsic cracks are quite harmless to the extent of acceptable limits of cracks as given in the code of practices of IS456:2000 [2] (table1)

Table 2 acceptable limits of non-structural cracks in different exposure conditions

Exposure condition	Width of Cracking
Members where cracking is not harmful and does not have any serious adverse effects on reinforcement& durability	0.3 mm
Members where cracking in tensile zone is harmful, exposed to moisture/contact with soil or ground water	0.2 mm
Severe exposure conditions	0.1 mm

- Non Structural cracks includes
  - Moisture changes
  - Thermal movement
  - Elastic deformation
  - Creep
  - Chemical reaction
  - Foundation movement and settlement of soil
  - Vegetation

2.4.1.1 Cracking due to 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.

❖ **Reversible Movement**

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

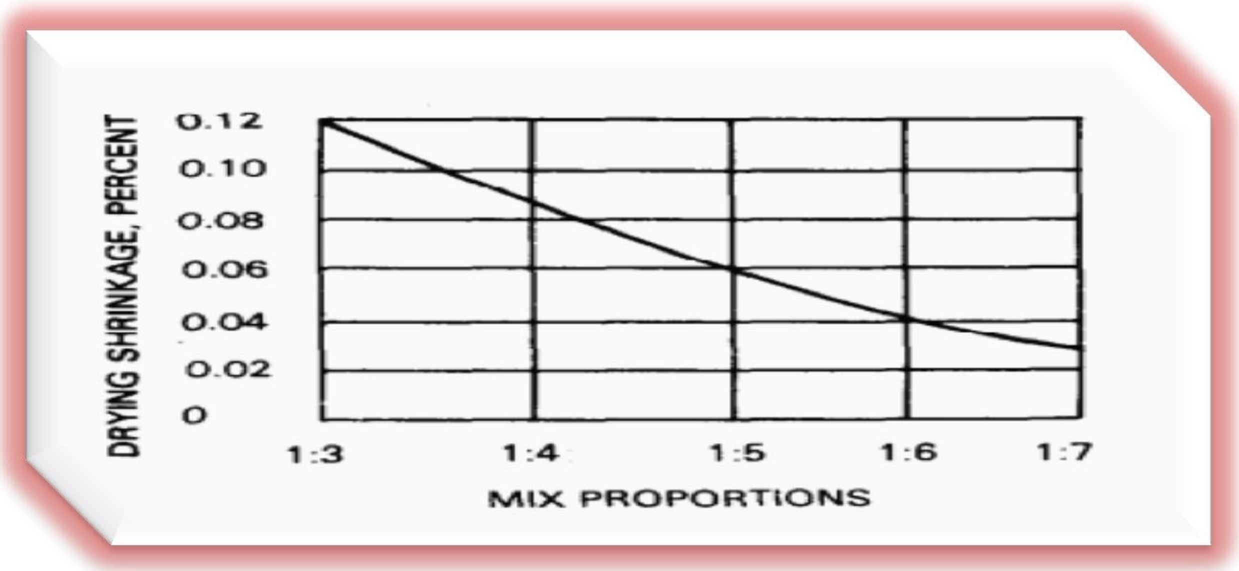
a) Materials having very small moisture movement, as for example, burnt clay bricks, igneous rocks, limestone, marble, gypsum plaster, metals, etc. The use of these materials does not call for many precautions.

b) 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.

- **Initial shrinkage**

Initial shrinkage, which is partly irreversible, normally occurs in all building materials or components that are cement/lime based, for example, concrete, mortar, masonry units, masonry and plasters. This shrinkage is one of the main causes of cracking in structures. Influence of these factors on shrinkage is as follows:

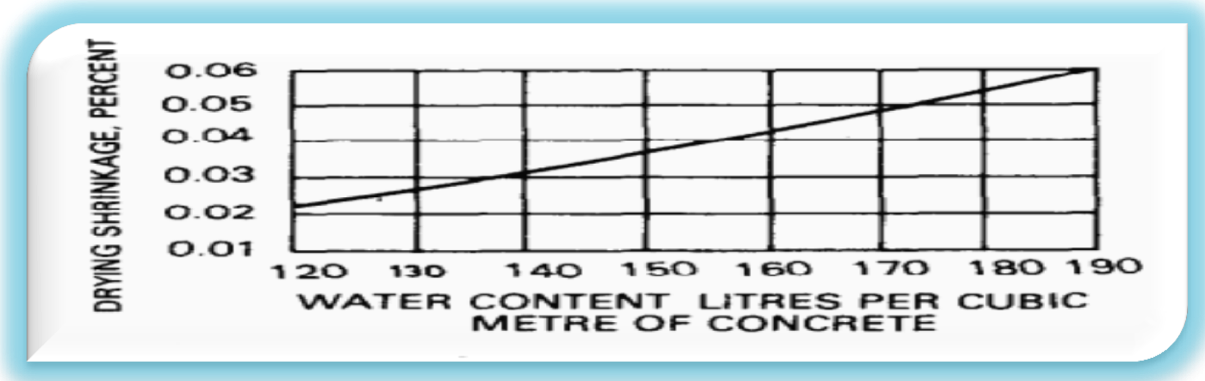
a) Cement content:- as a general rule, richer the mix, greater the drying shrinkage. Conversely, the larger the volume of aggregate in concrete, lesser the shrinkage is. For the range of aggregate content generally used for structural concretes, increasing the volume of aggregates by 10 percent can be expected to reduce shrinkage by about 50 percent [Jaiy Krishna and Jain , Plain and reinforced concrete] .Relation between mix proportion and shrinkage is shown in fig.1 below.



Reproduced from [Principles of Modern Buildings ,1961 volume 1]

Figure 1 relationship between mix proportion and drying shrinkage of cement concrete mortar

b) Water content:- greater the quantity of water used in the mix, greater the shrinkage is. Thus a wet mix has more shrinkage than a dry mix. That is why a vibrated concrete, which has low slump, has lesser shrinkage than a manually compacted concrete, which needs to have greater slump. In terrazzo and concrete floors, use of excess water in the mix is one of the principal causes of cracking in such floors. A typical relation between water content and drying shrinkage is shown in Fig.2 [Control of cracking in concrete structures, report of ACI committee 224]



[(Based on graph given in ‘Control of Cracking in Concrete Structures]

Figure 2 Effect of variation in water content of concrete on drying shrinkage

c) Aggregates:- By using the largest possible maximum size of aggregate in concrete and ensuring good grading, requirement of water for concrete of desired workability is reduced and the concrete thus obtained has less shrinkage because of reduction in the porosity of hardened concrete. Any water in concrete mix in excess of that required for hydration of cement, to give the desired workability to the mix, results in formation of pores when it dries out, thus causing shrinkage. Fig.3 illustrates the effect of aggregate size on water requirement.

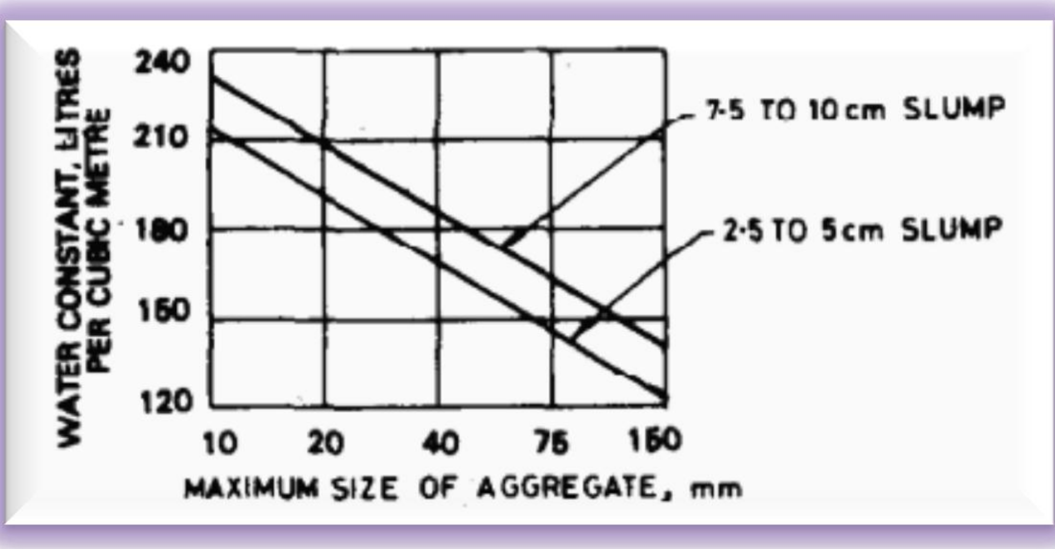


Figure 3 Effect of Aggregate Size on Water Requirement of Concrete

d) Curing: Curing also plays an important part in limiting shrinkage. If proper curing is started as soon as initial set has taken place and it is continued for at least 7 to 10 days, drying shrinkage is comparatively less, because when hardening of concrete takes place under moist environments, there is initially some expansion which offsets a part of subsequent shrinkage. Steam curing of concrete blocks at the time of manufacture reduces their liability to shrinkage as high temperature results in pre carbonation. [IS 456-2000 Code of Practice for plain and reinforced concrete third revision, Indian Standard Institutions]

e) Humidity: - Extent of shrinkage also, depends on relative humidity of ambient air. Thus shrinkage is much less in coastal areas where relative humidity remains high throughout the year. Low relative humidity may also cause plastic shrinkage in concrete.

f) Composition of cement:- Chemical composition of cement used for concrete and mortar also has some effect on shrinkage. It is less for cements having greater proportion of tri calcium silicate and lower proportion of alkalis like sodium and potassium oxides. Rapid hardening cement has greater shrinkage than ordinary Portland cement.

g) Temperature:- an important factor which influences the water requirement of concrete and thus its shrinkage is the temperature of fresh concrete. This is illustrated in Fig.4 based on studies made by Bureau of Reclamation,[USA, Control of cracking in concrete structures, report of ACI committee 224, ACI JORNAL, 1972]

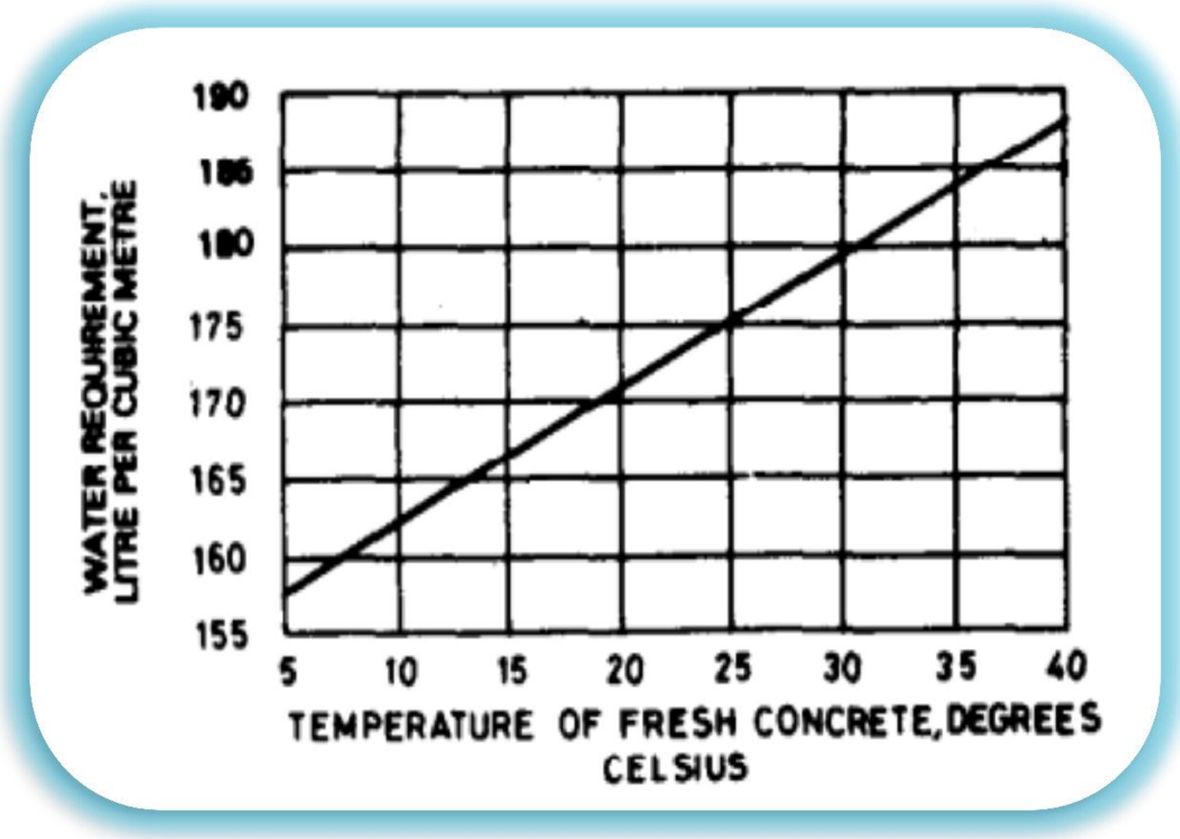


Figure 4 effect of temperature of fresh concrete on water requirement.

If temperature of concrete gets lowered from 38°C to 10°C it would result in reduction of water requirement to the extent of about 25 litres per cubic meter of concrete for the same slump.

2.4.1.2 Cracking due to thermal 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. Extent of thermal movement in a building 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 the table below.
[Data contained in the table below is from 'Principles of modern buildings. Vol. I1]

Table 3 Coefficient of thermal expansion of some common building materials

Sr. Number	Material	Coefficient of thermal expansion
1	Cement mortar and concrete Metals	10 to 14
2	a) Aluminium	25
	b) Bronze	17.6
	c) Copper	17.3
	d) Lead	29
	e) Steel and iron	11 to 13
3	Bricks and brick work	5 to 7

2.4.1.3 Cracking 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. This phenomenon known as creep is explained in fig.5.

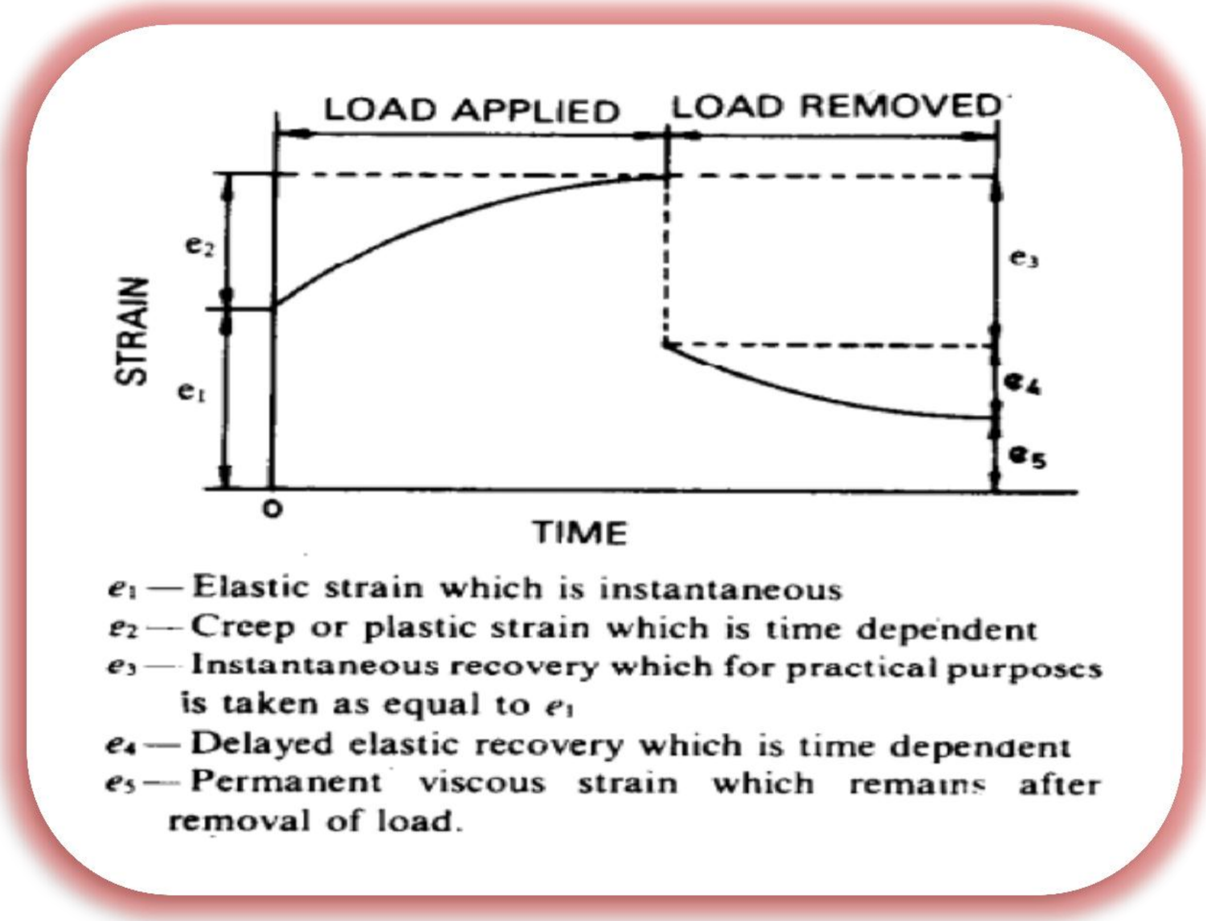


Figure 5 Phenomenon of creep for a Viscos-Elastic material

2.4.1.4 Cracking 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 alkali-aggregate reaction.

2.4.1.5 Cracking due to Sulphate Attack

Soluble sulphates which are sometimes present in soil, ground water or clay bricks react with tricalcium aluminate content of cement and hydraulic lime in the presence of 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, tri calcium aluminate and moisture all the three are present. Severity of sulphate attack in any situation depends upon:

- Amount of soluble sulphates present;
- Permeability of concrete and mortar;
- Proportion of tri-calcium aluminates' present in the cement used in concrete and mortar.

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, results in unequal settlement of foundation and cracks in the superstructure. If brick aggregate used in base concrete of flooring contains too much of soluble sulphates (more than 1 percent) and water table is high so as to cause long spells of dampness in the base concrete, the latter will in course of time swell up resulting in up heaving and cracking of the concrete floor. [Sulphate attack on brick work, British research establishment]. The sulphate attack can be shown in the figure below

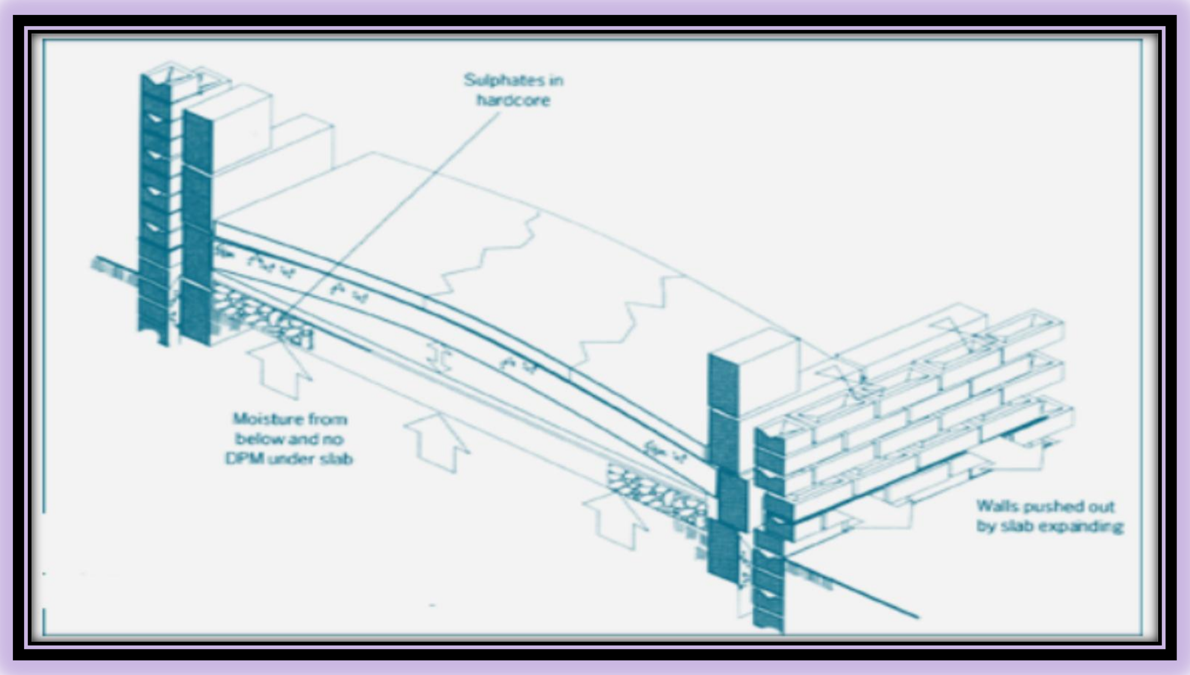


Figure 6 Cracking and up heaving of a tile floor due to Sulphate Action in base

2.4.1.6 Cracking due to Corrosion of Reinforcement

Under most conditions concrete provides good protection to steel embedded in it. Protective value of concrete depends upon high alkalinity and relatively high electrical resistivity of concrete, extent of protection, depending upon the quality of concrete, depth of concrete cover and workmanship.

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 Spalling of concrete, dislodging cover of reinforcement from the body of the concrete, thus seriously damaging the structure.[IS 456-2000 Code of Practice for plain and reinforced concrete third revision ,Indian Standard Institutions]

Corrosion of reinforcement is the most frequent cause of damage to reinforced concrete structures. The corrosion of steel produces iron oxide and hydroxide, which have a volume much greater than the volume of the original metallic iron. This increase in volume causes high radial busting stresses around reinforcing bars and results in local radial cracks these radial cracks. These splitting cracks may propagate along the bar, resulting in the formation of longitudinal cracks parallel to the bar. Crack provides easy access to oxygen, moisture, and chloride and thus even a minor split can create a condition in which corrosion continues and causes further cracking.

Reinforcing steel usually does not corrode in concrete because a tightly adhering protective oxide coating forms in a highly alkaline environment. This is known as passive protection. However, if the alkalinity of the concrete is reduce through carbonation or passivity of the steel is destroyed by aggressive chloride irons, the reinforcing bars may corrode. Crack transverse to reinforcement usually do not cause continuing corrosion of reinforcement if the concrete has low permeability. If the concrete cover is sufficient to restrict the flow of oxygen and moisture, corrosion slowdown.

Figure 7 Cracking due to corrosion of reinforcement

2.1.4.7 Bond between concrete and reinforcement

Bond between concrete and reinforcement ensures the force transfer mechanism between reinforcement and surrounding concrete and the load bearing capacity of the composite material. Without bond the reinforcement and the concrete could not work together. Bond is caused by chemical actions, forces from capillary source, friction and other mechanical actions that are activated at different stages of loading. Bond strongly depends on the surface texture of the reinforcement and its geometry.

2.4.1.8 Cracking due to alkali aggregate reaction (AAR)

Alkaline aggregate reaction refers to chemical reactions taking place within the concrete mix. Certain aggregates inside the concrete may react with alkalis, causing concrete expansion. The alkalis may be also be from within the concrete mix, or may be from outside sources like sea or ground water, or de-icing salts. In dolomite carbonate rocks, the reaction are called alkali-carbonate reactivity (Khan 2006, page 15). When these types of reactions, occur, they create a gel-like substance that swells when moisture reaches it. The stresses from the swelling create internal tensile forces, which may crack the concrete from within (Khan 2006, p.15).

2.4.1.9 Cracking due to 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.Building on expansion clays is extremely crack prone. The soil movement in such clay is more appreciable up to a depth of 1.5 to 2M and this cause swelling and shrinkage and results in crack in the structure. The cracks due to settlement are usually diagonal in shape. Crack appearing due to swelling is vertical.

Effect of expansive soil on building

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. Effect of moisture variation generally extends up to about 3.5m depth from the surface and below that depth it becomes negligible. Roots of fast growing trees, however, cause drying and shrinkage of soil to greater depth. Effect of soil movement can be avoided or considerably reduced by taking the foundation 3.5 m deep and using moorum, granular soil or quarry spoil for filling in foundation trenches and in plinth. Variation in moisture content of soil under the foundation of a building could be considerably reduced by providing a waterproof apron all-round the building. Use of under-reamed piles in foundation for construction on shrinkable soils has proved effective and economical for avoiding cracks and other foundation problems. It is necessary that bulb of the pile is taken to a depth which is not much affected by moisture variations.[Principles of foundation engineering ,Braja M,Das ,six edition page 649].

2.4.1.10 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. Large trees growing in the vicinity of buildings cause damage in all type of soil conditions. If the soil is shrinkable clay cracking is severe.

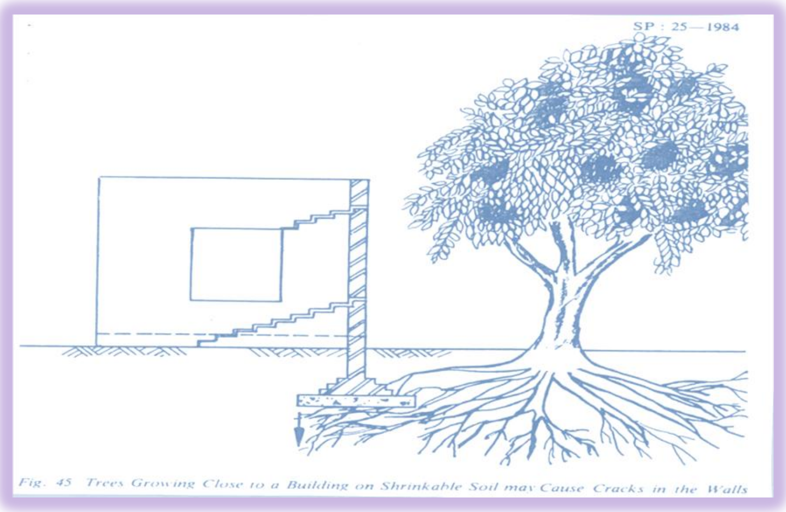


Figure 8 effect of vegetation on buildings causing cracks on walls

2.4.2 Structural cracks

Structural Cracking in concrete occurs in tension, flexure or a combination of the two effects (eccentric tension). When this happens, splitting of the concrete occurs at the surface, penetrating inwards. Under direct tension, the crack generally runs through the thickness of the member (wall or slab), whereas under flexure, the crack is limited to the flexural tension zone. In all cases, the spacing of cracks as well as width of individual cracks depends not only on the magnitude of tensile force acting, but also on the reinforcement detailing, properties of concrete and thickness of section. It is observed that wide crack spacing is associated with relatively wide crack-widths, which is undesirable. Such cracking is often associated with low reinforcement percentages, wide spacing of bars and the use of high strength reinforcing steels.

The tensile strength of concrete is small and tensile forces in concrete structures are generally carried by steel reinforcement. The purpose of this reinforcement is not to prevent cracking of the concrete, the tensile strain capacity of the concrete is small compared with the usual working strains in the steel and cracking is thus inevitable. However, it is necessary to limit the widths of the cracks so that aesthetic requirements are not violated and also so that the embedded steel does not corrode as a result of penetration of water into the cracks.Structural cracks mainly occur due to;

- ✓ Defective design and defective load assumptions and perception of behavior of the structure.
- ✓ In correct assessment of bearing capacity of foundation soil and soil properly.
- ✓ Defective detailing of joints of components like roof with brick wall corner joints of walls
- ✓ Defective detailing of structural detailing of steel reinforcement.
- ✓ Lack of quality control during construction.

2.4.2.1 Flexural Cracking

In reinforced concrete flexural members, the small tensile strain capacity of the concrete and the relatively large working strains in the steel reinforcement combine to make flexural cracking inevitable in the tensile zone. The width and spacing of flexural cracks are controlled primarily by geometric factors (the neutral axis height and the cover to the reinforcement) and are relatively in sensitive to the quality of bond between the steel and concrete. These natural control factors usually ensure that flexural cracks are numerous and of acceptably small width [Timoshenko and Gere1972].The following figure shows flexural tension crack in wall masonry.

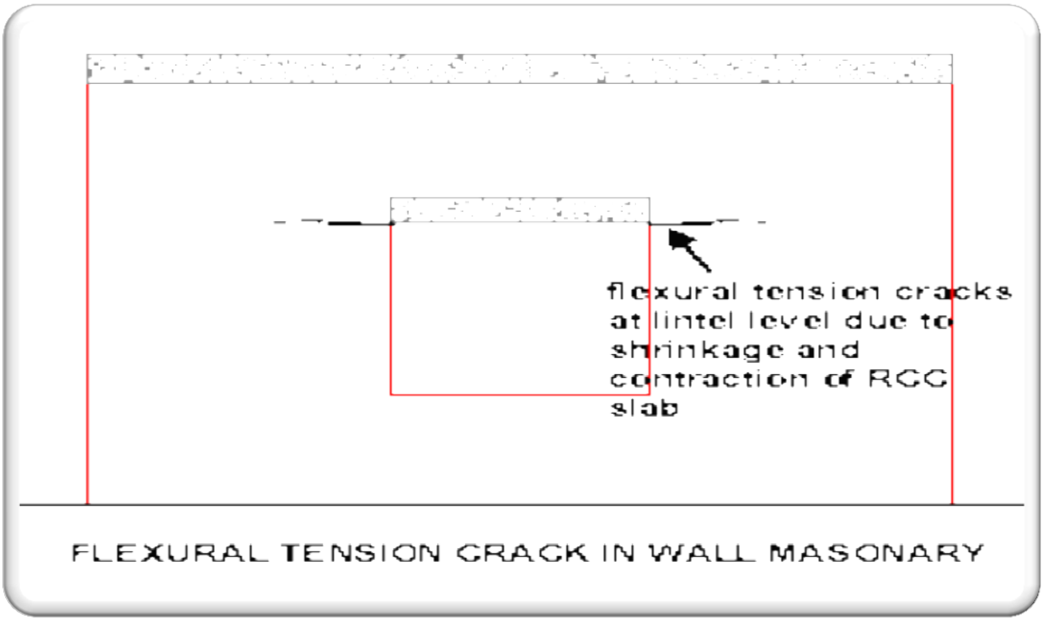


Figure 9 Flexural tension crack in wall masonry.

2.4.2.2 Shear cracking

In reinforced concrete, shear cracking is usually better described as diagonal tension cracking. That is to say, it occurs as a result of the inclined principle tensile stress caused by combined bending and shear. Cracking caused by a pure shearing action is rare in concrete structures. The following figure shows shear crack in masonry wall.

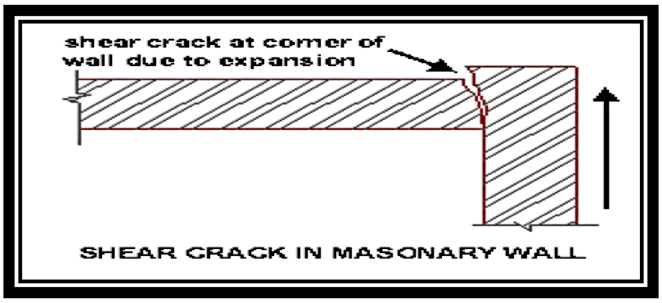


Figure 10 Shear crack in masonry wall.

2.4.2.3 Internal Micro Cracking

Two quite different forms of micro cracking occur. In situations such as end blocks of pre stressed beams and elsewhere where tri axial stress zone occur, a principal tensile stress may cause very local micro cracking long before visible cracking occurs. The second form of micro cracking results is from compressive loading. This micro cracking occurs parallel to compressive stress. Generally structural cracks can be caused by the following reason. Such as;

a) Crack due to incorrect design
b) Crack due to faulty construction
c) Crack due to Over loading

2.4.2.4 Cracking due to incorrect design

The effects of improper design and/or detailing range from poor appearance to lack of serviceability to catastrophic failure. These problems can be minimized only by a thorough understanding of structural behaviour.

Errors in design and detailing that may result in unacceptable cracking include use of poorly detailed re-entrant comers in walls, precast members and slabs, improper selection and/or detailing of reinforcement, restraint of members subjected to volume changes caused by variations in temperature and moisture, lack of adequate contraction joints, and improper design of foundations, resulting in differential movement within the structure. Whether the high stresses result from volume changes, in-plane loads, or bending, the designer must recognize that stresses are always high near re-entrant comers.

The importance of proper design and detailing will depend on the particular structure and loading involved. Special care must be taken in the design and detailing of structures in which cracking may cause a major serviceability problem.

2.4.2.5 Cracking due to poor construction work

A wide variety of poor construction practices can result in cracking in concrete structures. Foremost among these is the common practice of adding water to concrete to improve workability. Added water has the effect of reducing strength, increasing settlement, and increasing drying shrinkage. When accompanied by a higher cement content to help offset the decrease in strength, an increase in water content will also mean an increase in the temperature differential between the interior and exterior portions of the structure, resulting in increased thermal stresses and possible cracking. By adding cement, even if the water-cement ratio remains constant, more shrinkage will occur since the relative paste volume is increased.

Lack of curing will increase the degree of cracking within a concrete structure. The early termination of curing will allow for increased shrinkage at a time when the concrete has low strength. The lack of hydration of the cement, due to drying, will result not only in decreased long-term strength, but also in the reduced durability of the structure.

Other construction problems that may cause cracking are inadequate formwork supports, inadequate consolidation, and placement of construction joints at points of high stress. Lack of support for forms or inadequate consolidation can result in settlement and cracking of the concrete before it has developed sufficient strength to support its own weight, while the improper location of construction joints can result in the joints opening at these points of high stress.

2.4.2.6 Cracking due to overloading

Overloading a concrete member may cause several types of cracks. Depending on the direction and location of the crack (vertical, diagonal, top, bottom, etc), the type of loading stress can be identified. For example, vertical cracks at the bottom of a simply supported beam and in the center indicate positive flexural cracks. Negative flexural cracks show up over the supports on the top of the beam, also as vertical cracks [Pirro 2012, page 47]. It should be noted that flexural cracks may be related to longitudinal splitting cracks. This relationship is based on splitting cracks allowing moisture to reach the steel pieces in the concrete and corrode them, reducing their ability to resist flexure cracks. Reduction in resistance may cause additional flexural cracks [Giuriani 1998, page 1]. Shear cracks may appear as diagonal cracks at quarter points along the beam member [Pirro 2012, page 47]. See the diagram below in Fig.11 for better understanding of locations of cracking. These cracks can indicate a deeper structural issue if the crack width or lateral displacement exceeds 1/4" [CFA 2005, page3].

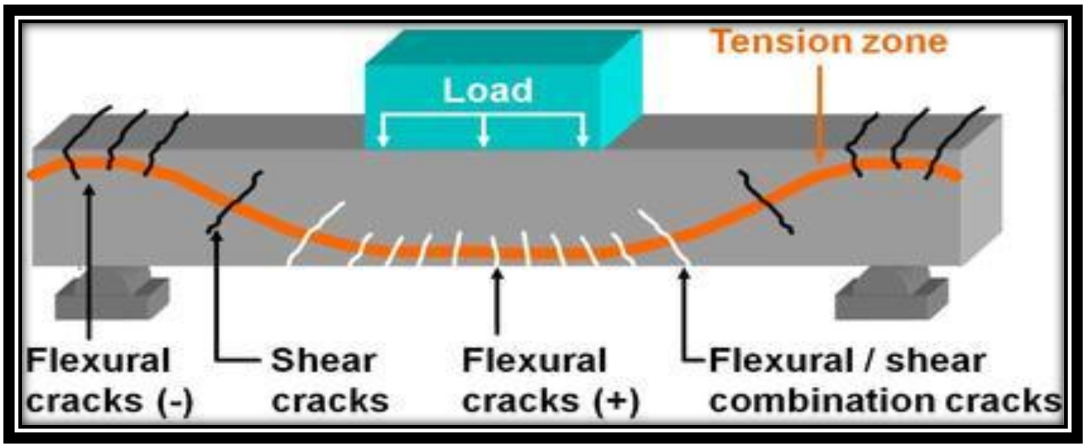


Figure 11 Diagram of locations and directions of overloading cracks [Diagram Credit: Robert Pirro]

The cross section of concrete is designed with both calculated and estimated loads, determined from building codes. Design includes such factors as the strength of the concrete, the number, sizing, and placement of reinforcing bars, and size and shape of the concrete cross section. When a structure is overloaded to the extent not covered in safety factors, concrete may be damaged or fail. Overloading may be in shear, flexure, or tension, or may be a result of fatigue or cyclic loading. Each of these has a different cracking pattern.

Loads induced during construction can often be far more severe than those experienced in service. Unfortunately, these conditions may occur at early ages when the concrete is most susceptible to damage and they often result in permanent cracks. Precast members, such as beams and panels, are most frequently subject to this abuse, but cast-in-place concrete can also be affected. A common error occurs when precast members are not properly supported during transport and erection. The use of arbitrary or convenient lifting points may cause severe damage. Lifting eyes, pins, and other attachments should be detailed or approved by the designer. When lifting pins are impractical, access to the bottom of a member must be provided so that a strap may be used.

Operators of lifting devices must exercise caution and be aware that damage may be caused even when the proper lifting accessories are used. A large beam or panel lowered too fast, and stopped suddenly, results in an impact load that may be several times the dead weight of the member.

Pre tensioned beams are present unique cracking problems at the time of stress release usually when the beams are less than one day old. If all of the strands on one side of the beam are released while the strands on the other side are still stressed, cracking may occur on the side with the unreleased strands.

2.5 Types of cracks on building

Concrete cracking and its patterns can often indicate its cause or causes and can help to define whether the crack is architectural (affecting aesthetics only) or structural (may affect the load carrying capacity). Some of the main types of cracking are described below.

2.5.1 Crazing

Crazing is a web-like series of fine cracks, usually at the surface of the concrete. These can be caused by surface shrinkage, which can occur in low humidity, hot air or sun, and wind [PCA 2001, p. 3]. Since these cracks occur on the surface and do not penetrate deeper into the concrete, they do not indicate a deeper structural issue. A general pattern of crazing can be seen below in Figure 14.

Figure 12 Crazing pattern [Image Credit: Victoria Interval]

2.5.2 Disintegration

Concrete disintegration can be a result of freeze/thaw cycles on the surface. Moisture enters concrete pores and expands. The expansions can cause micro cracking or they may force off a small amount of the surface. Figures 15 and 16 depict disintegration on concrete surfaces. When tiny pieces of the surface come off, it is called disintegration [Pirro 2012, p. 38].

Figure 13 Concrete disintegration around column base [Photo Credit: Robert Pirro]

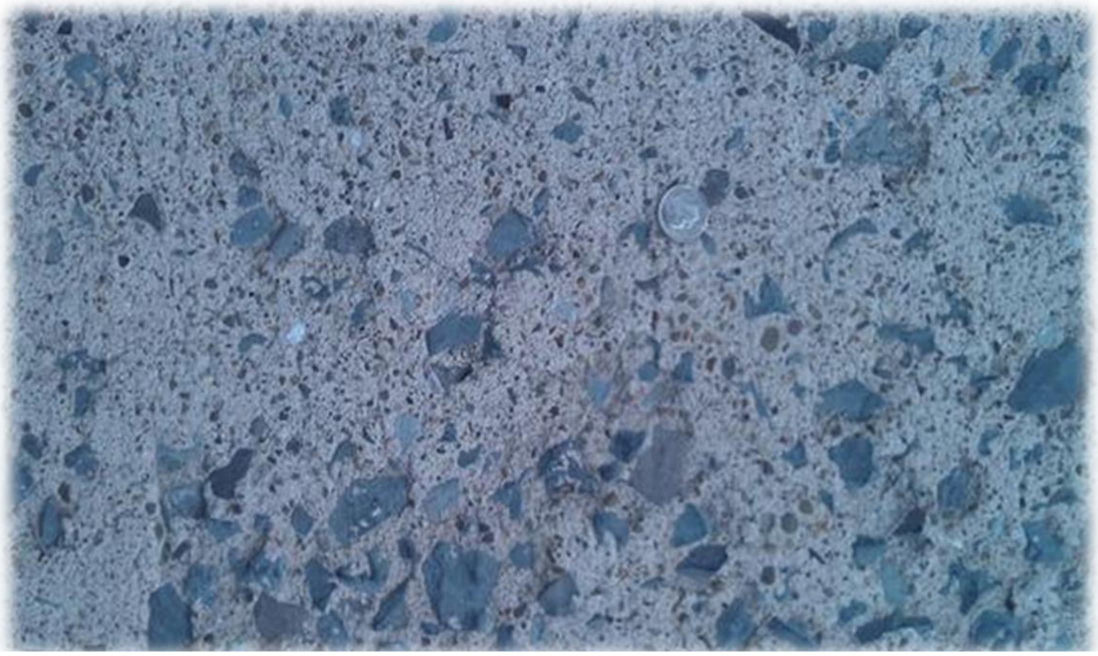


Figure 14 Sidewalk disintegration [Photo Credit: Victoria Interval]

2.5.3 Hardened Cracks

Hardened cracks occur after the concrete has hardened, and are generally caused by drying shrinkage, settlement of the structure below grade, and thermal contraction effects. The cracks form because while the concrete is drying, its volume is being reduced. The condition of the concrete is restrained, so instead of just shortening the slab or member length, cracks form throughout to allow the reduction in volume [Emmons 1993, p. 30]. This kind of crack is depicted below in Figure 18. Drying shrinkage is the shrinking (or reduction in volume) of the concrete due to loss of water (evaporation through the concrete surface) [Barth 2001, p. 2]. These kinds of cracks may indicate improperly spaced joints [PCA 2001, p. 2].

Figure 15 Hardened cracks [Photo Credit: Robert Pirro]

2.5.4 De lamination

De lamination occurs when the surface of a concrete is finished prematurely. When concrete cures, it is necessary for the excess water to escape to the surface (a process called "bleeding"). If a concrete is finished before bleeding has occurred, it can trap the water below the surface. When the water does escape, it leaves hollow patches just below the surface. These patches may break open, resembling shattering, to expose the aggregate below as seen in Figure 19 (PCA 2001, p. 12). This type of defect occurs near the surface, and does not indicate a structural threat (unless over a cantilever, where the reinforcing steel is near top portion of the slab).

Figure 16 De lamination of concrete caused by premature finishing

2.5.5 Spalling

Spalling is primarily a result from the corrosion of the reinforcing steel and/or embedded objects such as clips, chairs, anchors, etc. When the steel corrodes, the rust expands to 10 times the original volume, creating internal tension forces in the concrete. Concrete is unable to handle the tension forces, and the pieces between the corroded steel and the nearest surface will break off, called "spalling" [PCA 2001, p. 12].

Even just a small spall can indicate a much larger issue for two main reasons. First, a small spall can expose the steel, leaving it ultra-vulnerable to more corrosive elements. This can be seen in Figure 10. If the steel corrodes more, there will be more spalling, as seen in Figure 18. Second, a spall in one area may be the first piece of a larger issue beneath the surface. It is likely that other rebar in the immediate area has also been affected by the corrosive effects and will begin to spall soon. Small spalls are relatively simple and inexpensive to fix, and repairing these early on can help to avoid large spalling areas.

A large spall area in a slab may indicate immediate danger to a structure. If enough concrete has spalled off of the bottom, exposing the reinforcing grid, then the concrete and steel are no longer working together to handle the compressive and tension forces. Essentially, when the concrete reaches its tensile limit, it will fail. The steel is not engaged by the concrete to take the excess tensile forces, and is only acting as a cage to hold up the concrete. At this stage, repairs may be enormously expensive. Figure 18 shows a whole building spalling failure.

Figure 17 Small spall area caused by corrosion of reinforcement

Figure 18 Large spall area [Photo Credit: Robert Pirro]

3. EVALUATION OF CRACKS

3.1 INTRODUCTION

Before proceeding with repair of cracks, the location and extent of cracking should be first identified. It helps us to determine whether the observed cracks are indicative of current or future structural problems, taking into consideration the present and anticipated future loading conditions. The cause of cracking should be established before repairs are carried out. The evaluation of cracks is necessary for the following purpose;

- ✓ To identify the cause of cracking
- ✓ To assess the structure for its safety and serviceability
- ✓ To establish the extent of the cracking
- ✓ To establish the likely extent of further deterioration
- ✓ To study the suitable various remedial measures

3.2 Determination of location and extent of concrete cracking

Location and extent of cracking can be determined by;

- ❖ both direct and indirect observations,
- ❖ non-destructive and destructive testing,
- ❖ Tests of cores taken from the structure.
- ❖ From drawings and construction and maintenance records.

3.2.1 Direct and indirect observations

The locations and widths of cracks should be noted on a sketch of the structure. A grid marked on the surface of the structure can be useful to accurately locate cracks on the sketch. Crack widths can be measured to an accuracy of about 0.001 in. (0.025 mm) using a crack comparator, which is a small, hand-held microscope with a scale on the lens closest to the surface being viewed as shown in the figure below.

Figure 19 Comparator for measuring cracks widths (courtesy of Edmound Scientific Co.)

Crack widths may also be estimated using a clear comparator card having lines of specified width marked on the card. Observation such as spalling, exposed reinforcement, surface deterioration, and rust staining should be noted on the sketch. Crack movement can be monitored with mechanical movement indicators of the types shown in the fig. 20. The indicator, or crack monitor, shown in the fig.23 below gives direct reading of crack displacement and rotation.

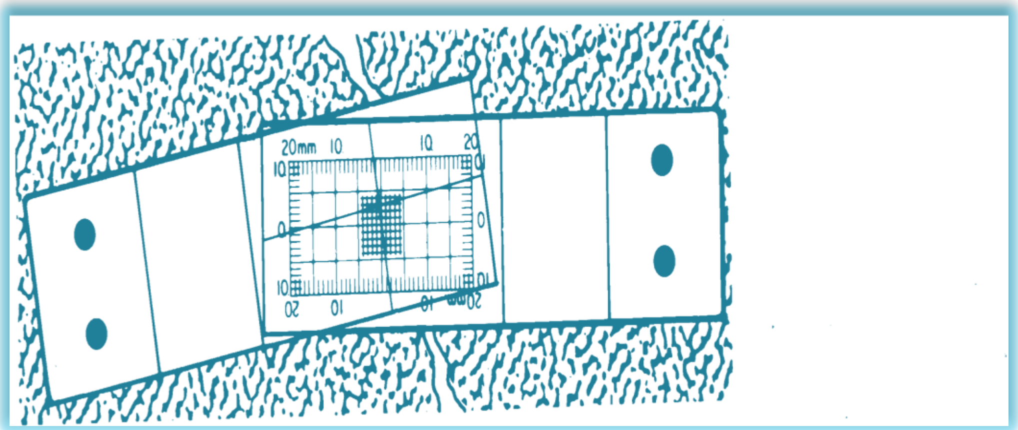


Figure 20 a crack monitor (courtsy avongard)

3.2.2 Non-destructive testing

Non-destructive tests can be made to determine the presence of internal cracks ,voids and the depth of penetration of cracks visible at the surface. Tapping the surface with a hammer or using a chain drag are simple techniques to identify laminar cracking near the surface. A hollow sound indicates one or more cracks below and parallel to the surface.

The presence of reinforcement can be determined using a pachometer. [Malhotra1976]. A number of pachometers are available that range in capability from merely indicating the presence of steel to those that may be calibrated to allow the experienced user a closer determination of depth and the size of reinforcing steel. In some cases, however, it may be necessary to remove the concrete cover (often by drilling or chipping) to identify the bar sizes or to calibrate cover measurements, especially in areas of congested reinforcement.

3.2.3 Tests on concrete cores

Significant information can be obtained from cores taken from selected locations within the structure. Cores and core holes afford the opportunity to accurately measure the width and depth of cracks. In addition, an indication of concrete quality can be obtained from compressive strength tests; however, cores that contain cracks should not be used to deter mine concrete strength. Petro graphic examinations of cracked concrete can identify material causes of cracking such as;

- alkali reactivity's,
- cyclic freezing damage,
- expansive aggregate particles,
- fire-related damage,
- Shrinkage and corrosion.

Petrography can also identify other factors that may be related to cracking such as the water-to-cement ratio, relative paste volume, and distribution of concrete components. Petrography can frequently determine the relative age of cracks and can identify secondary deposits on fracture surfaces, which have an influence on repair schemes. Chemical tests for the presence of excessive chlorides indicate the potential for corrosion of embedded reinforcement.

3.2.4 Review of drawings and construction data

The original structural design and reinforcement placing or other shop drawings should be reviewed to confirm that the concrete thickness and quality, along with installed reinforcing, meets or exceeds strength and serviceability requirements. A detailed review of actual applied loading compared to design loads should get special consideration. Calculations can indicate whether the reinforcement provided is adequate for the applied loads.

4. CRACK REPAIRAND PREVENSION METHODS

4.1 CRPACK REAIR METHODS

Following the evaluation of a cracked structure, a suitable repair procedure can be selected. Successful repair procedures account for the cause(s) of cracking. For example, if cracking is primarily due to drying shrinkage, then it is likely that, after a period of time, the cracks will stabilize. On the other hand, if the cracks are due to on-going foundation settlement, repair will be of no use until the settlement problem is corrected. The aim of crack repair has to be established a prior and achieved by proper selection of repair material and methodology.

This chapter provides a survey of crack repair methods, including a summary of the characteristics of cracks that may be repaired with each procedure, the types of structures that have been repaired, and a summary of the procedures that are used .As described in ACI 224.1R [3] 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.
- To reduce or prevent ingress of adverse agents, e.g. water, other liquids, vapour, gas, chemicals and biological agents [Principle 1 According to Principles and Methods related to reinforcement corrosion EN 1504 PART 9]
- To increase or restore the structural load-bearing capacity of an element of the concrete structure [Principle 4 According to Principles and Methods related to reinforcement corrosion EN 1504 PART 9]

Depending on the nature of the damage, one or more repair methods may be selected. For example, tensile strength may be restored across a crack by injecting it with epoxy or other high-strength bonding agent, if further cracking is not anticipated [ACI 503R]. It may be necessary, however, to provide additional strength by adding reinforcement or using post tensioning. Cracks causing leaks in water-retaining or other storage structures should be repaired unless the leakage is considered minor or there is an indication that the crack is being sealed by autogenously healing. Repairs to stop leaks may be complicated by a need to make the repairs while the Structures are in service. Cosmetic considerations may require the repair of cracks in concrete. The crack locations, however, may still be visible and, in fact, may even be more apparent due to the Repair. Depending on circumstances, some form of coating over the entire surface may be required.

To minimize future deterioration due to the corrosion of reinforcement, cracks exposed to a moist or corrosive environment should be sealed.

Materials for non-structural crack repair of dormant nature should be a rigid material.

According to ACI224.1R [4]; the crack should be three to four times wider than the largest aggregate particle and Cementations, polymer modified cementations 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 ACI224.1R [4]. Before repair of any non-structural cracks the factors have to be considered are (Cause and repair of cracks in concrete structures):

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

4.1.1 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. 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. ACI224.1R [5], 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 cementations material is being used, dry or moist crack edges must be wetted thoroughly.

4.1.1.1 cementations Grouts

It is used for repair of cracks that are 6 mm and greater in width. It is a mixture of cementations. Material and water, with or without aggregate is proportioned to produce a pourable consistency without segregation of constituents. 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. Shrinkage is a concern in such type of grouts. These are not suitable for structural repairs of active cracks.

For application of cementious grouts generally,

- Some forms 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 towelling 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. One of the potentially effective repair procedures is to inject epoxy under pressure into the cracks. The injection procedure will vary, subject to the application and location of the crack(s), with horizontal, vertical, and overhead cracks requiring somewhat different approaches. The approach used must also consider accessibility to the cracked surface and the size of the crack.

However, before any concrete repair is carried out, the cause of the damage must be assessed and corrected and the objective of the repair is understood. If the crack is subject to subsequent movement, an epoxy repair may not be applicable.

4.1.1.2 Polymer Modified cementations Grout

It is generally used to repair cracks that are 6 mm and greater in width. It is a mixture consisting primarily of cement, fine aggregate, water, and a polymer such as acrylic, styrene-acrylic, styrene-butadiene, or a water-borne epoxy. The consistency of this material may vary from a stiff material suitable for hand-packing large cracks on overhead and vertical surfaces to a pourable

Consistency suitable for gravity feeding cracks in horizontal slabs. These materials are generally more economical than polymer grouts, and the performance, with respect to bond strength, Tensile strength, and flexural strength, are improved compared with cement-based materials that do not contain any polymers. These materials are filled in the cracks by some form of routing and filling the crack.

4.1.2 Cementious Injection Grouts

Ultra-fine polymer stable cementations grouts are also being used for injections for cracks. It is very much compatible with concrete and can be more effective for identifying the concrete. It penetrates deep into micro-cracks, while ordinary cement slurry cannot. It fills effectively all honey combs inside the concrete. Its fineness value ranges from 6000 –16,000 cm2 / gm. which are 2 to 4 times higher than Ordinary Portland cement. The 28days compressive strength for cracks up to 0.8 mm is usually 40-50Mpa whereas for cracks above 0.8 mm width varies between 60-65 MPa[“Selection of a Crack Repair Method” 5 1985]

4.1.3 Routing and 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. Figure 3.1 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 (with a non sag sealant) 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 water proofing 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, poly sulphides, asphaltic materials, or polymer mortars. Cement grouts should be avoided due to the likelihood of cracking. For floors, the sealant should be sufficiently rigid to support the anticipated traffic. 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).

Active cracks should be repaired using a bond breaker at the base of the routed channel. 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 spilling and, for aesthetic reasons, to create a more uniform-appearing.

4.1.4 Near-surface reinforcing and pinning

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 fibber-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 [“Selection of a Crack Repair Method” 5198].

4.1.5 Drilling and plugging

Drilling and plugging a crack consists of drilling down the length of the crack and grouting it to form key features. 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” 5198].A hole (typically 2 to 3 in. [50 to 75 mm] in diameter) should be drilled, cantered 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. If water tightness is essential and structural load transfer is not, the drilled hole should be filled with a resilient material of low modulus instead of grout. If the keying effect is essential, the resilient material can be placed in a second hole, with the first being grouted.

4.1.6 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 [Rodler et al. 1989; ACI RAP-2]. High molecular- weight methacrylate, urethanes, and some low viscosity epoxies have been used successfully. The lower viscosity is the finer 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 boomed 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. If the cracks contain significant amounts of silt, moisture, or other contaminants, the sealant cannot fill them. Water blasting followed by a drying time may be effective in cleaning and preparing these cracks. Cores may be taken to verify crack filling and the depth of penetration measured. 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. [U.S. Bureau of Reclamation 1975; “Crack Repair Method]

4.1.7 Polyurethane (PU) injection

Polyurethane grouts are usually used to repair cracks that are 0.12 mm and greater in width, both wet and active, and leaking a significant amount of water through joints or cracks. These grouts are semi flexible; thus, they may tolerate some change in crack width. The reaction time to form the foam may be controlled from 30 to 45 seconds up to several minutes using different catalyst additives. Polyurethane grouts generally are not suitable for structural repairs. Additionally, a highly skilled work crew is required along with special injection equipment. Finally, these materials typically are not stable when exposed to UV light. Once the resin contacts water, a chemical reaction occurs.

4.1.8 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 [U.S. Bureau of Reclamation 1975; “Crack Repair Method: Dry packing” 1985]. Because of the low water content mortar 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. 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.

If the patch must match the colour of the surrounding concrete, a blend of grey Portland cement and white Portland cement may be used. 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. `

In some instances, cracks will reappear after being repaired. This condition sometimes is related to soil conditions rather than actual foundation problems. If the soil has high clay content, cracks will be more prevalent in the home. If there are a lot of cracks and the home is old, the cracks might simply be the result of age. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures [Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete,] 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 [Barlow 1993]. The use of a low-modulus, flexible adhesive in a crack will not allow significant movement of the concrete structure [Gaul 1993]. The effective modulus of elasticity of a flexible

Adhesive in a crack is substantially the same as that of a rigid adhesive [Adams and Wake 1984] because of the thin layer of material and high lateral restraint imposed by the surrounding concrete.

4.2 Prevention of Cracks

4.2.1 Some measures for controlling shrinkage

- Shrinkage in plastering can be reduced by ensuring proper adhesion. The plastered should not be stronger than the back ground.
- Shrinkage cracks in masonry can be minimized by avoiding use of rich cement mortar and by delaying plastering till masonry has dried after proper curing and has undergone most of its initial shrinkage.
- Investigations of shrinkage cracking may include investigations of the conditions under which the concrete was placed--hot and dry weather promote early age shrinkage cracking; the addition of water to the concrete during placement makes the material more susceptible to shrinkage cracking.
- Investigations should also be undertaken to discern shrinkage cracking from structural cracking.
- 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 terrazzo flooring is an example of this measure. In case of in-situ/ terrazzo 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 [IS 456-2000 code of practice for plain and reinforced concrete ,third revision ,Indian standard institution] Contributing factors causing shrinkage and their prevention are as follows:

Cement content:

Prevention;

- Do not use excessive cement in the mortar mix.
- As a general rule, the richer the mix is, the greater the shrinkage/drying will be.

Excessive Water content

Prevention;

- Use minimum quantity of water required for mixing cement concrete or cements mortar according to water cement ratio.
- Never allow cement concrete work without mechanical mix and vibrator.

Un graded Aggregates:

Prevention;

- Use largest possible aggregate and ensure good grading of materials.
- The use of water according to required workability has less shrinkage because of reduction in the porosity of hardened concrete. Hence it results a best solution.

Curing

Preventive mechanisms;

- Proper curing should be started as soon as initial setting has taken place and be continued for at least seven to ten days.
- When hardening of concrete takes place under moist environment, the shrinkage due to drying is comparatively less

Presence of excessive fines:

Prevention;

- Do not use fine materials containing silt, clay and dust.
- Use coarse sand/fine aggregate in cement concrete and cement mortar mix which has silt and clay less than 4%.
- Use coarse aggregate and fine aggregate after washing to reduce

4.2.2 Prevention of thermal movement

General measures for controlling thermal movement are given below [IS 456-2000 code of practice for plain and reinforced concrete(3rd edition), Indian standard institutions].

- 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.
- 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.

4.2.3 Measures for Prevention of Cracks Due To Creep

- 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.
- Water cement ratio has to be controlled.
- Reasonable pace of construction should be adopted.

4.2.4 General measures to reduce cracks due to sulphate attack

- In case of structural concrete in foundation, if sulphate content in soil exceeds 0.2 percent use very dense concrete and either
  - increase richness of mix to 1:1/5:3 or
  - use sulphate resisting Portland cement/ super-sulphated cement
  - Adopt a combination of the two methods depending upon the sulphate content of the soil.

5 CASE STUDY OF CRACKING IN CONCRETE AND MASONRY

5.1 Introduction

When anticipating repair of cracks in concrete, it is important to first identify the location and extent of cracking. It should be determined whether the observed cracks are indicative of current or future structural problems, taking into consideration the present anticipated future loading conditions. The cause of crack should be established before repairs are specified. Drawing, specifications, and construction and maintenance record should be reviewed. If these documents along with field observation do not provide the needed information, a field investigation and structural analysis should be completed before proceeding with repairs.

Crack need to be repaired if they reduce the strength, stiffness, or durability of the structure to an inacceptable level, or if the function of the structure is seriously impaired. In some cases, such as cracking in water retaining the function of the structure will dictate the need for repair, even if strength, or appearance are not significantly affected.

5.2 cracking in concrete

5.2.1 Cracking behaviours

Many cause of concrete cracking appear after concrete construction. The cracking of concrete was occurring due to various factors as mentioned in previous chapter in literature review. The crack observed (i.e. in summit condominium chirkos site) were showing somehow similar pattern. The pattern of the crack depends on the cause of the crack. The common location of the crack was at the concrete surface, column, beam, and wall or anywhere depending on the cause of cracking such as condition of concrete, durability, concreting and the other factor. From literature review, we can simplify the characteristic of the concrete cracking on the table below.

Table 4 The characteristics of the concrete cracking [Control of cracking in concrete structures, report of ACI committee 224, ACI JORNAL, 1972]

Causes Of crack	**Time appearance**	**Common location**	**Crack pattern**
Plastic Settlement	Hours	Deep section, top of column	Along rebar's or change of section
Plastic Shrinkage	Hours	Slabs	Diagonal or random

Early thermal Contraction	Days	Thick walls and slabs	Similar to structural cracks but with regular spacing and uniform width.
Crazing	Days	Slabs	Fine and shallow, irregular, often polygonal
Dry shrinkage	Week or month	Thin slab and wall	Along or parallel to rebar's
Freeze/thaw Action	Years	Road slabs	Fine, closely spaced or parallel to edges
Steel Corrosion	Years	Anywhere especially exposed area	Along rebar's
Alkali-aggregate Reaction	Years	Damp place	Random and short, often star-shape
Sulphate attack	Years	Foundation	Random and short
Foundation Movement	Months	Anywhere	Diagonal or along wall junctions
Structural Distress(overload)	Anytime	Anywhere	Transverse or inclined, tapering towards compression zone
Fire attack	Anytime	Anywhere	Surface crazing, cracks/spalling parallel to edge

To assess the causes of cracks in the building; it is necessary to determine its location, pattern, width, length, depth, age and whether it is active or not, how catastrophic it is and how to repair it. The maximum allowable width of cracks in structural elements is 0.3mm-0.1mm for water retaining structures. EBCS-2, 1977 provides Classification of cracks based on visual damage to the member as presented in table below.

Table 5 characteristic crack width for concrete members

Type of exposure	Dry environment: interior of buildings of normal habitation or offices (MILD)	Humid environment: interior components (e.g.laundaries); exterior components; components in non-aggressive soil and /or water (MODERATE)	Seawater and/ or aggressive chemical environment: components completely or partially submerged in sea water; components in saturated salt air; aggressive industrial sphere (SEVERE)
Characteristic crack width in mm	0.4	0.2	0.1

Figure 21 diagonal crack on column from assessed building

Figure 22 vertical crack on column from assessed building

Figure 23 cracks due to water leakages from assessed building

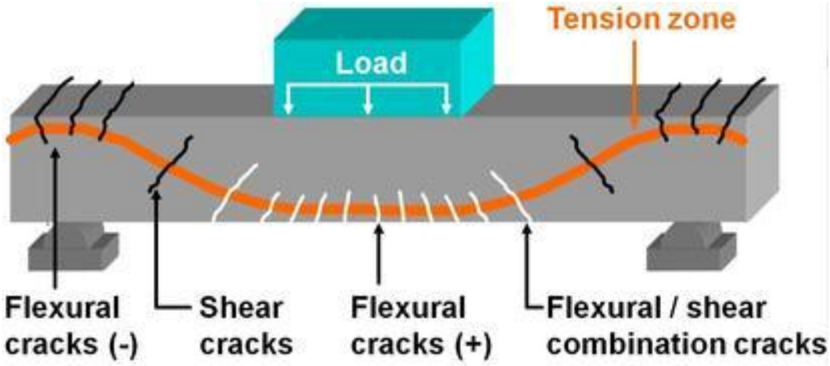


Figure 24 beam cracks due to combined effect

5.3 masonry crack

Masonry encompasses relatively masonry units, mortar, or grout alone or in any combination. Cracking may be caused by a variety of conditions, such as improper material choice wrong field installation, oversized anchors, structural settlement, etc. Sometimes the location, orientation and form of crack give an indication of the cause of the failure. It is generally known that cracks can be minimized or even eliminated by using proper masonry detailing, design and construction. This can be accomplished by introducing bed-joint reinforcement, properly sized and spaced movement joints, adequate support and anchoring , good artisanship and supervision, combined with better than just adequate mortar mix designs, thus ensuring improved flexural bond and reduced shrinkage. Instead of these, owners and designers attempt to achieve very high compressive strengths. This is usually counter-productive, as rarely does masonry fail in compression.

Masonry deterioration may start from something as insignificant as small crack in some of the individual units, then progress through cycles of thermal movement alone, or in combination with freezing and thawing cycles, to wider cycles over a larger area, which sooner or later may become structurally significant, especially if not mapped and monitored early in the process. The summarized about the cause, symptom and failure mechanism were show in table 6.2

Table 6 causes, symptoms, mechanism, and effect of failure in masonry cladding.

CAUSES	SYMPTOMS	FAILURE MECHANISM
Deformation of reinforced Concrete frame	Crushing, spalling or cracking of veneer; possible buckling of the cladding	Shrinkage and creep of frame imposes compressive load on cladding
Expansion of clay brick masonry	Vertical crack near corners and offset; oversalling and diagonal cracking of parapet;	Moisture-induced expansion of brick masonry against restraint induces significant

	bowing and arching of wall; damage to adjacent members.	compressive forces in the wall.
Thermal movement of building element	Horizontal, vertical and or diagonal cracking near steel beam and concrete slabs. Crack open and close with temperature changes.	Tensile, compressive and shear stresses are induced in the cladding by thermal movement of attached elements.
Post tensioning/pre stressing movement of building elements	Damage to adjacent members	
Movement/sagging of supports	Vertical crack near supporting elements (beams, slabs, etc); cracks wider at the lower ends; also some diagonal and (seldom) possible horizontal cracks; crack width may increases with time even under constant loads.	Excessive deflection of supporting slab subjects cladding to in-plane bending.
Movement/sagging of cantilevered elements such as balconies	Vertical cracks near supporting elements (beam, slab, etc);crack wider at the lower ends; also some diagonal; crack width may increase with time even under constant loads	Torsion of face beam that runs parallel with building envelope and supports masonry above. This masonry above the beam cloud ends up in shear and flexure. If there is masonry below the beam, besides shear and flexural stresses, it could be compressed to the point of spalling or total failure.
Movement of foundation	Vertical and diagonal crack; usually cracks wider at one	Uneven settlement of foundation subject building

	end.	and cladding to shear and flexural joints.
Poor shelf angle detail	Spalling or crushing of veneer at shelf angles location; buckling of veneer	Contraction of frame plus expansion of veneer induce large compressive stresses in the veneer, in the absence of proper movement joints.
Shrinkage of concrete masonry	Crack of rather even widths around thickness and height changes and openings; cracks are vertical and or diagonal; cracks evenly space along wall	Tensile rapture under tensile stress which is generated when shrinkage is restrained.
Inadequate tie/anchor system	Buckling of veneer under vertical loads (its own weight, unless upper shelf angle deficiencies or poor structural design add weight from the masonry above; wind collapse of veneer; cracking at tie/anchor location.	Tie system has inadequate strength to provide lateral bracing to cladding, or withstand section force of wind; tie corrosion generates expansive forces in joints.
Poor water path provisions(i.e flashing, weephole, and vapour barrier system) and detail	Dampness at floor levels; spalling of units and heaving of veneer in cold	Water is not quickly drained away from cavity, and freezes of flashing, inside the mortar or grout mass, and in units; vapour condenses on cold inside face veneer.

Figure 25 masonry cracking due to foundation settlement from assessed building

6 CASE STUDY OF STRUCTURAL ASSESSMENT

6.1 INTRODUCTION

Addis Ababa is capital and largest city of Ethiopia. It is located on a well-watered plateau surrounded by hills and mountains, in the geographic centre of the country. The city lies at latitude and longitude of 9°1’48”N 38°44’24”E and an elevation of 2500 meters. Summit condominium Chirkos site is located in central part of Addis Ababa city .The condominium house started to function since 2005E.C.and currently most of the construction in the site are completed. The condominium buildings are investigated for the presence of crack and the possible cause for these cracks. The study was conducted at the chirkos site block No. 351. It is located at Latitude $9^0$0’8”N and Longitude $38^0$47’59.64”E.The building is a four storey.

The study was carried out in three stages; the reconnaissance survey; the building inspection and calculating the limited width of crack according to ETHIOPIAN BUILDING CODE STANDARD-2, 1995 by using assumed data’s from the study area. The reconnaissance survey was aimed at studying the immediate environment of the building in study. Matured trees and drainage system around the vicinity of the structure were analysed with respect to their influence on the crack development on the building. The building inspection was carried out to diagnose the cracks in the building. Their location, width, depth and orientation pattern have been identified and measured using the standards of building inspection. Meter rule, tape, protractor and digital camera were used for this purpose.

6.2 Reconnaissance Survey

The preliminary survey conducted indicates that the building was constructed on a dry area. There are no any matured trees near the building which can influence the initiation of the cracks and all the drainage systems within the building area are concrete lined channels. Therefore, the cracks in the building are neither caused by ingress of tree roots in the building nor because of water penetrating into the ground due to lack of proper drainage system.

6.3 Building Inspection

As mentioned earlier the building inspection was carried out by measuring the width, length and orientation of the cracks. Therefore, at the beginning of the study the length and width of the cracks were marked and monitoring activities were continued from time to time to see whether these parameters increases with time or not. The monitoring activity of the cracks indicated that the cracks in the building are dormant cracks shown by the appearance of no new crack edges during the building inspection. Most of these cracks are classified as Moderate categorized as serviceability cracks with an average width less than 15mm (Burland and Day, 1977) in the foundation masonry walls and slight crack categorized as aesthetic crack with average crack less than 5mm on the columns, beams and wall.

6.3.1 Measurement and Monitoring Crack Width

TABLE: Crack width measurement during the monitoring of crack propagation

NB:- crack width are measured using cm ruler thus it is difficult to notice the increase of crack width during the time interval of measurement.

Table 7 measurement of crack width in concrete member. from assessed building

Date of measurement	Average column crack width(mm)	Average beam crack width(mm)	Average wall crack width (mm)	Average masonry crack width(mm)
10 November 2015	2.4	2.5	3.0	9
15 November 2015	2.4	2.5	3.0	9
20 November 2015	2.4	2.5	3.0	9
25 November 2015	2.4	2.5	3.0	9
30 November 2015	2.4	2.5	3.0	9
04 December 2015	2.4	2.5	3.0	9

6.3.2 Measurement and Monitoring Crack Length

Table 8 measurement of crack length in concrete member. from assessed building

Date of measurement	column crack length(cm)	beam crack length(cm)	wall crack length(cm)	masonry crack length (cm)
10 November 2015	20.5	15.0	18.0	35
15 November 2015	20.5	15.0	18.0	35
20 November 2015	20.5	15.0	18.0	35
25 November 2015	20.6	15.0	18.0	35
30 November 2015	20.6	15.0	18.0	35.1
04 December 2015	20.6	15.0	18.0	35.1

6.3.3 Measurement and Monitoring Crack Depth

Table 9 measurement of crack depth in concrete member from assessed building

Date of measurement	Average column crack depth (mm)	Average beam crack depth (mm)	Average wall crack depth (mm)	Average masonry crack depth (mm)
10 November 2015	5.0	4.5	3.5	20
15 November 2015	5.0	4.5	3.5	20
20 November 2015	5.0	4.5	3.5	20
25 November 2015	5.0	4.5	3.5	20
30 November 2015	5.0	4.5	3.5	20
04 December 2015	5.0	4.5	3.5	20

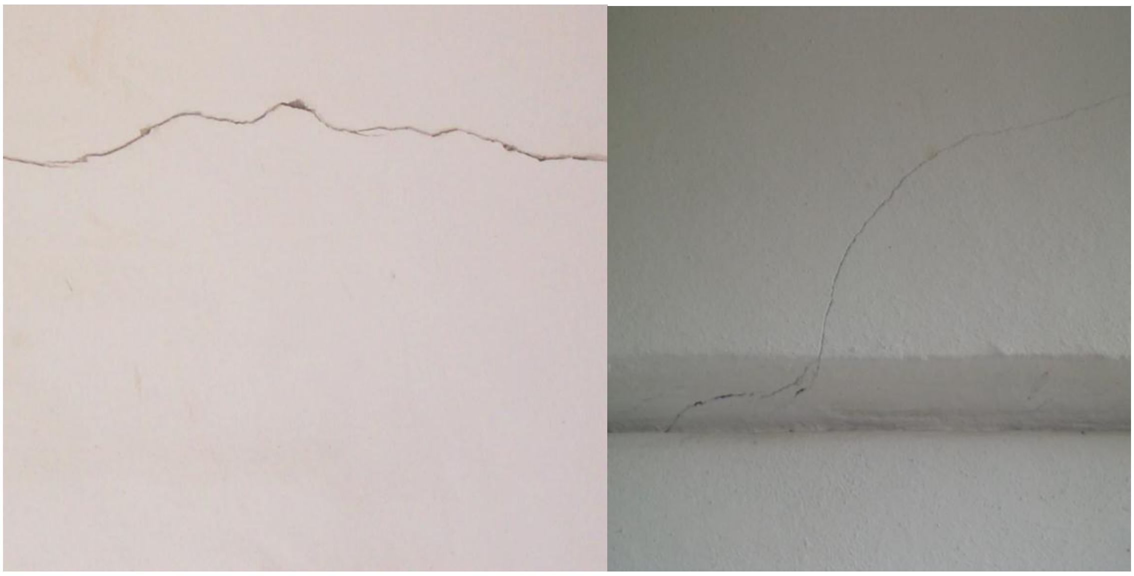


Figure 26 crack width and orientation of the crack

6.4 Limit State of Crack Width Calculation

The data necessary for the calculation of limit state of crack width for flexure and shear for the building are the following to calculate the limit state of crack width by using data from Bole sub city.

EXAMPLE

A singly reinforced concrete beam 200mm wide and 400mm deep is subjected to 40kNm.Concrete mix C25 and steel having fyk = 500 MPa are used. Consider effective cover as equal to 40 mm. It is required to design the steel reinforcement to the resist applied moment and to check the satisfaction of cracking limit state in the ETHIOPIAN BUILIDING CODE STANDARD.

SOLUTION

step1: For C25, f_{ck} = 20 MPa (from table 2.3 of EBCS 2) **,**

$$f_{cd} = \frac{0.85 f_{ck}}{\gamma_c} = \frac{0.85*20}{1.5} = 11.33 \text{ MPa}$$

For steel f_{yk} = 500 MPa,

$$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1.15} = 434.78MPa$$

M_u=ultimate factor * bending moment

Assuming the factor 1.5

M_u=1.5 * 40 =60KNm

Effective depth d = overall depth – effective cover

d = 400 – 40 = 360 mm

Depth of neutral axis for a balanced section

$$x_b = \frac{0.0035\,E_s\,d}{(0.0035E_s + f_{yd})} = \frac{0.0035*2*10^5*360}{(0.0035*2*10^5)+(434.78)} = 222.07mm$$

Moment of resistance for a balanced section

$= 0.8x_b\, b\, f_{cd}\, (d – 0.4x)$

$= 0.8 * 222.07 * 200 * 11.33 * [360 – 0.4(222.07)] * 10^{-6}$

= **109.27 kNm**

Moment to be resisted = 60 kNm < 109.27 kNm

Therefore the section can be under reinforced.

$$\rho = \left[1 - \sqrt{1 - \frac{2M_u}{bd^2 f_{cd}}}\right]\frac{f_{cd}}{f_{yd}} \quad = \left[1 - \sqrt{1 - \frac{2*60*10^6}{200*360^2*11.33}}\right]\frac{11.33}{434.78} = 0.006$$

$A_s = \rho bd = 0.006 * 200 * 360 = 432\ mm^2$

Number of 12 mm dia. rods = $\frac{432}{(\pi*12^2/4)} = 3.8$

Provide 4 numbers of 12 mm diameter rods.

Step 2: cracked section analysis calculation of the value of w_k

Step 2.1: calculation of the depth of the neutral axis, c

The first moment of area of the cross-section about the neutral axis must be equal to zero.

$b \times c^2 \frac{1}{2} = n \times A_s \times (d-c)$

$200 \times c^2 \frac{1}{2} = 10 \times (4 \times 113.1) \times (354 - c)$

Solving the quadratic equation for c, c=106.

Step 2.2: calculation of I_{Cr}

$I_{cr} = B \times \frac{C^3}{3} + n\ A_S\ (d-c)^2$

$I_{cr} = 200 \times c^3 \frac{1}{3} + 10(4*113.1)\ (354-106)^2 = 3.57*\ 10^8 mm^4$

Step 2.3: calculation of steel stresses, f_s

$F_s = n \times \frac{M}{Icr} \times (d-c) = 10 \times \frac{40 \times 10^6}{3.57 \times 10^8} \times (354-106) = 277.9 N/mm^2$

Step 2.4: calculation of cracking moment, M_{cr}

$M_{cr} = 1.70\ f_{ctk}\ Z$,

Use C-25 concrete strength, $f_{ck} = 25Mpa$

$F_{ctk} = 0.7 \times 0.3 (f_{ctk})^{2/3} = 0.21 f_{ck}^{2/3} = 1.5$

$Z = \frac{I_g}{Y}$, $I_g = \frac{bd^3}{12} = \frac{\mathbf{200 \times 400^3}}{\mathbf{12}} = 1.07 \times 10^9 mm^4$

$Y = \frac{d}{2} = \frac{400}{2} = 200mm$

$M_{cr} = 1.7 \times 1.5 \times \frac{1.07}{200} \times 10^9 \times \frac{1}{10^6} = 13.64 KN.m$

Step 2.5: calculation of steel stress f_{sr}

For n = 10, c= 106mm, d=354mm, $I_{cr} = 3.57 \times 10^8 mm^4$

$F_{sr} = n \times \frac{M_{cr}}{I_{cr}} \times (d-c) = 10 \times \frac{13.64 \times 10^6}{3.57 \times 10^8} \times (354 - 106) = 94.75\ MPa$

Step 2.6: calculation of ρ_r

$\rho_r = \frac{A_s}{A_{cef}}$ 40mm

$A_{cef} = b \times t_{eff}$

$t_{eff} = 2.5 \times (h-d) = 2.5(400-354) = 115$

$\rho_r = \frac{4*113.1}{200*115} = 0.0197$

Step 2.7 check the value of W_k

$W_k = \beta \times S_{rm} \times \varepsilon_{sm}$

$S_{rm} = (50 + 0.25 k_1 k_2)\frac{\emptyset}{\rho_r}$

$S_{rm} = [50 + 0.25 \times 0.8 \times 0.5 \times \frac{12}{0.0195}] = 111.01$

$\varepsilon_{sm} = \frac{f_s}{E_s}[1 - \beta 1 \beta 2 \left(\frac{f_{sr}}{f_s}\right)^2] = \frac{277.9}{2\times10^5}[1 - 0.8 \times 0.5 \left(\frac{94.75}{277.9}\right)^2]$

$\varepsilon_{sm} = 0.00132$

$W_k = 1.7 \times 111.01 \times 0.00132 = 0.25mm$

From Table 4.3, of Egyptian standard, w_{kmax} for category one is equal to 0.3

6.5 Discussion

The structures were found to be structurally safe for service and source of cracks were found to be structural and non-structural. Then poor workmanship, the inadequate quality of material used and the poor method of construction can be the possible cause of the non-structural cracks (laboratory test must be conducted). The weather condition may also contribute to the formation of those cracks but its contribution is very negligible to be discussed.

Most of the cracks occurred diagonal to the masonry wall which are structural cracks. Based on this condition, it can be noticed the building was exist the differential settlement. This crack width is within slight category of aesthetic classification with crack width 2mm-3.0mm, but structures lose its performance and appearance due to water penetration at the masonry foundation. Then crack repair can be taken to limit the cracks width less than 0.4mm. Crack patterns and mode showed that there is high value of dry shrinkage rate for both plasters and floor screed. The length of crack is not increasing considerably during the time interval of measurement thus the cracks are dormant in nature.

7.0 CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

Draw the following conclusion based on the literature reviews and findings.

- Most of cracks occur due to unable of the structure to resist the shear and normal stress acting on the structure. If the crack is continuously increased in certain period, it indicates that there will be a time when the structure is not capable to carrying load any more.
- With so many causes and types of cracks, it can be difficult to identify which cracks indicate a more serious structural issue and which are simply architectural. Many cracks are caused by overloading, corrosion, shrinkage, or poor workmanship. When looking at specific cracking pattern in Concrete, sometimes the cause can be attributed to a specific reason. Other times the pattern may have multiple causes leading to its current state due to a combination of factors.
- Cracking in buildings can be the result of one or a combination of factors such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, sub grade settlement, and applied loads. Cracking cannot be purely prevented but it can be significantly reduced or controlled when the causes are taken into account and preventative measures and repair methods are taken.
- Most of the causes of cracks observed during case study are due to bond failure between the concrete section and the reinforcement. The bond failure occurs when the thickness of concrete cover used is larger than the allowable concrete cover.
- Most of the cracks observed can be maintained by a simple repair method such as using a cementations grout method, routing and sealing repair method.
- The non-structural crack on the dormitory buildings can be the causes of structural cracks if there is worst weather condition and situation which in turn undermine the dormitory's safety and serviceability criteria throughout the life of the building.
- Even though, there are structural cracks in the building, they did not affect the performance, strength and serviceability of the condominium building at the current time. Use of appropriate repair method is enough at the current time

7.2 RECOMMENDATION

Based on the literature reviews, findings and studies, I hereby recommend the following points:

- Most of the condominium buildings are Susceptible to cracking. Thus; further deep investigation must be carried out Cirkos site building No.351. so as to minimize the risk of crack and to increase the service life of the buildings.
- Most of the causes of crack in the building are related to non-structural cracking. This comes from poor work man ship and poor quality materials that has been used during construction. Therefore, care and material quality control should be taken during construction of buildings.
- For interior walls, cracks can be repaired by using thin coat of Signed gypsum powder mixed with ordinary Portland cement at a ratio of 1:4 (cement gypsum) after recoating the wall with the same thin coat of finish material (sand, cement, mortar). The gypsum manufacturer’s instruction should be observed.
- For exterior wall, recoat the wall from architectural break with the same finish material but sand should be washed and be free from clays.

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