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# Study and Repair Concrete Structure

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# الإهداء

بسم الله الرحمن الرحيم

(قل إعملوا فسيرى الله عملكم ورسوله والمؤمنون)

صدق الله العظيم

اهدي هذا البحث الى كل من ساهم في تعليمي الى من علمونا حروفا من ذهب وكلمات من درر وعبارات من أسمى وأجلى عبارات في العلم إلى من صاغوا لنا علمهم حروفا ومن فكرهم منارة تنير لنا سيرة العلم والنجاح إلى أساتذتنا الكرام وكذلك اخص بجزيل الشكر الى استاذتي الدكتوره شذى صادق

وكذلك اذا كان الاهداء يعبر ولو بجزء من الوفاء فالاهداء الى زميلاتي و زملائي وعائلتي وإلى من كلله الله بالهيبة والوقار .. إلى من علمني العطاء بدون انتظار .. إلى من أحمل أسمه بكل افتخار ... والدي العزيز.

الى عنوان المحبه ورمز الوجود ... الى احب الناس إلى ملاكي في الحياة .. إلى معنى الحب وإلى معنى الحنان والتفاني .. إلى بسمة الحياة وسر الوجود إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أغلى الحبايب.. أمي الحبيبة.

إلى رفيق دربي إلى من تطلع لنجاحي بنظرات الأمل إلى من أرى التفاؤل بعينه والسعادة في ضحكته الى من بوجوده اكتسب قوه ومحبه لا حدود .... اخي

مع جزيل الشكر والتقدير

فدك محمد الموسوي

# Chapter one

# Introduction

## 1-1 introduction

Concrete structures are inherently durable and usually require a minimum of repair and maintenance. However, there are occasions when damage in defects requires remedial treatment to be carried out. Before carrying out any remedial measures on a concrete structure, it is most important to identify the basic causes which have made repair necessary. Otherwise, an inappropriate and consequently ineffective repair technique may be selected. This Current Practice is a general introduction to assist the reader in identifying likely causes of defects or deterioration. It deals both with the defects apparent shortly after construction and also with deterioration which occurs after many years of use. In some cases, e.g. fire damage, the cause is obvious. In other cases, the causes may only be established by means of detailed programs of testing and examination. Generally, the first step is to visually inspect the structure and review its history. In most cases, deterioration of a concrete structure can be attributed to one or more of the following causes with the symptoms included with each cause:

1. **Structural deficiency**

This may result from errors in either design or construction or alternatively from improper or altered use of a structure. It is usually characterized by cracking in highly stressed regions and the cracking is commonly perpendicular to the main reinforcement. Foundation movement can also be considered a structural deficiency; however, the resulting cracks are not necessarily perpendicular to the main reinforcement .

2. **Corrosion of reinforcement**

Steel reinforcement is added to concrete to increase its tensile strength. Steel is a product of naturally-occurring iron ore. A great amount of energy is required to convert iron ore to steel. Without proper protection, the process reverses, and oxidation occurs. Corrosion is simply the process by which steel tends to return to its natural, oxidized state

3. **Chemical attack**

Chemical attack occurs when aggressive liquids of damp chemicals are in contact with concrete. Etching or softening of the surface may result (e.g. acidic attack). Alternatively, the concrete may crack and spall due to sulfate attack

4. **Fire damage**

Fire damage can result in cracking and spalling of concrete.

5. **Internal reaction in the concrete**

In certain rare circumstances, reactions can occur between cement and substances present in the aggregates, resulting in expansive forces with subsequent cracking and spalling.

6. **Restrained thermal contraction and expansion**

Concrete, in common with other materials, contracts and expands with variations of temperature and when the contraction or expansion is restrained, damage can result. Temperature variations can occur either as a result of externally applied heat or cold or due to the quite considerable quantities of heat generated by concrete during setting and hardening.

7. **Restrained shrinkage**
8. **Creep**
9. **Rapid early evaporation**
10. **Plastic settlement**

Another form of cracking present within hours of casting is plastic settlement cracking which occurs when fresh concrete hangs up on either reinforcement or formwork.

## 1-2 objective

This study specifically consists of the following objective :-

- Study the factor controlling the deterioration in concrete structure like (durability , permeability of concrete , carbonation , chemical aggression to concrete , physical and chemical aggression to concrete and corrosion concrete )
- Study the investigation of defects in concrete structure in order to repair the cracks in concrete structure
- Study the materials that most widely used in repair of concrete structure
- Investigate the defects in building and repair it

## 1-3 Scope

The work presented in this thesis is given in five chapters:

- Chapter one / presents the general introduction of the research
- Chapter two/ presents the factor controlling the deterioration of concrete .
- Chapter three/ deals with the materials used in repair of concrete structure
- Chapter four/ includes the investigation of defects in concrete structure and how repair a small structure of Concrete .
- Chapter five/ the conclusions and recommendations for future works are summarized.

## *Chapter 2*

## *(Factors Controlling the Deterioration of Concrete)*

### 2.1 Introduction

It is intended in this chapter to consider the more important factors which can cause deterioration in reinforced concrete structures. It is only by carefully reviewing why and how this deterioration occurs that satisfactory techniques can be developed for the repair. This review will also be useful in helping to prevent this deterioration from taking place in future structures. The accumulation of knowledge and experience is a continuous process.

### 2.2 Durability

A structure would be considered durable if it fulfilled its intended duty for the whole of its design life with the minimum of maintenance. The design life of the structure will usually be laid down by the client in consultation with the designer. It would be unrealistic to expect any structure to maintain it's as new condition without any maintenance whatever.

However, Portland cement concrete has the potential of an almost unlimited life unless it is subjected to chemical attack by an aggressive environment, or suffers physical damage. Weather staining and similar discoloration should not be confused with lack of durability. On the other hand, deep carbonation, chemical attack on the concrete, cracking and spalling due to poor quality materials or workmanship, and or corrosion of the reinforcement, would be a clear case of low durability.

The question of how to achieve durability in concrete is discussed in the next Section, in which it will be seen that durability is closely related to permeability. In some cases, certain parts of a structure may be subject to physical deterioration such as abrasion caused by steel wheeled trolleys on a floor, a jet or stream of high velocity water containing grit impinging on a concrete wall or floor, spalling and surface flaking due to freeze-thaw cycles, and damage by wave action abrasion by sand and shingle in the case of marine structures.

## 2.3 Permeability

For durability, it is accepted that concrete should possess low permeability. Unfortunately it has been found impossible so far to set limits for permeability which can be subjected to practical tests.

Permeability should not be confused with absorption. The permeability of concrete is not a simple function of its porosity but depends on the size, distribution and continuity of the pores. The size of capillary pores. The concrete is about f-3pm, and the gel pores are very much smaller. The volume of pore space in concrete. as distinct from its permeability, is measured by absorption, and the two quantities are not necessarily related.

The subject of permeability is very complex, but most concrete engineers agree that the following are the main factors involved:

**(a)** The quality of the cement and aggregate.

**(b)** The quality and quantity of the cement paste; the quality of the cement paste depends on the amount of cement in the mix. The water cement ratio and the degree of hydration of the cement.

**(c)** The bond developed between the paste and the aggregate.

**(d)** The degree of compaction of the concrete.

**(e)** The presence or absence of cracking.

**(f)** The standard of curing.

**(g)** The characteristics of any admixtures used in the mix.

## 2.4 Carbonation

Carbonation is the effect of carbon dioxide ($CO_2$) in the air on Portland cement products, mainly calcium hydroxide ($Ca(OH)_2$) in the presence of moisture. The $Ca(OH)_2$ is converted to calcium carbonate ($CaCO_3$) by absorption of carbon dioxide. The calcium carbonate is only slightly soluble in water and therefore, when it is formed it lends to seal the surface pores of the concrete, provided the concrete is reasonably dense and impermeable.

The pH of the pore water in concrete is generally between 12.5 and 13.5 but if, due to carbonation, it is lowered to 9.0 and below, corrosion of the reinforcement may occur. Therefore the depth of carbonation in reinforced concrete is an important factor in the protection of the reinforcement; the deeper the carbonation, the greater the risk of corrosion of the steel. The extent of carbonation can be determined by treatment with phenolphthalein; the presence of alkalinity shows as a pink colour, while the carbonated part of the concrete remains without colour change.

Good quality dense concrete carbonates very slowly; even after a period of 50 years carbonation is unlikely to penetrate to a greater depth than 5-10 mm. On the other hand, a low strength, permeable concrete may carbonate to a depth of 25 mm in less than 10 years. Experience suggests that low quality cast stone products are particularly prone to carbonation. Carbonation does not adversely affect the durability of the concrete itself; it is the indirect effect it has on steel rebars that makes it undesirable in a reinforced concrete

structure. There is reason to believe that carbonation of concrete tends to reduce permeability to the passage of moisture.

In recent years it has become the practice also to include in the term 'carbonation' the reaction between oxides of sulphur (sulphur dioxide and sulphur trioxide) and the calcium hydroxide in the cement. These oxides in solution in rain water and atmospheric moisture arc acidic and therefore react with the alkalis in the cement paste in the same way as does carbon dioxide.

***Measurement of the Degree of Carbonation***

During drying, the pore water in the concrete evaporates and is replaced by air which contains carbon dioxide and other acidic gases which react with the alkaline constituents of the concrete thereby reducing the degree of the concrete alkalinity. The normal protection against corrosion provided by the concrete is lost as a result of carbonation and corrosion of steel reinforcement will occur if moisture and oxygen are available. Evaluation techniques for carbonation of concrete have been studied by number of investigators. W/C ratio, cement composition, age of concrete, and exposure conditions are the primary controlling factors. On site, the simplest and the best technique of measuring the depth of carbonation is by exposing a fresh concrete surface using a hammer and chisel and then spraying this surface with a 2 percent solution of phenolphthanlein ethanol which is a pH indicator. Magenta color is usually observed in the un-carbonated concrete. The color change occurs at a pH of about 10

## 2.5 Chemicals attack

Chemical attack occurs when aggressive liquids of damp chemicals are in contact with concrete. Etching or softening of the surface may result (e.g. acidic attack). Alternatively, the concrete may crack and spall due to sulfate attack.

Chemicals attack on the concrete is likely to occur from one or more of the following causes:

(a) Aggressive compounds in solution in the sub-soil and or ground water.

(b) Aggressive chemicals in the air surrounding the structure.

(c) Aggressive chemicals or liquid stored in, or in contact with, the structure.

(d) Chemical reaction between the constituents of the concrete ,i.e, alkali-aggregate reaction; this is a special case.

## 2.6 Alkali Aggregate reaction (AAR)

It is believed that this type of deterioration in concrete was first identified in the USA in about 1940 .since then it has been found in many countries .

There are two forms of AAR .alkali silica reaction (ASR) and alkali carbonate reaction .The former (ASR) is much more common the world over .Both types result from the interaction of alkalis in the concrete(mainly originating in Portland cement)and certain types of siliceous aggregate.

The key factor is the alkalinity of the pore fluid in the concrete . This originates mainly but not exclusive from alkali metal salts in Portland cement. External sources of these metallie salts,e.g. sea water and deicing salts will increase the total alkalinity if they

penetrate into the concrete but at present they are considered to be of minor importance Irrespeetive of the amount of alkali in the concrete ,the reaction (AAR) will only occur when certain types of aggregate are used (in the case of ASR),this means siliceous aggregates of special crystalline type) and there must be adequate supplies of external moisture.

There are three serious problems associated with ASR:

**(a)**There is at present no really reliable short term test to determine whether a particular cement and aggregate in specific mix proportion , will or will not result in ASR in the long term.

**(b)** For the reaction to became visible at a general inspection , a period of up to or more than 10 years may be required.

**(c)** There is no known method of effecting a lasting cure.

On the other hand , the reaction may under certain favourable conditions (such as a reduced ingress of moisture) proceed so slowly that the useful life of the structure may not be substantially reduced.

From the point of view of the diagnosis of ASR it is not always easy to recognise the visible symptoms. The signs are random surface cracking (map cracking) and sometimes the exudation of a whitish gel from the cracks. Cracking is always present , but the crack pattern can be quite similar to that caused by drying shrinkage. The gel is not always present on the surface.

## 2.7 physical aggression to concrete

physical aggression (wear and damage) to concrete can arise from a number of causes , the principal ones being :-

1. Freezing and thawing on the outside of structures .
2. Thermal shock caused by a sudden and severe drop in the temperature of the concrete. Such as spillage of liquefied gases.
3. Abrasion to concrete, such as that caused to floors in industrial buildings by steel wheeled trolleys. Similar damage can be caused to the inside of silos, bins and hoppers containing coarse granular material.
4. Damage from high velocity water. This damage can be subdivided into three types: cavitations; abrasion from water containing grit; impact from a high velocity jet.
5. Abrasion in marine structures caused by sand and shingle thrown against the structure by heavy seas and gale force winds.

## 2.8 CORROSION OF METALS IN CONCRETE

The metals which will be considered here are used for reinforcement or for fixings in concrete, namely , mild and high tensile steel, stainless steel, phosphor-bronze and gunmetal. Brief comments are also given on aluminum and copper as these are often fixed in direct contact with concrete.

The deterioration of concrete due the corrosion of the reinforcement may be described as following the stages set out below:

1. Passivation after the placing of the concrete.
2. Reduction and final destruction of the passivation.

3. The expansion of the rust resulting in the cracking of the concrete cover to the rebar's.
4. As the rust continues to from, the cracks are extended in width and length and pieces of concrete became unstable and eventually fall off (spalling).

Steel embedded in concrete does not normally corrode. Nevertheless, when there is insufficient cover, areas of poor compaction, or large amounts of chloride present, rusting may occur and because rust occupies considerably more volume than steel, stresses are set up which cause cracking or spalling of the overlying concrete. Characteristic of this type of damage is cracking or spalling which follows the line of the reinforcement, and in fact emanates from it Corrosion of steel in concrete is an electrochemical process. Therefore, electrochemical potential must be generated to form corrosion cells. This can occur when two dissimilar metals are embedded in concrete, such as steel rebars and aluminum conduit pipes, or significant variations exist in surface characteristics of steel .

## 2.9 Sulfate Attack

Agricultural soils and waters and the decay of organic matter can result in sulfate attack. Due to the presence of magnesium and alkali sulfates in these materials, SO4 concentrations are higher than normal. The form of the deterioration process depends on the concentration and source of sulfate ions in water, and the composition of the cement paste in concrete. Either expansion of concrete or a progressive loss of strength and mass will occur. Sulfate attack can be classified by four degrees of severity: negligible attack, moderate attack, severe attack, very severe attack. Very little sign of sulfate attack was observed in Mississippi.

## 2.10 Fire damage

Fire damage can result in cracking and spalling of concrete. There is usually no difficulty in identifying the cause and methods are available to evaluate the extent of the deterioration.

## 2.11 Other causes of deterioration of concrete

Typical causes:

- Poor curing
- Inadequate or excessive vibration during concrete placement causing segregation, bleeding or honeycombing
- Shutter work or reinforcement movement during concrete placement.
- Poor design detailing
- Chemical attack by aggressive chemicals such as acids or sugars or even soft water.
- Biological attack in sewers.
- Stray currents or bimetallic corrosion.
- Temperature, concentration and length of exposure to chemicals.
- Change of use , or exposure conditions from original design.

## *chapter three*

## *(Materials used in repair of concrete structure)*

### 3-1 Introduction

The range of materials which can be effectively use d for the durable repair of concrete structures is fairly limited. Those most widely used are concrete and mortar. Made as far as practicable with the same type of cement and aggregates as were used in the original structure. When deterioration is due To chemical attack. It may be necessary to use a different cement and or protective coatings.

When repaired areas fail it is in many cases due to failure or partial failure of the bond between the old and new work.

The standard of bond developed between the old and new concrete is directly related to the care taken in the preparation of the base concrete. In recent years a great deal of attention has been paid to the development of bonding agents. The choice of the repair material is directly related to the function of the repair and the expected service life of the structure after repair. The primary ingredients for most repair materials include one or more of the following:

**(i)** Ordinary or rapid hardening Portland cement

**(ii)** Epoxy resins

**(iii)** Polymer latex

**(iv)** Polyester resins

**(v)** Polyvinyl accelate

**(vi)** Fine and /or coarse aggregate filler

## 3-2 Selection of repair Materials

A variety of repair materials have been formulated to provide a wide range of properties. Since these properties will affect the performance of a repair, selecting the correct material for specific application requires careful study. Concrete repair materials have been formulated to provide a wide range of properties. It is likely that more than one type of material will satisfy the design criteria for durable repair of specific structure. In these cases other factors must be taken into consideration which includes:

**(i)** Ease of application.

**(ii)** Cost.

**(iii)** Available labor skills and equipments.

**(iv)** Shelf life of the material.

**(v)** Pot life of the material.

A guideline for the selection of repair materials is shown in Table (4-1).

### 3-2-1 Determining Material Properties

Once the project objectives are determined the next step is to select a repair material that will allow for a successful repair given the previously determined conditions. This proper selection requires an understanding of how the repair material will respond under the expected conditions. Each separate condition could cause a response to occur in many spots in the repaired area. The surface, repair material, reinforcing steel, interface, or original concrete could all experience some sort of responses. These responses could eventually lead to a failure in any of the affected areas.

Knowing how the repair material will respond to the various conditions will make it possible to determine the material properties required for a proper repair. However, many times when one or two properties are optimized it will be at the expense of other required properties. Whenever numerous properties are needed for a successful repair those properties must be prioritized in order to know which ones are most critical for success. A repair material should not be selected until properties that are needed for a successful repair are determined. However, most of these properties are not provided by repair material manufacturers. The properties of major concern are:

(a) **<u>Bond Strength</u>**

Bond strength determines how well the repair material will bond to the existing concrete substrate.

(b) **<u>Dimensional Behavior</u>**

The difference in dimensional behavior between the new repair material and the existing concrete substrate is a key contributor to a failure in the repair.

(c) **<u>Durability Properties</u>**

For concrete to be considered durable it must be able to it hstand numerous service conditions, weathering, chemical attack, and abrasion.

(d) **<u>Mechanical Properties</u>**

In order for a repair material to perform correctly it must have the proper mechanical properties to allow it to carry and transfer loads as concrete would.

**<u>3-2-2 Repair Material</u>**

There are many concrete repair materials in today's market that are very capable of producing successful concrete repairs. However, before a successful repair can be made a general material selection process is needed to insure that the best repair material is selected. This selection process first involves determining the project objectives. These objectives are:

- **<u>Causes of deterioration</u>**:

Determining the causes of deterioration is the first step in selecting the proper material for the repair. The information for this section will come from the other chapter on concrete deterioration.

- **Owner requirements:**

This step of the selection process is simply to make sure that the scope of the project is properly understood. Some of the items to consider are project budget, appearance, expected service life, and any structure utilization needs during rehabilitation.

These are some of the basic considerations, which must be taken into account before any other decisions are made about repair materials.

- **Service conditions**:

Determining service conditions is important because it allows you to determine the physical and chemical properties needed in the repair material depending on the different load factors that the bridge will see. These load factors include weather, chemical environment, and live loads.

- **Application conditions**:

Determining application conditions allows you to further determine the best repair material for the task at hand. Some of these application conditions include project time frame, weather conditions, access, and operating conditions. This will be discussed further in determining material properties.

## 3-3 cements

### 3-3-1 portland cement :ordinary and rapid hardening

The basic difference between the two cements is the rate of gain strength. The increase with the rapid hardening cement is largely due to the finer grinding and this cement usually has a specific surface of about 4300cm /g. the rapid hardening is accompanied by an increase in the rate of evolution of heat of hydration which in turn raises the temperature of the maturing concrete during the first 15-40 h after casting easting. It should be noted ,however ,that the rate of hardening and evolution of heat of hydration does not depend on the fineness of grinding alone. And that chemical composition of cement also plays a part.

The use of Portland cement types I to V as the basic component in the repair material is always worth considering as it provides a comparable material to the concrete being repaired and is usually a less expensive alternative. The disadvantage associated with the use of cement-based repair material is basically the lower bond between old concrete and repair material. To increase this bond, various types of bonding agents are used either at a surface preparation stage or in the concrete repair mix. The incorporation of a suitable bonding emulsion such as polymer latex in cement mortar will improve its bonding to existing concrete, reduce its permeability and increase its tensile strength .

Polymer emulsion alone is effective for bonding fresh mortar to the surface of hardened concrete, provided it is not allowed to dry out before fresh mortar or concrete is placed. The materials most commonly referred to in this category are Styrene Butadiene Rubber (SBR) and acrylics. Another polymer bonding agent with a similar purpose is Polyvinyl acetate (PVA) which has the tendency of demulsifying on contact with moisture, thus it use is only advisable in situations where the concrete remains -permanently dry.

### 3-3-2 sulphate – resisting Portland cement

the cement is similar in its strength and other physical properties to ordinary Portland cement. However ,it is generally darker in color than most The essential difference is in the limitation of the tricalcium Aluminates (C3A) content to a maximum of 3%.

It is tricaleium Aluminate in Portland cement which is attacked by sulphates in solution and this chemical reaction results in the formation of cttringite which can have a disruptive effect on the concrete. Causing dimensional changes and reduction in strength . It is advisable to consult the cement manufacturer before using any type of admixture with this type of cement. But calcium chloride should not be used as the sulphate resistance in the long term will be reduced. Sulphate-resistance Portland cement, in common with all Portland cements, is vulnerable to acid attack.

### 3-3-3 white and coloured Portland cements

White Portland cement is a true Portland cement .The special point about this cement is that the raw materials are specially selected ,the clay is a white china clay and the manganese and iron content is kept to an absolute minimum. Coloured Portland cements allow for the presence of pigment in the cement. It is not possible to give an answer to this in the form of a straight "yes" or "no". where durability and/or impermeability are important factors, the author considers that allowance for the pigment should be made by increasing the specified cement content by weight of pigment. Where strength is overriding ,than the only satisfactory solution is to make trial mixes because the strength of ordinary Portland cement varies within certain hunts.

### 3-3-4 HIGH Alumina cement (HAC)

HAC differs foundamentally from Portland cement as it consists predominantly of calcium aluminates. It is much darken in colour than ordinary and rapid hardening Portland cement. The setting time is similar to that of Portland cement. With increasing in ambient It is very careful wet curing is required to prevent thermal cracking. The rapid gain in strength makes it extremely useful for emergency repairs.

### 3-3-5 Chemically resistant cement

These special cement are not used for concrete except where very small quantities are required. They are used for mortar and grout for resistant tiles and bricks bedding and jointing chemically .

type cements are mainly based on modified phenolic resins, blended epovies, cashew nut resin cement, furane resin, and polyester resin. The silicate cements are based on sodium silicate and polyester resin. The silicate cements are based on sodium silicate and potassium silicate, and are resistant to very high temperature as well a wide range of aggressive chemicals.

( Chemically resistant cements usually consist of a powder and a gauging liquid sometimes termed a syrup ) which are mixed together in the prescribed proportion immediately before use.

## 3-4 steel reinforcement

### 3-4-1 galvanised reinforcement

The object of the galvanizing is to provide additional protection to the rebars and prestressing wire in especially adverse condition of exposure.

## 3-4-2 Stainless steel

There are three basic group of stainless steel: martensitic. Ferritie and austenitic . Of these , it is the austenitic steels which are the most widely used in building and engineering and the information which follows relates to this group. Austenitic steel is an alloy of iron, chromium and nickel, and two types in this group contain also a small percentage of molybdenum. The type most generally suitable for use in external repair work. It is very resistant to corrosion but is also very expensive _ compared with mild steel. The steel can be welded.

However, it may be non-magnetic or only slightly magnetic , and therefore it may not be possible to locate it with a normal type of cover meter.

## 3-5 AGGREGATES

Aggregate is a broad category of coarse particulate material used in construction, including sand, gravel ,crushed stone, recycled concrete and geosynthetic aggregates. Aggregates are a component of composite materials such as concrete and asphalt concrete the aggregate serves as reinforcement to add strength to the overall composite material. Due to the relatively high hydraulic conductivity value as compared to most soils, aggregates are widely used in drainage applications such as foundation and French drains, septic drain fields, retaining wall drains, and road side edge drains. Aggregates are also used as base material under foundations, roads, and railroads. To put it another way, aggregates are used as a stable foundation or road/rail base with predictable, uniform properties (e.g. to help prevent differential settling under the road or building), or as a low-cost extender that binds with more expensive cement or asphalt to form concrete. it is impossible to construct a city with out using natural aggregate .developed countries cannot sustain their high level of productivity and economies of developing nation cannot be expanded without the extensive use of aggregate.

## 3-6 ADMIXTURES FOR CONCRETE

A simple definition of an admixture is that it is a chemical compound which is added to concrete. Mortar or grout at the time of mixing for the purpose of imparting some additional and desirable characteristics to the mix. Admixtures are sometimes referred to as additives, but it is better to use the latter word for the addition of chemical compounds to cement at the cement works, where they are ground-in at the time of manufacture.

## 3-7 ORGANIC POLYMERS

Organic polymers are complex chemical compounds derived mainly from the petrochemical industry. These materials are often referred to as "resins", and the principle resins used in the construction industry are epoxide, polyurethane , polyester, acrylic, polyvingl, acetate, and styrene-butadiene. For coatings used for the protection of concrete and to reduce permeability, epoxies, polyurethanes and acrylics are in most general use

for use in mortars and concretes, acrylics and styrene butadiene compounds are used successfully. Polyvinyl acelate (PVA) is used as a bonding agent for floor screeds and toppings to increase adhesion with the base concrete; it is also used in cement mortar mixes to improve certain characteristics of the mortar and bond with the substrate. Polyester resin are used in cement-based proprietary floor toppings.

### 3-7-1 EPXIDE RESINS

The resin are marketed by the formulators and have the special properties required for the specific use to which they will be put. For example, some resins can be successfully applied and cured under water. While most epoxies are rigid when cured, it is now possible to obtain a type which is slightly flexible.

### 3-7-2 POLYESTER RESINS

Polyester resins are used with Portland cement and selected aggregates to from a polymer-cement aggregate mortar. Such mortars possess a number of desirable qualities such as good resistance to a wide range of chemicals, high resistance to abrasion They are a number of important differences between the properties of polyester resin and epoxide resins. The polyesters can be used in a wider temperature range; they offer rather better resistance to heat. But have appreciably higher shrinkage characteristics; the bonding properties to concrete are generally lower.

### 3-7-3 STYRENE BUTADIENE AND AREYLIC RESINS

These materials are also known as latexes and polymer emulsions. Some of the properties of a proprietary styrene- butadiene copolymer emulsion (latex) used with Portland cement in grout, mortar and concrete are:

pl l 11.0

Total solids content 47% (nominal)

Specific gravity 1.1

Butadiene content 40% (nominal)

The advantages claimed for the use of these latexes in Portland cement grout, mortar and concrete include reduced permeability, reduced initial drying shrinkage, improved resistance to attacked by certain dilute acids and solution of sulphates, and improved bond to the substrate.Special precautions have to be taken by formulators with styrene butadiene latexes when these are used with OPC to reduce air entrainment and the effect of the retardation of the cement.

## 3-8 JOINT FILLERS

Fillers for joints are sometimes known as "backup" materials. They are used in full movement joints to provide a base for sealant and also to prevent the ingress, during the construction period, of stones and debris which may prevent the joint from closing. Materials for these fillers include specially prepared fibers, cellular rubber and granulated cork compounds. The materials used should fulfil the following requirements:

**(a)** It must be very durable

**(b)** It must be chemically inert.

**(c)** When in contact with potable water it most be non-toxic and non-tainting and should not support bacterial or fungoid growth.

**(d)** It must be resilient and should not extrude so as to interfere with the sealing compound, and should not bond to the sealant as this latter could induce undesirable stress in the sealant.

**(e)** It should be easily formed to the correct dimensions and be readily inserted into the joint.

**(f)** In certain cases e.g. floors, it should provide proper support for the sealant but should not bond to it.

# *Chapter Four*

## *(Non-structural cracks and their repair)*

### 4-1 Introduction

Perhaps the number one consideration in any remedial treatment is the repair of existing cracks.

### 4-2 Types of creaks

Cracking is a common manifestation of concrete deterioration which can be caused by a variety of factors. Cracks which are found in bridges and overpasses are generally described as structural or nonstructural. Structural cracks are caused by both dead and live load stresses, which can lead to eventual failure of the structure. Flexure structural cracks are vertical and begin in areas of maximum tension or moment. Shear structural cracks are diagonal and are usually found in the web of a member. They may begin at the bottom and move diagonally toward the center of the member.

Nonstructural cracks can be caused by thermal expansion and contraction of concrete, contraction of the concrete during the curing process, or temperature gradients within massive sections of concrete. Also, the presence of rust stains around nonstructural cracks normally indicates corrosion of steel reinforcements in a concrete member. These cracks generally do not affect the load-carrying ability of a member, but may lead to higher susceptibility to other types of deterioration.

Cracks in concrete represent one of the most difficult problems in the repair and maintenance of concrete. Cracks often form as unintended movement joints, and designers frequently want to seal them and make them invisible. It is important to be quite clear why it is required that a particular crack should be treated:

**(a)** To prevent water penetration,

**(b)** To protect the reinforcement,

**(c)** To prevent staining from material leached out, and

**(d)** To conceal the crack

There are many causes of cracking in reinforced conc. Structures, but for practical purposes, these can be placed in to main categories:

1- **Structure cracking**: This would indicate that the structure, or for more likely, one part of the structure was showing signs that the times was approaching or had been reached, when it could not safety support the loads to which it has being subjected. This state of affairs may be brought about by:

   **a)** Error in design

   **b)** Loading in excess of the design load even allowing for the built in factor of safety

   **c)** Some error or short coming in construction

   **d)** Physical damage, explosion, impact, fire

   **e)** Severe deterioration resulting in serious corrosion of reinforcement (many factors can cause this).

2- **Non-structural cracking**: This is cracking by any cause except those listed above.

However, it must be kept in mind that in reinforced conc. If cracking of this type is ignored, corrosion of rebars can proceed, and after a period

of time, the bars become so corroded that the member or structure becomes structurally unsafe

In the other wards if non structural cracks neglected it may result in structural distress.

A careful examination of the cracks will give valuable information and will generally indicate their cause such factors as:

1) Crack position, pattern, direction ( vertical, horizontal or inclined).
2) Cracks direction in relations to the main reinforcement (whether parallel or transvers, are all important).
3) Any deflection of the members is also significant.
4) The width of the cracks should be measured as accurately as possible.
5) The depth of cover to the reinforcement must also be measured.

## 4-3 Non-structural cracks

There are many types of non –structural cracks as follows:

### 4-3-1 Plastic cracking:

Another form of cracking present within hours of casting is plastic settlement cracking which occurs when fresh concrete hangs up on either reinforcement or formwork. It typically occurs in columns, deep beams, or walls with mixes which have a tendency to bleed. There are two categories of plastic cracking. The first, and most common, results from a too rapid evaporation of moisture from the surface of the conc. While the conc. Is still plastic, and is usually referred to as a plastic shrinkage cracking.

When the rate of evaporation exceeds the rate at which water rises to the surface (known as bleeding) plastic cracking s very likely to result.

The rate at which the water in the mixed conc. reaches the surface and the total quantity involved depends on many factors as:

**a)** Grading moisture content, absorption, and type of aggregate. Used

**b)** Total quantity of water in the mix.

**c)** Cement content.

**d)** Thickness of the concrete Slab.

**e)** Characteristic of any admixtures used .

**f)** Degree of compaction obtained and therefore the density of the compacted concrete.

**g)** Whether the form work (or sub-bale) on which the conc. was placed was dry or wet.

The rate of evaporation of water from the surface of conc. Depend on the following factors

**a)** Relative humidity

**b)** Temperature of the concrete.

**c)** Temperature of the air

**d)** Wind velocity

**e)** Degree of exposure of the surface of the slab to the sun and wind

Plastic shrinkage cracking shows itself as fine cracks which are usually fairly straight and can vary in length from about so to 750 mm, they are often transverse of the cracks are parallel to Each other and the spacing can vary from about 50mm to 90mm.

The cracks are usually shallow and seldom penetrate below the top layer of rein for cement.

- The second form of plastic cracking is due to settelement of the conc. In the formwork after compaction has been completed.

Plastic sett element cracking can be caused in two basic ways:-

**a)** The first is by the resistance of the surface of the formwork to the downward movement of the plastic conc. Under the influence of the poker vibrators and the force of gravity this resistance delays the downward movement of the conc. And so, as the conc. Stiffen, a crack is very likely to form This is a surface defect close to the formwork the cracks do not penetrate deeper than about 20-25mm and are wider at the surface.

**b)** With the second type of plastic settelement cracking, the cracks are caused by the conc. becoming "hung- up" on either the reinforcement or spacars (or both) and a creeks penetrate at last to the reinforcement and are usually winder inside the conc. Than on the surface, and when the conc. Is cut a way void are found adjacent to the conc. has become hung-up.

Crack injection is the best repair method for this type of plastic cracking with both of these types of plastic sett element cracking changes in the mix proportions and revibration of the Conc. A short while after the first compaction has caused will usually cure the trouble.

## 4-3-2 Drying shrinkage cracking

During shrinkage cracking is generally confined to:

**a)** Non – structural members which have either no reinforcement or only nominal reinforcement for handling purpose

**b)** Thin toppings, screed and rendering In most case it is caused by:-

**a)** Badly designed mix

**b)** The effects of which are aggravated by inadequate caring.

**c)** The use of calcium chloride as an admix true

**d)** The presenle of chloride in the aggregate will increase drying shrinkage.

**e)** In addition to the factors mentioned above there is also the use of shrinkable aggregate.

## 4-3-3- Thermal Contraction Cracking

During the setting and early hardening process of conc. considerable heat is evolved by the chemical reaction between the water and the cement which results in a rise in temperature. of the concrete.

The actual rise, the peak temp., and the time taken to reach the peak and then to cool down will depend on large number of factors of which the following are the most important:-

**a)** The ambient air temperature.

**b)** The temperature of the concrete. At the time of placing .

**c)** The type of form work used, and the time the formwork is kept in position.

**d)** The ratio of the exposed surface area of the conc. (i.e the area not protected by formwork, to the valium of conc.)

**e)** The thickness of the section cast

**f)** The type of cement used and the cement content of the mix

**g)** Whether any provision is made

For the thermal isulation of the method of curing . Thermal contraction cracks extend night through the member and normal drying shrinkage will tend to wider these cracks, which when first formed are usually very fine, often no wider then 0.1mm, for this reason they are often not noticed for several weeks after casting. This type of cracking is often wrongly attributed to drying shrinkage. The latter takes place slowly under normal conditions.

### <u>4-3-4 Cracking Caused by Al Kali-Agg reaction :</u>

This cracking is found to occurs many years after the structure was complete. The crack pattern varies, but in many cases it is seen to form a random distribution known as a map cracking and is often confused with during shrinkage, but the latter occur in the very early history of the concrete.

In structural members such as columns and beams where reinforcement is in the form of fairly heavy main bars, the cracks often follow the lines of the bars. In addition to the cracks, there is sometimes a yelowish gel. Extruded from the cracks However carbonation may turn this to a whitish Colour so that it looks like the leaching of line

## 4-4 EXPERIMENTAL PROGRAM

### 4-4-1 Preparation for Concrete Repairs

Preparation for repairs is unanimously regarded as the most important step and several repair failures have been traced to inadequate preparation. This phase involves:-

**(a)** Removal of all deteriorated concrete,

**(b)** Cleaning products, and

**(c)** Preparing the concrete surface for treatment.

#### (a)Removal of Deteriorated Concrete

Removal of spalled and loose concrete is carried out using scrabbles, chisels and hammers and any other suitable mechanical means, manual or pneumatic. Defective concrete is also removed by the use of percussion tools, grit blasting .

#### (b) Cleaning of concrete

Cleaning follows the removal of all loose and defective concrete.. This operation is particularly important.

#### (c) Preparing Concrete Surfaces for Bonding

Concrete surfaces to be repaired or on which primer coating is to be applied should be newly exposed parent concrete free of loose unsound materials.

### 4.4.2 Repair Material

There are many concrete repair materials in today's market that are very capable of producing successful concrete repairs. However, before a successful repair can be made a general material selection process is needed to insure that the best repair material is selected.

The choice of the repair material is directly related to the function of the repair and the expected service life of the structure after repair. Thus, repair could be performed cheaply to prolong the use of the structure for a limited life, or more expensively such that no remedial work will be required for many years. Table (4-1)show the materials used in repair of Concrete structure .

### 4.4.3 Bonding Coats

The effectiveness of any repair method will largely depend upon its ability to achieve an effective bond with existing concrete. When applying conventional concrete, sprayed concrete or sand/cement repair mortars, bond is often a problem

## 4.4.4 Repair of a small crack

Fig (4-1,2 ,3)shown the small non structure crack in a small building .

The first thing we kept in mind that the cause of this crack so that a careful examination of the crack was done .

We obtain as much information as possible about the crack structure .

We used mortar to repair this small crack as shown in FIGURE(4-4,5,6,7)

Table 4.1 Typical characteristics of selected repair materials [129]

| Materials | Ingredients | | Application Requirements | | | Material Properties | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Binder | Typical additives/admixtures | Thickness Limitations (in) | Installation Temperature (F) | Curing | Drying Shrinkage | Coefficient of Thermal Expansion | Compressive Strength (psi) 1 Hr. | 24 Hrs. | 3 Days | 28 Days | Elastic Modulus (psi) | Permeability (% of Concrete) | Freeze-Thaw Resistance | Non-sag Quality | Exo-therm |
| Portland Cement Mortar | Portland Cement | Water Reducing Air-Entraining | 0.5-2.0 | 40-90 | Wet 7 Days | Moderate | Similar to Substrate | 0 | 650 | 2500 | 5000 | $3.4x10^6$ | 90 | Good | Mod-erate | Mod-erate |
| Portland Cement Concrete | Portland Cement | Water Reducing Air-Entraining | >1.75 | 40-90 | Wet 7 Days | Low | Similar to Substrate | 0 | 650 | 2500 | 5000 | $3.8x10^6$ | 90 | Good | N/A | Low |
| Microsilica-Modified Portland Cement Concrete | Portland Cement | Silica Fume, HRWR, Air-Entraining | >1.25 | 40-90 | Wet 7 Days | Low | Similar to Substrate | 0 | 3000 | 4000 | 7500 | $4x10^6$ | 60 | Good | Good | Low |
| Polymer-Modified Portland Cement Concrete | Portland Cement | Polymer Latex | >1.25 | 45-95 | Wet 2 Days | Low | Similar to Substrate | 0 | 2000 | 4000 | 6000 | $2.5x10^6$ | 50 | Excellent | N/A | Low |
| Polymer-Modified Portland Cement Mortar | Portland Cement | Non-Sag Fillers, Polymer Latex or Powder | 0.25-2.0 | 45-95 | Moist 3 Days | Moderate | Similar to Substrate | 0 | 1500 | 3000 | 5000 | $2.5x10^6$ | 50 | Excellent | Low to Excel-lent | Mod-erate |
| Magnesium Phosphate Cement Concrete | Magn. Phosphate Cement | | >0.50 | 0-100 | Air | Low | Similar to Substrate | 2000 | 6400 | 7000 | 84000 | $4.7x10^6$ | 90 | Good | Low | High |
| Preplaced Aggregate Concrete | Portland Cement | Pozzolans, Fluidifier | 3.0 | 40-90 | Wet 7 Days | Very Low | Similar to Substrate | 0 | 500 | 2250 | 45000 | $3.8x10^6$ | 100 | Good | N/A | Low |
| Epoxy Mortar | Epoxy Resin | Sand | 0.13-0.38 | 50-90 | Air | Low | 1.5-5x Concrete | 0 | 9000 | 11000 | 12000 | $1.6x10^6$ | 10 | Excellent | Mod-erate | High |
| Methyl Methacrylate (MMA) Concrete | Acrylic Resin | | 0.25-0.5 | 20-120 | Air | Moderate | 1.5-5x Concrete | 4000 | 1200 0 | 12000 | 12000 | $2.0x10^6$ | 10 | Excellent | N/A | High |
| Shotcrete | Portland Cement | Silica Fume, Pozzolans, water reducing accelerator latex | >0.5 | 40-90 | Wet 7 Days | Moderate | Similar to Substrate | 0 | 800 | 3500 | 5000 | $3.8x10^6$ | 60 | Good | N/A | Low |

Figure (4-1)

Figure (4-2)

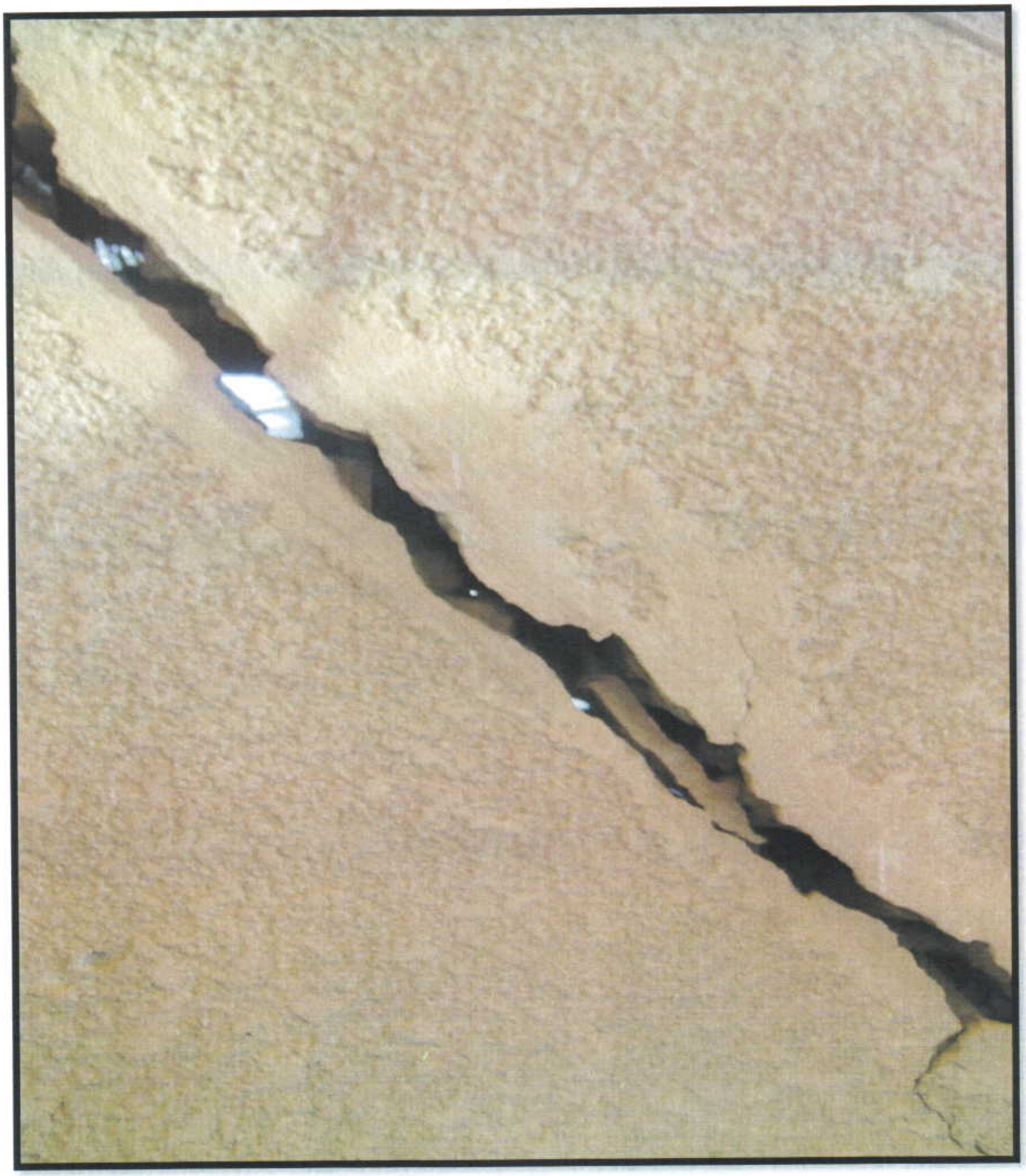

Figure (4-3)

Figure (4-4)

Figure (4-5)

Figure (4-6)

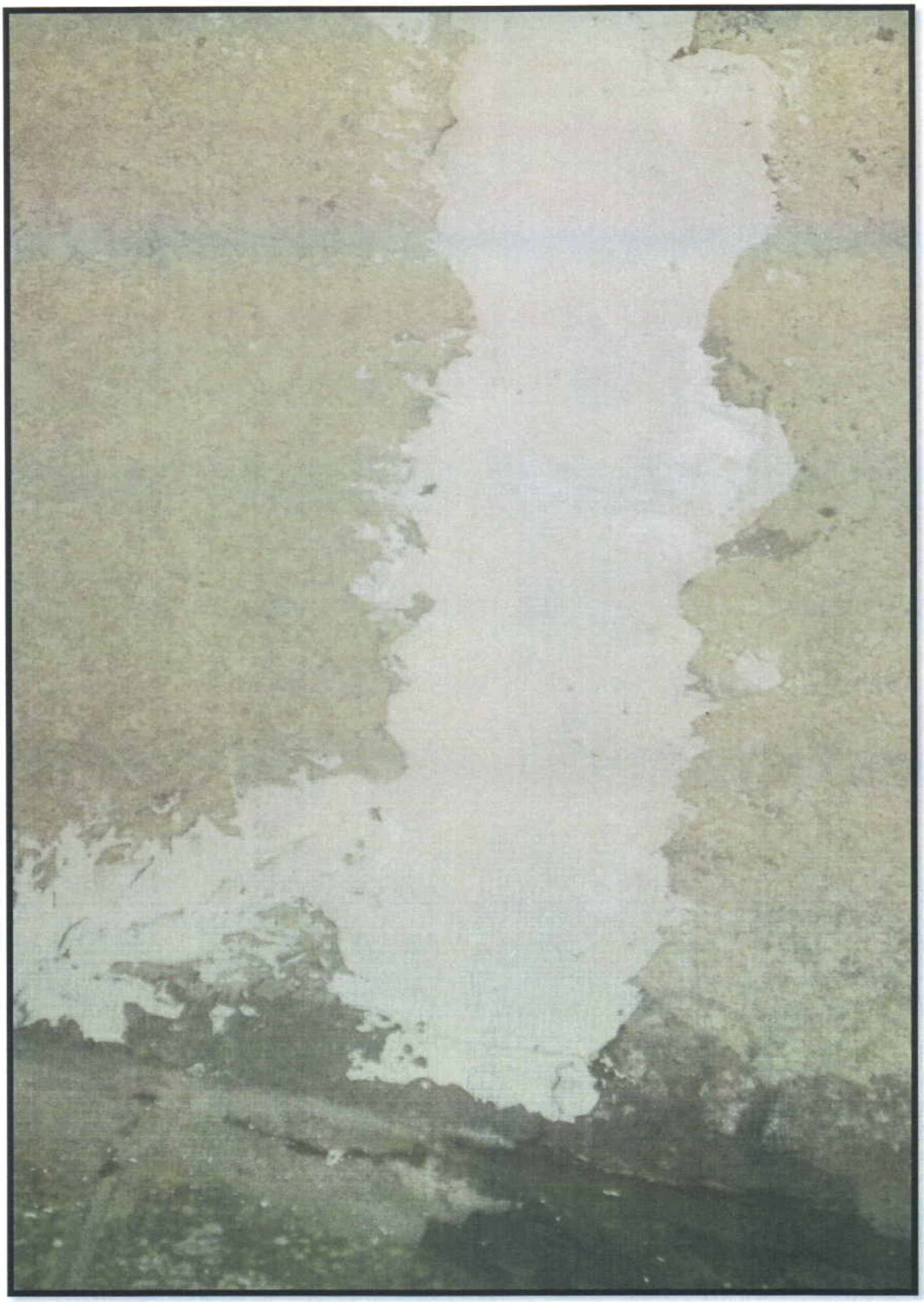

*Figure (4-7)*

Figure (4-8)

Figure (4-

# *Chapter Five*

## *(Conclusions and Recommendations for further works)*

### 5-1 conclusion

Depending on the investigation and study of this research on repair of concrete structure the following conclusions can be drawn :-

1- There are many factors controlling the deterioration of concrete like durability , permeability,...etc.

2- The range of materials which can be effectively used for the durable repair of concrete structures is fairly limited . These most widely used are concrete and mortar , made as far as practicable with the same type of cement and aggregate as were used in the original structure , but sometimes it may be necessary to use a different cement and \or protective coatings.

3- The engineer should obtion as much information as possible about the structure .

## 5-2 recommendations for future works

On the basis of the pervious works and the present study , further investigations are recommendation:.

1- Study required to investigate the types of cracks in concrete structure .
2- Study is required to investigate the repair of concrete bridges, external wall .
3- Further studies are required to investigate the repair of concrete floors and roofs and study method used .
4- There is a need to study the effect of using another types of materials such as polymers and another types method used in repair .

Futher studies are required to compare between structure repair and non-structure repair of Concrete .

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