University of Technology

Building and Construction Engineering Department

Building Materials and Projects Management Engineering Branch

R.C.Structure Defects and Rehabilitation

Prof. Dr. Shakir A. Salih

Lec.No.1

Introduction:

The buildings and other different reinforced concrete structures often suffer of some defects and deterioration which affect the structure by many ways. There are various causes of these defects and deterioration relate to all construction steps; the design, materials, shop drawings, work conditions, quality control and others.

It is aimed from this vital subject to teach the 4^{th} class student the defects and deteriorations which may be happened to the reinforced concrete buildings and structures and why they happened in the structures which are in service. As well as, the measures which must be taken to prevent or decrease them in the new structures (during the construction period or in the structures which are to be built in the future), then study the best way to repair them.

To achieve that, the subject will be studied from all its sides. The construction activities and stages will be displayed and discussed. The design criteria, structural materials, specifications, site conditions, workers' skills and execution technology and its effect on the commonly happened defects are to be discussed too. The traditional construction stages such as foundations, columns, beams and slabs are to be discussed thoroughly and the best practical ways to avoid these defects and deterioration during construction period or in the future.

It is worthy to point out that this subject is not existed in a specific text book. It depends on many references and subjects the student has had in the previous years. The references of materials technology, concrete technology, structural theory, soil mechanics, reinforced concrete design, project management, quality control and others can be useful.

Below is a brief of the most important topics and references in the syllabus:

This subject is for the 4^{th} class students. 2–hour lecture is to be delivered weekly, which means 60 hours over the academic year. It is hopeful to discuss and study the following topics:

1. The design criteria and their effect onbuilding defects and deterioration and their maintenance.

2. Evaluation of defected reinforced concrete structures.

3. The structural materials used to repair defects and deterioration.

4. The main causes of cracking in concrete structures and their repair methods.

5. The foundations' defects and causes and their repair methods.

6. The reinforced concrete columns' defects and causes and their repair methods.

7. The reinforced concrete beams' defects and causes and their repair methods.

8. The reinforced concrete slabs' defects and causes and their repair methods.

9. The roofing work defects and cause in buildings and their repair methods.

I'd like to turn the student attention that what is existed in internet is just an abbreviation of the subject and very brief, so, the student has to attend the lectures to have all the information about the subject and to discuss it.

At last, it is possible to make use of the following references for more information about any subject discussed in the lecture.

1. Derek Osbourn and Roger greeno, "Introduction to building", Pearson Prentice Hall, 3^{rd} Ed. 2002.

2. Philip H. Perkins, "Repair, Protection and Water Proofing of Concrete Structures", E.A.S.P., London and Newyork 1986.

3. Neville A.M, and Brooks J.J." Concrete Technology", John Wiley and Sons, Newyork, 2005.

.4المصدر   السابق باللغة العربية ترجمة الاستاذ الدكتور شاكراحمد صالح والاستاذ الدكتور محمد ايوب العزي.

5. الخلف, د. مؤيد ويوسف, د هناء عبد " تكنولوجيا الخرسانة" وزارة التعليم العالي, الجامعة التكنولوجية, 1991.

6. The lecturer theoretical and practical experience in design and in site works.

R.C.Structure Defects and Rehabilitation

Prof. Dr. Shakir A. Salih

Lec.No.2

Guide for Evaluation of Concrete Structures

Before Rehabilitation

Introduction

This lecture outlines procedures that may be used forthe evaluation of concrete structures before rehabilitation.The evaluation work is generally performedfor one or several of the following purposes:

a) To assess deterioration due to exposure conditions;

b) To evaluate structural damage or distress resulting from unusual loadings, improper design, poor construction, overloads, fire, flood, foundation settlement, abrasion, fatigue effects, chemical attack, weathering, or inadequate maintenance;

c) To determine the feasibility of changing the use ofa structure;

d) To assess the capacity of a structure to accommodate larger loads;

e) To enlarge a structure or change the appearanceof the structure;

f) To determine the feasibility of modifying an existing structure to conform to current codes and standards; and

g) To verify the structural adequacy and integrity of a structure or selected elements within a structure.

There is no absolute measurement of structural safety in an existing structure, particularly in structures that have deteriorated due to prolonged exposure to the environment, or that have been damaged by a physical event.

1.2-Definitions

The following definitions are defined here as in ACI

116R:

Preservation-The process of maintaining a structure in its present condition and arresting further deterioration

Rehabilitation-The process of repairing or modifying a structure to a desired useful condition

Repair-To replace or correct deteriorated, damaged, or faulty materials, components, or elements of a structure

Restoration-The process of reestablishing the materials, form, and appearance of a structure to those of a particular era of the structure

Strength-The ability of a material to resist strain or rupture induced by external forces.

Strengthening-The process of increasing the load-resistance capacity of a structure or portion thereof.

evaluation—using the results from investigations and structural engineering principles to derive conclusions regarding a structure's behavior, condition, integrity, and the need for preservation, rehabilitation, restoration, or strengthening.

inspection—the process of using aided and unaided visual techniques to ascertain the physical condition of a structure and extent of deterioration, damage, or distress present.

investigation—collecting and assembling data and detailed information regarding a structure's behavior, condition, and strength, acquired from analyses of documents, surveys,observations and tests, and other means, such as conducting interviews with persons knowledgeable of the structure.

sampling—identifying and removing materials or components from the structure for the purpose of conducting laboratory tests to determine material or structural properties or to further quantify physical condition.

structure—the building, components of a building, or other structural system; considered to be concrete unless otherwise noted.

testing—quantifying material or physical properties of the structure through the use of testing procedures and calibrated equipment, either in the field or laboratory. Testing may be nondestructive or destructive; destructive testing often requires follow-up repair.

Purpose and scope

The purpose is to provide a source of information on the evaluation of concrete structures (except those subjected to seismic effects) prior to rehabilitation. This is of particular importance since there is a substantial difference between the complexity of rehabilitation design, as compared with the design of a newstructure. Evaluation of specialty structure types such as bridges, dams, and tunnels are considered beyond the scope of this report, though the concepts are similar.

Preliminary and detailed investigation

The goals of the preliminary investigation are to provide initial information regarding the condition of the structure, the type and seriousness of the problems affecting it, the feasibility of performing the intended rehabilitation, and information on the need for a detailed investigation.

Investigation: overview

Preliminary and detailed investigations often contain varying levels of some or all of the following items:

1. Document review;
2. Field investigation;
3. Sampling and material testing;
4. Evaluation

preliminary investigation

The preliminary investigation develops an initial assessment of the concrete structure's behavior, condition, and existing performance based on an established objective or reason for performing the rehabilitation. A preliminary investigation may be sufficient when the proposed usage changes involve the same or similar loadings, where extensive documentation on the construction and maintenance of a structure exist. The preliminary investigation may determine that it is undesirable to proceed with a further detailed investigation, as in the case economically restored or where it becomes obvious that the owner's objectives cannot be satisfactorily met.

A preliminary investigation is not intended to be a comprehensive study. Preliminary investigations are general in nature, and may not be comprehensive enough to achieve the established objective. Preliminary investigations commonly recommend the need for a detailed investigation to more thoroughly evaluate concrete structure.

Detailed investigation

A detailed investigation is performed when the initial site visit or preliminary investigation has identified a need for a more in-depth assessment of the concrete structure's behavior or condition to meet the owner's goals for the work and rehabilitation objectives.

Document review

Intensive effort should be made to locate, obtain, and review the pertinent documents relating to the structure. Thorough review of the available documentation will save both time and cost for any evaluation and follow up rehabilitation project.

Field investigation

An investigation generally documents the nature and extent of observed conditions and identifies any problems and the related components or elements. If structural problems, should use experienced structural engineers for the further investigation an evaluation. Field notes, photographic records, and videos are valuable aids in classifying and communicating information on the conditions and problems observed in the field. When serious distress or deficiencies are discovered that may result in unsafe or potentially hazardous conditions, the owner should be notified immediately. In such a case, temporary evacuation, temporary shoring measures, or other emergency safety measures should be recommended to the owner. Subsequent monitoring of movements, cracks, and progressive distress may be needed. Even with complete documentation and construction information, field observation is required to verify reliability and accuracy of these documents. Field observation should not only address the as-built geometry and materials of construction, and the loads to which it is subjected.

Sampling and material testing

In addition to field observation, it may be necessary to employ nondestructive tests (this subject will be discussed later) on components of the structure or in-place materials to investigate the condition and strength or to take samples for laboratory tests.

-Nondestructive *testing*-Limited nondestructivetesting can supplement observations and measurements.

-*Exploratory removal*-Exploratory removal is used when there is substantial evidence of serious deterioration or distress, when hidden defects are suspected, or when there is insufficient information.

-*Sampling testing, and analysis***-**sampling andtesting are not usually performed during the preliminaryinvestigation. When performed, sampling generally consists

of extracting cores or small specimens, or collectingother readily obtainable samples for compressive strengthtesting.

Evaluation

The results of the preliminary investigation should be summarized in a report that will generally include structural capacity check, project feasibility, identification of structural problems, strengthening requirements, and needs for further investigation.

-*Structural capacity check*-The structural capacity check generally produces one of three results:

(1) The structure or individual members are adequate for the intended

use; (2) The structure or individual members are adequate for the existing loads but may not be adequate for intended use; (3) The analysis may be inconclusive. Depending on the results, the adequacy of the structure must be established. It may also be necessary to propose immediate action to deal with a condition affecting the safety or stability of the structure.

-*Project feasibility*-An assessment based on technical and cost considerations should indicate whether a proposed rehabilitation is feasible. Points that should beconsidered in reaching a conclusion regarding project feasibility include the expected effectiveness of the rehabilitation and its estimated life-cycle cost. The effects of the rehabilitation on the structural system and the anticipated impact on the operation of the structure should also be considered.

-*Structural problems*-when structural problems are identified, they should be described in terms of their seriousness and extent. Steps should be taken to verify
the significance of the structural problems discovered and to determine whether or not corrective action is required to remedy the existing conditions or to protect the existing
structural system. It is not unusual to encounter problems that require immediate action to mitigate deficiencies.

-*Strengthening requirements*-Actions taken to strengthen existingstructures must take into consideration the operation ofthe structure both in terms of current and possible futureuse. The investigation should also consider the costeffectiveness of repairing, replacing, or strengthening theexisting structural members.

-*Further investigation*-The need for a furtherdetailed investigation should be identified.

DOCUMENT REVIEW

-Design information

Nonhistoric structures—Documents that may contain useful information include:

(a) Design drawings, specifications, addenda, and calculations.

(b) Shop drawings.

(c) Placing drawings of concrete reinforcement.

(d) Alteration plans, addenda, submittals, and change orders.

(e) As-built drawings, photographs, job field records, test data, and correspondence.

(f) Applicable building code(s) at the time of original design.

(g) Manufacturer's technical information, descriptions of construction materials, patents, and test data.

(h) Textbooks written at the time of design.
(i) Previous maintenance, inspection, and repair reports; and
(j) Design and applicable age-appropriate building codes.

Historic structures—Buildings may be designated as historic structures on multiple levels—federal, state, or local—with each entity establishing their own restrictions on the extent of required preservation and rehabilitation. Often, rigid rules need to be carefully studied and followed.

- **Materials information**

- **Construction information**

- **Service history**

- **Project documents**

FIELD INVESTIGATION

1. Preparation and planning: conditions, maintenance concerns, schedule and scope of the survey, access to the facility, impact of the observation and survey on the structure as well as the users of the facility, and the expectations of the owner
2. Verification of as-built construction: Geometry and structural materials—Spans and cross sections of the structural components and elements.
3. Condition survey of the structure: The condition of a structure should be surveyed without prejudging the cause and type of any deterioration identified.
    (a) Measure and record crack width, depth, length, location, and type (that is, whether structural or nonstructural). Structural cracks should be further identified as flexure, shear, or direct tension, if known. Crack patterns should be plotted and a determination of whether the crack is actively moving or dormant should be made.
    Refer to ACI 224R, 224.1R, and 224.2R for further information.
    (b) Surface defects such as spalling or delamination due to distress or corrosion of embedded reinforcing steel, scaling, honeycombing, and efflorescence.
    (c) Corrosion of reinforcement, including the extent and amount of reduced cross section.

(d) Loose, corroded, or otherwise defective connectors for precast concrete elements, or ties to architectural elements or cladding.
(e) Permanent or transient deformations, out-of-plumb columns, and other misalignments. Continuous monitoring may be appropriate.
(f) Signs of foundation settlement or heave and related distress.
(g) Water problems, such as leakage and areas of poor drainage or ponding.
(h) Evidence of physical or chemical deterioration due to chemical or environmental attack.
(i) Erosion of concrete matrix (washing out of cement and fine aggregate); and
(j) Other concrete material problems, such as, alkali-aggregate reaction or scaling.

- Visible deterioration
- Visible deviations and deformations
- Foundation settlement

Unsafe or potentially hazardous conditions

When conditions that appear to be unsafe or potentially hazardous are discovered at any point during the field investigation, the owner should be immediately notified.

SAMPLING AND MATERIAL TESTING

- **Determination of testing requirements**

The selection of the suitable test methods and the number of tests and their locations will depend on:

1. Variation in material properties within the structure.
2. Variations in exposure, loading, and use.
3. Critical locations, such as connections and lateral loadtransfer Points.
4. Probable error in a test result.
5. Extent of the structure over which a property is measured.

- **Testing and evaluation**

a. Evaluation procedures for concrete , *Core sampling*, Sampling of concrete with sawed beams, Random sampling of broken concrete,
b. Evaluation procedures for steel reinforcement

Samples of steel reinforcement can be tested to determine its physical or chemical properties. The characteristics, selection, and preparation of samples are discussed in ASTM A 370. Some general considerations related to nonprestressed reinforcement are:

1. Specimens should be removed at locations of minimum stress in the reinforcement. Not more than one specimen should be removed from the same cross section of a structural component or element.

2. Specimen locations should be separated by at least the development length of the reinforcement to avoid excessive weakening of the component.

3. For structural elements having a span of less than 25 ft (7.5 m) or a loaded area of less than 625 ft2 (60 m2), at least one specimen should be taken from the main longitudinal reinforcement (not stirrups or ties) (ACI 437R).

4. For longer spans or larger areas, more specimens should be taken from locations well distributed through the portion being investigated to determine whether or not the same strength of steel was used throughout the structure.

5. Information from grade marks and mill marks from reinforcing bars should be collected when possible and used as appropriate in guiding sample collection.

6. Newer nonprestressed reinforcing steel typically exhibits low variability in material properties across a structure. As a result, less sampling may be needed to gain reasonable confidence in in-place mechanical properties. For older structures, where smooth, square, or iron-based reinforcement was used, additional sampling may be needed; and

7. The minimum gauge length for testing mechanical properties should be in accordance with ASTM A 370. Shorter samples may still be useful. Coupons for testing may be obtained from samples even 4 in. (100 mm) in length, which will provide some information on physical properties.

EVALUATION

Dimensions and geometry, Materials evaluation, Structural evaluation, Cost evaluation and Evaluation of rehabilitation alternatives

Design Criteria and their Effect on Building Defects and Maintenance

When there is a need to construct a project, all the involved sides start working and coordination to fulfill the task in the best possible way. This is to insure the following:

- Good looking.
- Strength.
- Durability.
- Efficiency in use.
- Maintenance needs.
- Least cost.

They aim to put measures to be applied in design and execution processes so as to take the following in consideration:

- Expected defects and deteriorations.
- Construction monitoring and periodical maintenance.

The above mentioned points affect the cost, likewise during construction period and during the use of construction.

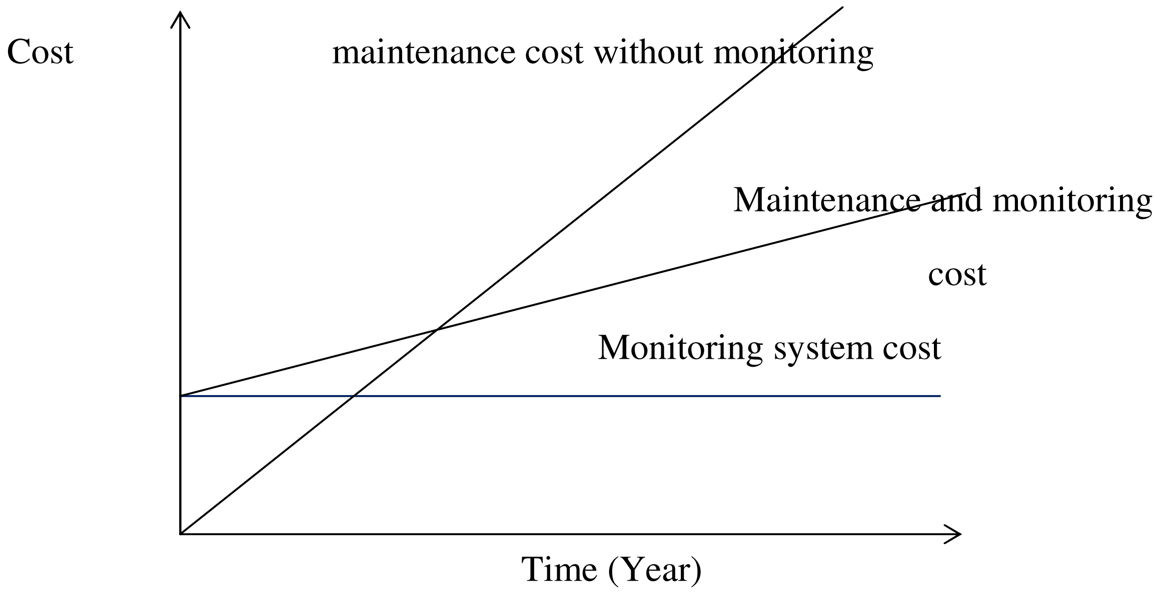
Aiming to use the construction for the longest possible time with least periodical maintenance cost, three weeks will be devoted to discuss the following:

- Importance of design criteria.
- Design criteria effect on defects and maintenance.
- Design criteria effect on construction efficiency and its useful life.

The periodical maintenance and monitoring system effect on the cost:

With regard to building construction and use, the common mistake now is that there is no monitoring system for the building during use. Besides, no thinking in maintenance needs during design or execution processes. This affects the cost remarkably.

It's wrong to postponed defects maintenance after they take place. The problem will escalate. And this leads to increase maintenance cost. In other words, building cost increases with time. The following Fig. represents the relationship between cost and time with and without periodical monitoring system.



2nd lecture/ (3)

Defects Reasons in Buildings:

There are many reasons cause some defects in buildings, among which are:

1. Design.

2. Specifications

3. Materials.

4. Site & Construction.

5. Use.

From what above mentioned there are many probabilities may lead to defects in any specific structure, and to limit or at least to reduce those defects to prolong the structure life and to reduce its periodical maintenance cost, maintenance issue must be taken in consideration in all stages of the structure starting from choosing the site and the design until the way of using the building in the right way. This will be discussed in details later.

<u>Designs criteria and their effect on defects:</u>

The essential goal in all structures from the beginning and when the idea comes out even before making the needed designs is to construct an integrating building in which is as less defects as possible and is to be employed for the longest possible time and by the least possible maintenance cost.

To achieve this goal, a cooperation and coordination between many sides must be done in each of the project stages in a way that assures the fulfillment all the necessities to complete the task successfully.

Design stage is one the stages which should be taken in consideration to avoid the defects that take place due to design reasons and the design teams have to think about the maintenance and future defects treatment and put them in the design philosophy and never neglect this matter, while concentrate on good appearance only. The durability, use efficiency and total cost are important and must be taken in consideration for all buildings.

The good design must include the following criteria:

First: the parties who have essential role in design stage:

1. The owner………..

2. The designers…….

3. The executers……..

4. The monitoring and maintenance team…..

Second: the design at least must cover the following:

1. A good looking and suitable building……..

2. Suitable materials according to the specifications are to be used……

3. The construction must be guaranteed by quality control in accordance with needed specifications.

4. The design must not ignore any of the necessary services and utilities…..

5. The assurance of that the building is to be used for the purpose for which it is constructed.

Third: Cost & Useful life:

The building cost and useful life subject is an important matter, and the four parties (the designer, the executer, the owner and the maintenance team) have to have their decision towards it. The cost and useful life affect the following:

1. The materials which will be used and how much will they match the specifications.

2. Choosing the suitable finishing materials……

3. Providing other essential services in the building such as foundation protection, sewage and water supply works, electrical work, air conditioning and etc.

4. Choosing the suitable fittings and accessories …….

Fourth: the designer experience in building maintenance that the lack in experience in this subject leads to ignore some important things in this issue.

Fifth: the designer responsibility:

The common concept nowadays is that the designer responsibility ends with delivering the designs and drawings; this is wrong concept…….that the designer must stay responsible as long as the building is in use and a defect due to the design takes place.

Sixth: Making use of materials in the right way according to producer instructions and material's special specifications that ignoring this matter will affect the durability adversely….i.e. (the material which is to be used indoor must not be used outdoor).

Seventh: The bad design may lead to many defects in the structure which affect the total structure cost due to renovation cost.

Eighth: the designer has to take in his consideration the defects which may probably take place as well as he has to think about the maintenance needs during designing process, not to ignore this matter until it happens.

Ninth: when design any of the building parts; the good designer has to have answers to the following questions:

1. How to reach that part?

2. How to clean it?

3. How long is its useful life?

4. How to substitute it?

Tenth: the designer has to have enough detailed information about the durability effective factors in order to take them in his consideration during choosing between materials and protections alternatives. Example of these factors:

1. Water table.

2. The moisture.

3. Chlorides and other chemicals.

4. The temperature fluctuation.

5. Steel reinforcement corrosion.

6. Insects, bacteria and other organic materials and their effect on different building materials.

7. Other atmospheric conditions .

8. The expected natural disaster.

9. All environmental pollution types.

Eleventh: the designer has to know all the new materials and he has to be sure of these materials compatibility and suitability to be used in the proper place. This affects the building durability and how much this building will need a future maintenance.

Twelfth: Some changes may take place after or during construction period, the designers must know that. For example the offshore buildings expose to water currents and tide and high buildings expose to air currents or what belongs to environment pollution in the industrial structures and others.

Thirteenth: thermal and acoustic insulation must not be ignored and measures must be taken for heating, cooling and ventilation and other essential services.

Fourteenth: Site must be investigated thoroughly; trees, obstacles and old embedded services systems….etc.

Fifteenth: the designer must know the structure site surrounding buildings and their foundations and the site nearby available services.

……………………………………………………….

<u>The Effect of Dimensions Standardization on Defects Treatment:</u>

Generally each of structural materials especially finishing materials and fittings has its life cycle according to its type and the way it is used. For this reason the companies produce standard dimension materials.

A good design must deal by high accuracy with this matter that it has a significant effect on the maintenance in the future. The designer must take the materials standard dimensions in his consideration during design process, this will participate in simplifying the materials getting process in future to substitute them in maintenance work and defects’ treatment.

The interest in standardize the dimensions and the use of the available materials will undoubtedly; effect the inhabitation cost in the building and on maintenance simplicity and cost.

There are many examples of the standard dimension, such as:

Doors…..(all types).

Windows.

Bricks.

Tiles.

Ceramic tiles.

Marble…

Stairs.

False ceiling

Pipes (all different pipes).

Electrical fittings.

Sanitary fittings.

Mechanical fittings.

Plates.

reservoirs

furniture.

Plates and decoration.

Later, examples will be discussed.

………………………………………………………………………….

The construction materials used for defects treatment   Lec.No.4

The structural materials highly affect the structure's strength and durability and life cycle. There is a high percentage of defects due to structural materials. On this base, the engineer must have a good knowledge about common structural materials used in construction as well as the new materials in order to be able to choose the proper materials in both construction and repair and avoid future defects as well.

Structural materials are given to the student by many courses. In this course the focus will be on the measures which are to be followed by the engineer to use suitable materials for a specific construction.

Concrete

Huge quantity of concrete is used in construction sector in Iraq for the advantages it has and the availability of its raw materials. Concrete is a mix of cement, aggregate and water and sometimes with admixtures. Good materials (according to specifications) must be used to insure high quality concrete with regard to strength and durability, as well as high efforts must be given to all concrete producing process such as handling, compaction, finishing and curing….etc.

The following is a brief to what must be known about different concrete work materials and processes.

A. Cement: cement plays large role in concrete properties. The reliable specifications must be known, among which, Iraqi specifications No. 5, 1894. The most important things which must be known about cement are:

Type.

Initial and Final Setting Time.

Fineness.

Main compound.

Miner compounds, such as phosphates, alkalis and magnesia…

Soundness.

Insoluble residue.

Loss on ignition.

Compressive strength.

The specifications mention the allowable limits for each of the above properties to insure using high quality cement. For many reasons, in maintenance and defects treatment, the same old concrete cement type is used.

B. fine and coarse aggregate:

Aggregate represents 75% of concrete, so it has significant role on concrete properties, for this, the engineer must know the sampling and check the aggregate according to Iraqi specifications No.45, 1984. The things must be known are:

Source and mineral composition…

Type….

Grading and fine materials percent.

Maximum aggregate size.

Sulfate content.

Absorption.

Bulk density and specific gravity.

Organic and other materials percent.

C. water: it is used to produce fresh concrete and to cure hardened concrete. Water must not contain mud or salts or acids or any other chemicals. There are tests to check water but generally, there are no dangerous problems with regard to water in Iraq.

D. Admixtures: there are many admixtures used to add a specific desired properties while concrete is fresh or hardened. The common admixtures are:

Accelerators.

Retarders.

Plasticizers.

Superplasticizers.

Air entrained admixtures.

Water expelled admixtures.

Color admixture.

Fine mineral admixtures, such as pozzolana and silica.

British and American specifications (B.S 5075, ASTM C494) can be reliable to check out the admixture quality. Generally, an engineer has to know :

Admixture type, how does it work, the quantity to be used, how to use it, the side effects, suitability, cost and the future treatment….etc. it is preferable to make tests mixes to be sure of the concrete properties with admixtures.

E. Mix proportion: It affects highly the produced concrete properties. Mix proportion is decided to produce a concrete (fresh and hardened) with specific properties by using the available materials. British or American method is often used to design the concrete mixtures, during design the following things must be known:

The lower and upper water content limit.

The upper w/C ratio limit.

The required compressive strength.

The required workability (slump).

The used aggregate properties.

Cement type.

The admixture type (if existed).

Trial mixes are often required.

F. Concrete handling and compaction: there are many ways to convey, cast and compact the concrete. And in order to avoid any defect, the following things must be assured:

Homogeneous mixture.

Concrete must be cast in its place within the first hour .

Segregation must be avoided.

Bleeding must be avoided.

Good compaction in order to have the highest possible density with minimum porosity and permeability.

Good finishing and leveling.

Concrete must be workable enough to fill the form.

G. curing of concrete: there are many methods of curing, among which traditional and new methods. The curing purpose is to keep the concrete moist and prevent mixing water from evaporation to provide suitable conditions for cement hydration (reaction between cement and water) and strength gaining. Good curing participates in preventing plastic shrinkage cracks which affect the concrete strength and durability.

Among the common curing methods is continuous water spreading starting from solidification till seven days or put water on the concrete surface as it is done for slabs or steam curing in the precast industries, or making elastic membrane by using chemicals to prevent water evaporation from concrete.

……………………………………………………………………………………

Steel Reinforcement Lec.No.5

It is used in reinforced concrete structural parts to enhance the concrete to resist tensile stresses. On this base, an engineer has to know steel properties and the required measures to protect it against corrosion and other damages.

The followings should be known:

- Steel properties especially, Ultimate strength and Yield strength (Grade 40,50 or 60).
- Steel types:
  Reinforcing Bar.

  Wire.

  Prestress Bar.

Prestress wire.

PresstressSrand.

It is important to know the stress strain relationship and the measures to protect the steel against corrosion (concrete cover and painting).

The molds:

Molds have significant role during construction. The molds are used to support the concrete safely without deformation or seepage till the concrete solidifies and gains the required strength.

The following should be checked in mold work:

Mold design.

Proper side and vertical supports.

Leveling.

The thickness for concrete cover.

Molds parts must be well connected to each other.

Make the openings according to drawings.

Mold removal timing.

Walls building materials:

Walls building materials are so important especially, clay bricks. In order to avoid the probable defects, materials quality must be checked as well as building process. Accordingly, concentration must be on the following:

- The use purpose (partition or bearing wall).
- Dimensions and appearance.
- Strength.
- Absorption, toughness, fluorescence, salt content.
- Density of light weight blocks.
- Voids and openings.

Checking bonding type, wall thickness, mortar thickness, mortar strength, joints, straightness, perpendicularity, wall curing …..

Tiles, marbles and roofing concrete tiles:

Floor and roofing finishing works are so important and they represent high cost percent, important work precedes tiling. However, the measures in materials choosing:

Appearance, planeness, cracks and homogeneity.

Total thickness, mosaic thickness and color.

Type and reliable specifications.

Strength.

Absorption.

Salts.

Checking succeeding work.

Doors and Windows:

this is also important work. The cost varies from low to high that there are a lot of types in markets. Good work needs to know the following:

Type.

Section, frame and specifications.

Dimensions.

Bolts, hinges, handles ….etc.

Glass.

Painting.

Installation.

Service systems:

sanitary systems, sewerage system, water supply system ….execute according to drawings…(sewers, pipes, manholes, how to make inspection and substitution).

Water system…everything belongs to connection, storage and supply.

Electrical system…. everything belongs to electrical fittings and services.

Mechanical and air conditioning system….

Other building works

Building materials subject is so wide range one. And the above mentioned is just a brief. All building materials must be taken in consideration as plastering, false ceilings, painting….etc. each of them has its specification and life cycle.

……………………………………………………………………………

Foundation Defects and Solution. Lec.No.6

Foundations have great importance in constructions, that if defects appear in foundation, the results will be reflected on the whole construction. For this, special attention must be given to ensure high quality and durable foundations.

Site condition:

Site condition must be studied thoroughly before foundation design. What must be studied are:

Are there signs of defects in the neighbor buildings?

Are there special foundation type used in nearby buildings?

Are there signs of soil sliding….soil sliding may take place in sites with inclination more than 1: 1.5? The case may appear as wide parallel cracks and obvious soil failure.

Are there signs of that the soil is fill or transported from other sites or the site contains debris….etc?

Is the site soil stable during summer and winter?

Are there large and high trees in the site?

Are there signs that float from the nearby rivers come over the site or earthquake …etc?

What was the site used for?

Is there probability pollution in the site?

Is the site in oil well area or coal mine area……..etc.

Is there an old construction in the site? Will the demolition affects the nearby construction(s)?

Are there signs of old service system(s) embedded in the site?

Soil Investigation

The defects belong to soil maybe due to poor or insufficient study to the site nature and the surrounding conditions. These defects maybe due to improper foundation type with regard to transmitted forces or soil properties or foundation level.

After studying the site as mentioned earlier , the specialists are asked to make soil investigation report, accordingly, the following will be known:

1. Bearing Capacity: the soil failure under foundation due to stresses more than what the soil can resist.

2. Water table level that the variation and fluctuation of water table level due to nearby rivers or irrigation or seepage from services systems, the nearby trees also may cause defects in structures.

3. Soil nature with depth, is it sandy? Clayey? Or mix of them? Or rocky…..?

4. The particles size, this affects the water expelling rate which leads to settlement, then the soil strata will be compressed under building weight. For this, total or differential settlement by more than the allowable limit takes place.

5. In report, there are recommendations about the suitable foundation for the site soil and structure loads.

6. The expected settlement is also included in the report.

All the above mentioned information enable the designer to choose the suitable foundation and the report will be a guide for the executive engineer to avoid soil obstacles (if there is any) during execution.

Common Foundation Problems or Defects

The defects in structure may result from one reason or more. Among these reasons are the soil and the foundation. And among these defects which take place in all foundations' types:

1. The foundation differential movement due to loads. This often happens in shallow foundations such as strip foundation, isolated foundation, and combined foundation.

The loads compress the soil and according to this compression and soil properties settlement will take place proportionally with time, this settlement may keep on for 20 years, but the 1st five years often be the crucial period in determining the maximum settlement occurs due to loads.

The difference of loads on columns or bearing walls leads to differential settlement and this leads in all cases to additional stresses on the structure which lead to serious problems. These problems need to be treated.

Movements Resulting from other Causes

This movement may happen due to seasonal climate fluctuation which the soil displays to, or trees demolition or new trees planting. This problem depends directly on soil type, especially on particles sizes and their fineness degree which can be classified as:

A. Clay soils: as long as clay soil shrinks by drying and swells by moistening, this affects the shallow foundations.

The shrinkage in clayey soil is measured in summer with trees existence which absorbs the water from about 5 meters depth…..the shrinkage reaches 100 mm (very high shrinkage whichnegatively affects the structure).

The highest effect will be on foundation corners and edges.

The foundation must be far from the huge trees by a distance at least equal to the tree height if there is one tree but the distance must be equal 1.5 times the tree height if there is a group of trees.

When removing trees from clayey soil, sometime is to be given to the soil to let it takes its final shape then work can be started.

Generally, shrinkage of clayey soil under foundation may cause foundation deviation as a result of differential settlement or fractured foundation due to heterogeneous support under foundation.

………………………………………………………………………………

Lec.No.7

B. Sandy soil: the dense sandy soil is very good base for foundation but the water table which takes the fine particles will make it unstable soil. Besides, freezing water in soil pores leads to increase volume, this may takes place from surface to 600mm depth and causes lifting pressure which affects soil surface, foundation, floors and corridors….etc. this phenomenon called Frost Heave.

C. Organic Soil: the soil which contains organic materials such as decayed plants roots and other organic materials. This soil type distinguished by volumetric changes due to moisture content as well as it is a compressible soil. These characteristics negatively reflected on foundation stability and its durability.

The building of constructions on such soil is very dangerous and generally, affects the construction stability. Moreover, any repair does not mean getting rid of the problem that the damages may take place again because the differential movement for such construction cannot be calculated or estimated.

D. Fill or Make up Ground:

The fill soilhighly affects the foundation as it is mentioned in paragraph (C), unless the soil is well chosen and compacted in layers.

There are a lot of low lands filled up with debris and industrial residue or used up materials such as vehicles tires, metals, different types of containers or trash and so on, this leads to differential foundation settlement or cause damage to foundation.

Design of Foundations

Foundation design depends on many factors. And there are many foundations types, the foundation type is chosen according to loads and soil characteristics. Anyway, each foundation has dimensions and depth under natural ground level.

Foundation depth depends on;

1. How to reach a suitable bearing capacity.

2. The depth is to be suitable especially in clayey soil to avoid volumetric changes due to drying and wetting.

3. With regard to sandy soil, the depth must be far enough so as not to be affected by freezing to get rid of uplifting forces caused by freezing.

The failure may be resulted from unsuitable dimensions or reinforcement or depth.

Concrete in Foundations

Foundation concrete is affected by many factors, among which:

1. Cement type. 2. Aggregate type and characteristics. 3. Water content and mix proportion. 4. Mixing, handling, finishing, compacting and curing.

The produced concrete strength must be higher than the design strength.

Cement content must not be less than 300kg/m^3 and the strength at 28 days must not be less than 25MPa and w/c must be between 0.4 and 0.6.

Concrete type may cause early failure in foundation as well as the unsuitable dimensions especially the thickness may cause foundation failure.

Foundation Execution

There are many foundation defects caused by execution reasons in situ. Accordingly, execution must be with high accuracy in order to reduce these defects, this is done by the following measures;

1. Site leveling and cleaning till reaching the natural ground level.

2. Foundation layout on the ground according to drawings.

3. Excavation:

    - Accurate dimensions (length, width and thickness).
    - Ensure no damage is to be happened to the neighbor buildings.
    - Ensure the excavation straightness and perpendicularity.
    - The excavated soil must be away from the excavation not to fall down during work.
    - Ensure the excavation level and plainness.
    - Side support is to be used if there is a need for it.
    - Ensure accurate water table pumping.

4. Excavation bed must be well compacted and sub base layer must be used.

5. Broken bricks layer is used and or concrete layer of 10 cm with applying a water proofing cover.

6. Fixing steel reinforcement:

- According to drawings.
- Steel must be clean(no corrosion, mud or oil) so as to ensure good bonding.
- Ensure the concrete cover (this is very important).

7. Casting:

a. ensure homogeneous mixture and avoid extra water(to simplify the work) or reducing cement quantity (to reduce the cost).

b. Concrete segregation must be avoided and no mud is to be with concrete.

c. Concrete must be well compacted so as to expel the air and reduce voids as much as possible. Concrete must flow and surround steel reinforcement; special care must be given to the dense reinforcement places.

d. Measures must be taken in rain, hot or cold weather in order to ensure suitable circumstances during concrete casting process.

8. Ensure sufficient curing by water or other means.

9. Ready mix is to be used to have large quantity in short time.

The foundation concrete failure takes place as a result of either the concrete is weak, heterogeneous mixture or unsuitable concrete materials.

Settlement of Buildings

The buildings settle for many reasons:

- Inadequate or improper chosen foundation (foundation type, dimensions, reinforcement, concrete, execution…..etc.).
- Low bearing capacity.
- Soil shrinkage (in case of clayey soil drying).
- Huge trees nearby the buildings cause settlement at the end of summer season.
- Huge excavation nearby the buildings leads to settlement later.

- Settlement can be known from crack; especially those nearby the openings in the walls such as doors, windows and arches. It can be noticeable that the use of doors and windows is somehow hard, especially at the end of summer and the start of winter.

…………………………………………………………………………

The treatment or repair of settled foundationsLec.No.8

Foundation treatment andrepair is a difficult, complex and costly process in most cases and each case needs special treatment according to its conditions.

The defect in foundation must be repaired quickly so as to avoid damages accumulation.

There are many defects in foundations result of different reasons. Here, twomethods will be discussed which enhance:

- Strengthen the foundation for additional loads or to improve it.
- Settlement stoppage.
- Stoppage of wall cracks resulted from differential settlement.

First:

Underpinning of Foundation and Settlement

The damages in buildings walls resulted from differential settlement need radical reclamation by construct new foundation under the old foundation to support it. This is done by consecutive steps but with care not to cause any damage or failure to the building. Mostly, the reclamation is to the outer foundation according to the following steps:

1. Cleaning the area under repair.

2. Removing the live load as much as possible to reduce the load over the foundation under repair.

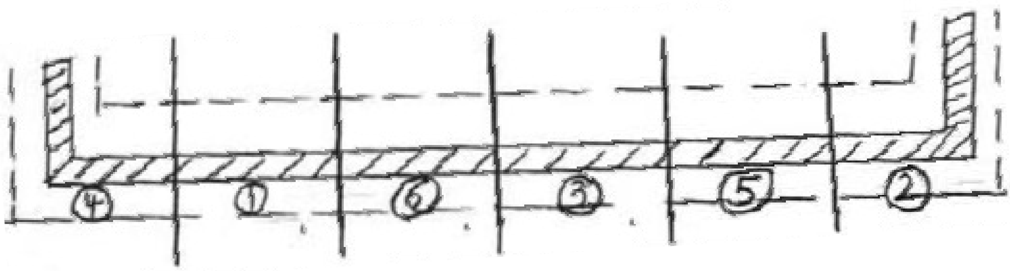
3. The walls and slabs over the foundation are to be supported by:

   - Vertical shores (for slabs).
   - Raking shores (for walls).
   - Flying shores (for walls).

4. After that, openings of suitable depth and width are to be excavated under and beside the foundation so as to simplify the casting of the new foundation. With regard to this point, the following must be taken in consideration:

a. The excavation under the foundation must be in parts, each part length must be within (1m to 1.5m) so as to ensure the old foundation safety or the distance must not exceed(1/4) times the length of the normal loaded bearing walls or (1/2) times the length of heavy loaded bearing walls.

b. The openings are to be excavated consecutively in a manner shown below so as each opening is being far from the other one:



c. The excavation of any part is never to be started unless the previous part is completely supported and as well as the old and new foundations are supported.

d. The excavation depth or width reaches the damaged soil and it often exceeds 90cm.

e. the excavation sides are to be vertical and well supported as well as the bottom must be leveled.

5. The supporting foundation must be casted according to designed dimensions as well as the steel reinforcement:

a. Ensure the needed foundation thickness and the reinforcement must be bent so as to ensure good bond with the other following parts.

6. Ensure good bond in brick work and in foundation reinforcement between all parts so as at last all parts will act as one part.

–

7. The process goes ahead till the end. Then, the temporary support is to be removed and wall exterior damages caused by foundation deterioration are to be treated. After that, the building is to be used in normal manner.

Second: Simple treatment to limit the deterioration:

The supporting method may be too expensive in specific cases (much damages and the depths are 5m or more, this may take place due to huge trees). In such cases, the building is to be surrounded byframe of pre-cast concrete slab (apron) with width of 1.5m, and then the building is to be left for a whole winter season. Then the cracks are to be repaired. This method ensure a protection to stop the fast deterioration in the building by suitable cost. The growing trees are to be removed, and then the repair is after one season.

It is worthy to be mentioned that there are complex cases out of this lesson scope.

……………………………………………………………..

Cracks in Concrete Structures: Methods of Repair.Lec.No.9

Introduction:

Cracks are so important to be studied for they cause damages to buildings and concrete structures. They are defects commonly appear in both reinforced and plain concrete structures especially in our country that most of our constructions are concrete structures.

For this, cracks reasons and the methods to repair them are to be studied to maintain buildings safety and insure long life and durability. Cracks may be different according to their types, shapes, their causes and how to find the suitable way to repair each of them, in addition to suggest the suitable materials to repair those cracks.

Cracks types:

Generally, there are two cracks types and there are many reasons cause each of them. They are:

1. Structural cracks.

2. Nonstructural cracks.

1.Structural cracks:

The cracks which take place in reinforced structural members, such as foundations, columns or beams …etc. they often dangerous and need rapid treatment.

2. Nonstructural cracks:

The cracks which take place for other reasons not those of structural cracks. They often not dangerous in the beginning and do not harm the structure but when ignore them, they are changed into dangerous cracks and their effect may accumulate to be dangerous structural cracks.

Cracks classification according to their nature:

Generally, cracks can be classified to:

a. Moving cracks: the cracks which their lengths, widths and/or depths are increased. They are the most dangerous and high experience and studies are needed to repair them.

b. The constant cracks: the cracks which if the cause is removed, they stay constant in lengths and widths. They are less dangerous than the 1st type and can be repaired easily.

c. Fresh concrete cracks: they often take place during casting process that hair cracks appear on concrete surface after some minutes of concrete finishing process.

d. Hardened concrete cracks: These cracks take place in hardened concrete due to drying shrinkage, chemical factors, oxidation, sulfate attack, freezing and concrete differential settlement effects.

Cracks diagnosis and monitoring: to know the reason of any crack and to suggest the best way to repair it, the engineer has to watch and study the crack as follow:

- Crack place.
- Crack direction.
- Crack path.
- Crack length, width and depth.
- The crack is deep or not.
- The crack seasonal extending with time.
- Crack propagation degree.
- The way of crack propagation (arbitrarily or systematically).

- The distance between two cracks.

The causes of nonstructural cracks in concrete:

First: in fresh concrete

There are many reasons cause cracks for concrete (structural or nonstructural), the most are:

1. Cracks due construction movement, they are of two types

- Cracks take place when the soil goes down under the concrete in the period between placing and gaining enough strength. This soil falling dawn is due to either by moisture content changes or incomplete soil compaction. Theses cracks appear within some hours or some days after casting process.
- Cracks due to form movement, this movement in the concrete early age may cause cracks even if it is simple movement which often happens due to unsuitable form design, form wood saturation, pins looseness and too much concrete compaction. These cracks appear within the early hours of casting.

2. Cracks due to settlement shrinkage: they are classified into two branches

- Cracks around steel bars, they occur when the concrete upper part partially sets while aggregate particles still in sedimentation, this sedimentation causes water rise between aggregate particles and then reduction in volume and concrete falling down in all form area except steel bars places, this leads to vertical cracks parallel to steel bars. These cracks may weaken or cause to lose the bond between concrete and steel bars. These cracks often occur in deep beams and within the early hours of casting.

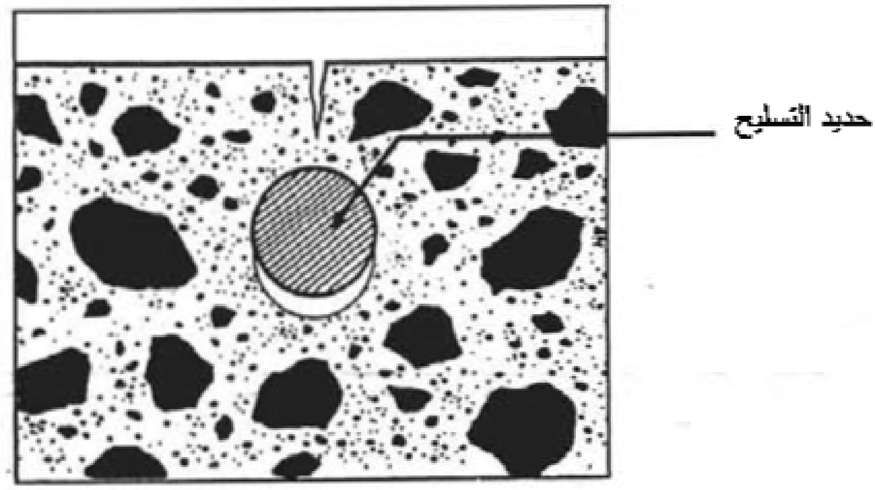


Fig (1)shows the sedimentation shrinkage around steel bars.

- Cracks around aggregate occur due to settlement shrinkage and the mechanism is similar to that of steel bars.

3. Cracks due to setting shrinkage: they are of two types

- Plastic shrinkage cracks, they occur when the evaporation from concrete surface is faster than bleeding (water rise to concrete surface. This happens due to high wind velocity, low relative humidity and high temperature. This leads to shrinkage in concrete surface more than that of the beneath concrete, tensile stresses in concrete surface and then (2–3) mm cracks appear in early hours.

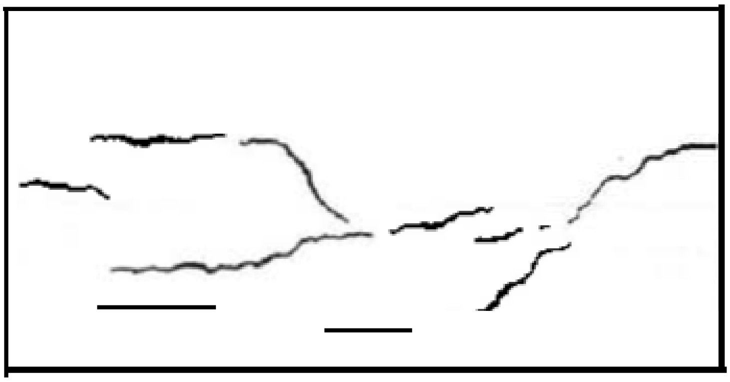


Fig .(2) shows plastic shrinkage cracks.

Lec.No.10

- Drying shrinkage cracks: these cracks are due to the evaporation of the water which is between concrete particles. This process lasts for a period of not less than two years and causes concrete contraction. The structural part is restraint by other structural parts and by steel bars, as well as the contraction difference between concrete surface and beneath surface concrete due to drying shrinkage is another reason of movement restraint that the surface is dryer than the beneath concrete, then the surface shrinkage is more than that of the concrete beneath the surface. This causes tensile stresses lead to surface cracks which may penetrate within time and be deeper when concrete is exposed to drying continuously. These cracks appear in some hours to some weeks.

Cracks may take place for other reasons such as slow concrete casting process, wrong compaction device use (more than needed compaction or compaction during solidification which leads to lose the bond between concrete and steel bars in addition to other negative effects, among which are cracks appearance).

The hardened concrete cracks:

There are many reasons for hardened concrete cracks, among which:

1. The late drying shrinkage cracks. The mechanism of these cracks is similar to that of drying shrinkage but they are deeper and appear after weeks or months.

2. Cracks due to chemical reasons such as the reaction of cement with carbon dioxide existed in the air (carbonation) or with aggregate particles or may be resulted from steel corrosion; accordingly, they can be classified as follow:

a. Carbonation: cracks result from chemical reaction between cement compounds and carbon dioxide from the atmosphere. They are so thin cracks and distributed irregularly on the concrete surface.

b. The aggregate alkali reaction: this type of cracks result from the reaction between active silica (non–crystalline silica which existed in some aggregate types) and cement alkalis, the result of this reaction is alkali silica gel which has the ability of unlimited swelling with the existence of external moisture, this leads to internal stresses and then cracks and concrete deterioration. These cracks are similar to carbonation cracks in appearance.

c. Oxidation cracks (corrosion): they are often caused by volume increment due to corrosion, corrosion products volume is as much as 2 or 3 time the original volume. Then, longitudinal cracks appear parallel to steel reinforcement. This type of cracks appears in a period of some months or years.

d. Salts attack cracks: the essential salts compounds are sulfates, chlorides and calcium or potassium or magnesium carbonate. Salts attack concrete through two ways; 1. External salts attack (soil and water contain salts). 2. Internal attack (salts in concrete constituents).

- External attack tacks place by:
    - Sulfate salts in soil react with aqueous calcium aluminate in concrete. This reaction causes swelling. In case of magnesiumsulfate, it attacks calcium hydroxide in cement paste.
    - Salt crystallization in the pores between cement and aggregate. This causes expansive forces which weaken the bonding between concrete and steel reinforcement, in addition to steel corrosion.

- Internal attack tacks place by the reaction between salt existed in concrete constituents and cement during setting or in the succeeding stages.

3. Thermal Cracks, there are four types:

A) Cracks due to cement hydration. Cement hydration is an exothermal reaction which emits heat, causes stresses during setting and solidification periods. The differentiation in temperature between concrete surface and inner concrete layers is the cracks cause. This differentiation increases when ambient temperature increases during casting days. Concrete surface cools faster than inside concrete. This increases the thermal differentiation and leads to tensile stresses in concrete surface. Those stresses may cause cracks in early days. Cracks depth does not exceed a few cms. However, these cracks are self–closed when the temperature inside concrete equals concrete surface temperature.

B) Cracks due to temperature fluctuation between day and night. In night time, concrete surface is colder than inside concrete, concrete surface shrinks more than the concrete beneath layers. This leads to stresses try to bend up concrete mass, concrete weight resists these stresses. This causes tensile stresses in upper concrete surface and compressive stresses in concrete lower surface. In day time the same mechanism takes place but in opposite direction.

C) Freezing cracks; when water inside concrete freezes before initial setting, no setting will be. When freezing happens after initial setting,the result is ice crystals. Ice crystals cause friable concrete due to water volume increment when freezes. Accordingly,concrete volume increases by 9%. When ice thaws, empty voids will be in concrete of volume equals to volume increment due to freezing. When water fills these voids and freezes, further volume increment takes place. This volume increment leads to tensile stresses, then concrete deterioration within time.

D) Cracks due to differential consolidation: the large temperature difference from zone to another in a same sectioncauses thermal stresses. As it is the case of casting large concrete mass. The outer layers may harden, while the inner concrete mass is still unhardened. This causes differential volumetric changes which lead to cracks.

Causes of Structural Cracks:

1. Design mistake such as:

- Reinforcement quantity calculations.
- Loads calculations.
- Soil bearing capacity (no laboratory results).

2. The structure is loaded by more than designed load. This is happened when the structures is used not for the purpose for which it is designed for, or when build additional story(s).

3. Constructional mistakes such as poor quality control (QA), wrong concrete mix proportions, poor compaction, leveling …etc. As well as, bad form work. In addition to poor execution, for example early loading before the structure has enough curing and strength.

4. Cracks due to wrong use. This happens when the structure is used for a purpose different from what it is designed for (such as the use of a residential building as a warehouse).Another case is making change in the building without asking the designer, for example, making openings in the slab for ventilation or installing air conditioning systems.

5. Cracks due to accidents happened to the concrete structure, such as fire, earthquake, impact and…etc. these accidents cause unexpected loads. So, they are not taken in design calculations.

6. Dangerous ignorance to repair the non-structural cracks which leads to change them into structural cracks.

7. The deterioration due to the accumulation of steel reinforcement corrosion.

Structural cracks types:

- Inclined shear cracks in beams and slabs.
- Horizontal structural elements deflection due to additional stresses associated with cracks perpendicular on the main reinforcement.
- Cracks parallel to the main reinforcement in columns due to extra loads.

Cracks effect on structure:

The effect can be known from:

1. Visual investigation in case of the crack is wide.

2. Nondestructive tests.

3. Core test.

4. Load test. The structure is loaded by designed load and observing whether the cracks width is increased or structural failure takes place. This test is carried out when there are doubts about reinforced concrete qualityand no believe I other tests.

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination.

Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. Non-destructive testing can be used in those situations as a preliminary to subsequent coring.

Typical situations where non-destructive testing may be useful are, as follows:

–Quality control of pre-cast units or construction *in situ*

–Removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance with specification

–Confirming or negating doubt concerning the workmanship involved in batching, mixing, placing, compacting or curing of concrete

–monitoring of strength development in relation to formwork removal, cessation of curing, prestressing, load application or similar purpose

–Location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure

–Determining the concrete uniformity, possibly preliminary to core cutting, load testing or other more expensive or disruptive tests

–Determining the position, quantity or condition of reinforcement

–Increasing the confidence level of a smaller number of destructive tests

–Determining the extent of concrete variability in order to help in the selection of sample locations representative of the quality to be assessed

–Confirming or locating suspected deterioration of concrete resulting from such factors as overloading, fatigue, external or internal chemical attack or change, fire, explosion, environmental effects

–Assessing the potential durability of the concrete

–Monitoring long term changes in concrete properties

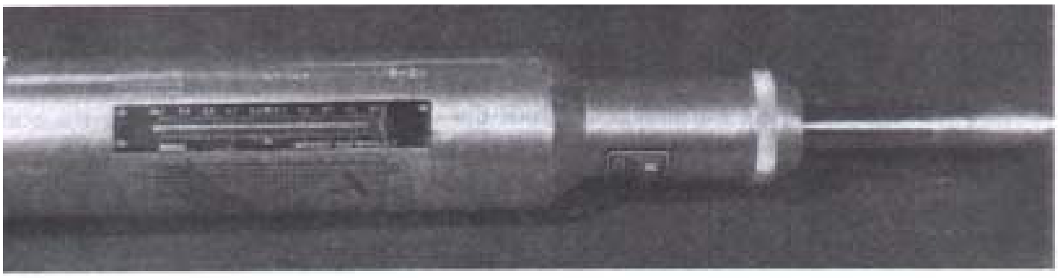
–Providing information for any proposed change of use of a structure for insurance or for change of ownership.

Basic methods for NDT of concrete structures

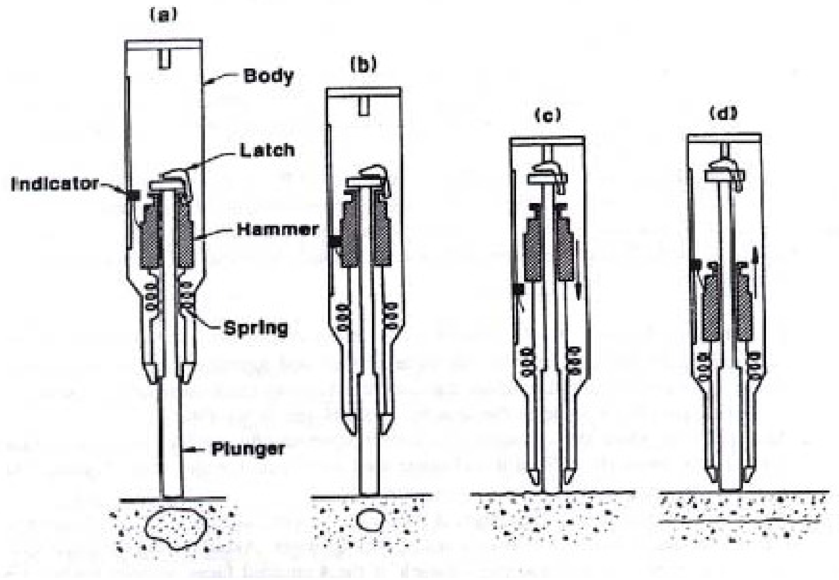
1–Visual inspection, which is an essential precursor to any intended non-destructive test. An experienced civil or structural engineer may be able to establish the possible cause(s) of damage to a concrete structure and hence identify which of the various NDT methods available could be most useful for any further investigation of the problem.

2–Schmidt/rebound hammer test, used to evaluate the surface hardness of concrete.

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. However, within limits, empirical correlations have been established between strength properties and the rebound number. The rebound distance is measured on an arbitrary scale marked from 10 to 100. (Below is the device picture)

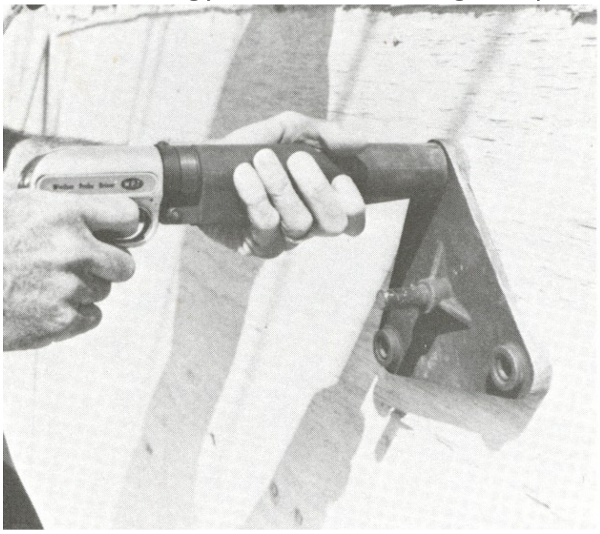


The method of using the hammer is explained using Figure below. With the hammer pushed hard against the concrete, the body is allowed to move away from the concrete until the latch connects the hammer mass to the plunger, Figure below (a). The plunger is then held perpendicular to the concrete surface and the body pushed towards the concrete, Figure below (b). This movement extends the spring holding the mass to the body. When the maximum extension of the spring is reached, the latch releases and the mass is pulled towards the surface by the spring, Figure below (c).The mass hits the shoulder of the plunger rod and rebounds because the rod is pushed hard against the concrete, Figure below (d). During rebound the slide indicator travels with the hammer mass and stops at the maximum distance the mass reaches after rebounding. A button on the side of the body is pushed to lock the plunger into the retracted position and the rebound number is read from a scale on the body.



3 – PENETRATION RESISTANCE OR WINDSOR PROBE TEST

The Windsor probe, like the rebound hammer, is a hardness tester. It looks like a gun. It is used to assess the hardness of concrete surface and the beneath concrete near the surface. The probe is driven into the concrete by firing a standard pin by standard energy, then measuring the penetration depth.



4. ULTRASONIC TESTING

The methodology of UPV is based at time monitoring of pulses in a section of the object. The UPV will depend on the density and the elastic properties of the material in study. The quality of many materials of construction is related with its rigidity, the measure of the UPV can be used to measure the concrete structures quality, estimate the mechanical properties, the compressive strength and the modulus of elasticity.

The Instrument generates pulses of ultrasonic frequency, which are coupled into the concrete specimen under test by the transmitting transducer. The receiving transducer is used to detect these pulses & to convert them back into electrical pulses.

Picture 1. UPVatConcrete.

Ultrasonic is a non-destructive test performed by sending high-frequency wave (over 20 kHz) through the media. By following the principle that wave travels faster in denser media than in the looser one, engineer can interpret the quality of material from velocity of the wave. This can be applied to several types of materials such as concrete, wood, etc.

Portable Ultrasonic Non-destructive Digital Indicating Test (PUNDIT) is used for this purpose. Two transducers, one as transmitter and the other one as receiver, are used to send and receive 54 kHz frequency.

Velocity of the wave is measured by placing two transducers, one on each side of concrete element. Apply thin grease layer to the surface of transducer in order to ensure effective transfer of the wave between concrete and transducer.

The time which the wave takes to travel is read out from PUNDIT's display and velocity of the wave can be computed as follows:

V = L / T ……………… (1)

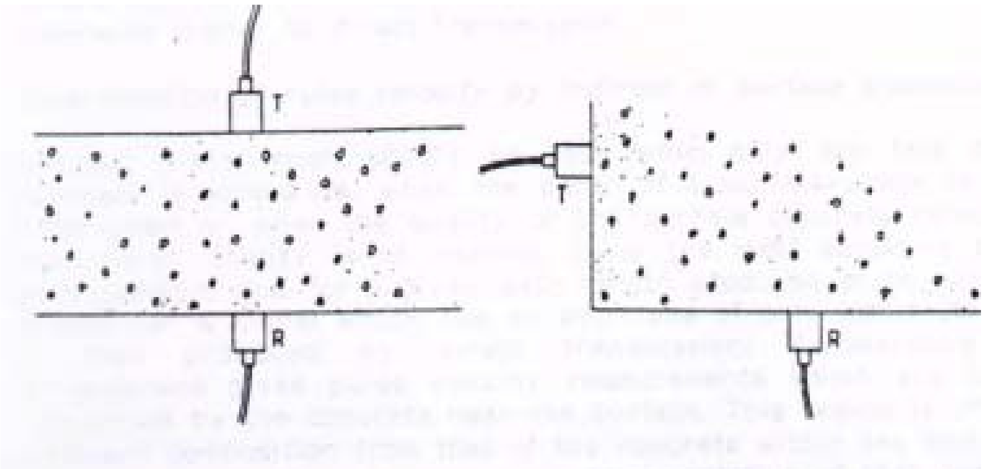
Where

V = Velocity of the wave, km/sec.

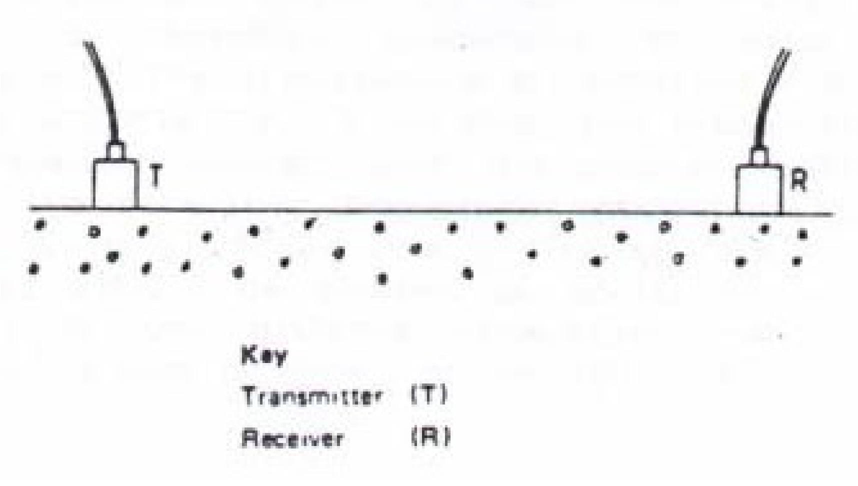
L = Distance between transducers, mm.

T = Travelling time, 10^{-6} sec.

Placing transducers to the concrete element can be done in three formats, as shown below.



(a): Direct transmission. *B)Semi-direct transmission.*



(c): Indirect or surface transmission.

Velocity of pulse in concrete decreases if there is any abnormalities such as air void, cracks, or any other foreign materials. Integrity of concrete can be interpreted from velocity of pulse as follow:

Pulse velocity, km/sec	Condition
Over 4.0	Good
3.6 - 4.0	Some defection
Below 3.6	Defected

Factors Affecting the Test Result

- Size of coarse aggregate.
- Water-cement ratio.
- Admixtures.
- Age of concrete.
- Water content.
- Path length.
- Steel reinforcement.
- Sample size.
- Probes touch to sample.

5– Core Test

Core test is carried out according to ASTM C42.

This test method provides standardized procedures for obtaining and testing specimens to determine the compressive, splitting tensile and flexural strength of in-place concrete.

Generally, test specimens are obtained when doubt exists about the in-place concrete quality due either to low strength test results during construction or signs of distress in the structure. Another use of this method is to provide strength information on older structures.

Concrete strength is affected by the location of the concrete in a structural element, with the concrete at the bottom tending to be stronger than the concrete at the top. Core strength is also affected by core orientation relative to the horizontal plane of the concrete as placed, with strength tending to be lower when measured parallel to the horizontal plane. These factors shall be considered in planning the locations for obtaining concrete samples and in comparing strength test results.

The strength of concrete measured by tests of cores is affected by the amount and distribution of moisture in the specimen at the time of test. There is no standard procedure to condition a specimen that will ensure that, at the time of test, it will be in the identical moisture condition as concrete in the structure. The moisture conditioning procedures in this test method are intended to provide reproducible moisture conditions that minimize within-laboratory and between-laboratory variations and to reduce the effects of moisture introduced during specimen preparation.

The measured compressive strength of a core will generally be less than that of a corresponding properly molded and cured standard cylinder tested at the same age. For a given concrete, however, there is no unique relationship between the strengths of these two types of specimens. The relationship is affected by many factors such as the strength level of the concrete, the in-place temperature and moisture histories, the degree of consolidation, batch-to-batch variability, the strength-gain characteristics of the concrete, the condition of the coring apparatus, and the care used in removing cores.

According to ACI 318, the concrete represented by the cores is considered structurally adequate if the average strength of three cores is at least 85 % of the specified strength and no single core strength is less than 75 % of the specified strength.

The apparent compressive strength of concrete as measured by a core is affected by the length-diameter ratio (L/D) of the core as tested and this must be considered in preparing core specimens and evaluating test results.

Cracks repair is done to return the structure to the efficiency in performance, use and apparent. During repair process, a structure may need strengthening measures to improve its efficiency comparing to its formal situation.There are many methods to repair cracks. The suitable method is chosen according to the available technology, structure importance and cost.

Among the most important methods are:

<u>1. Epoxy Injection:</u>this method is often used to seal and repair the narrow cracks of width (1–3) mm. As well as, it is used to repair the pre-cast concrete units, such as beams and piles or the insitu cast structural parts such as columns and slabs….etc. The procedures of this method are:

- The crack is well cleaned by compressed air, water or brushing or even using solvents sometimes.
- Close and seal crack surface by epoxy or special tap or any other suitable materials.
- Making holes along crack length and fix nipples (valves) in these holes to use them in injection process. Holes diameter and distance between holes depend factors, among which, crack type and width, epoxy type and viscosity and injection device type…etc. anyway, the distance between two holes is (0.5–1) m.
- The epoxy is mixed and prepared according to producer instructions.
- Then, the epoxy injected through the fixed tubes with alternating pressure. Injection continues in the 1st hole till the epoxy comes out from the following hole, or thepressure becomes stable and no more epoxy is to be injected. And so on the process goes on. When the crack is perpendicular or inclined, the injection process starts from down upwards. When the crack is horizontal, the injection process is alternatively right and left.
- The surface sealant and nipples are removed.
- Crack is treated according to used material producer directions.
- The surface is to be finished by using the same type of the old materias.

2. Stitching: this method is for the cracks occur in tension zone; tensile stresses on both crack sides. Crack sealing is not enough in such case (crack will appear again after repair). This method is:

- Making holes on both crack sides with depth not less than crack depth and distance of about 30 cm from crack to hole. And making groove between the two holes. This is to be done each (25 to 50) cm along the crack as it is in the drawing shown in Fig. (3).
- The groove is to be cleaned well.
- Putting a channel shape steel clipsso that each of the two vertical parts in a hole and the horizontal part in the groove.
- The channel shape steel clips are to be fixed in holes by epoxy or un–shrinkable mortar.
- The channel shape steel clips are to be put in right places to insure the resistance of tensile stress.
- The distance between two clips is to be minimized at crack end.
- Holes, grooves and crack are to be sealed and finished properly.
- It is preferable to make stitching from both concrete surfaces so as the structure movement does not bend the clips.
- Stitching process prevents crack propagation but does not close it.
- Crack is to be repaired before stitching when there is moisture to protect clips against corrosion. When there is movement, stitching is to be done first. Otherwise, crack repair materials will be crushed.
- The last step is the fishing.

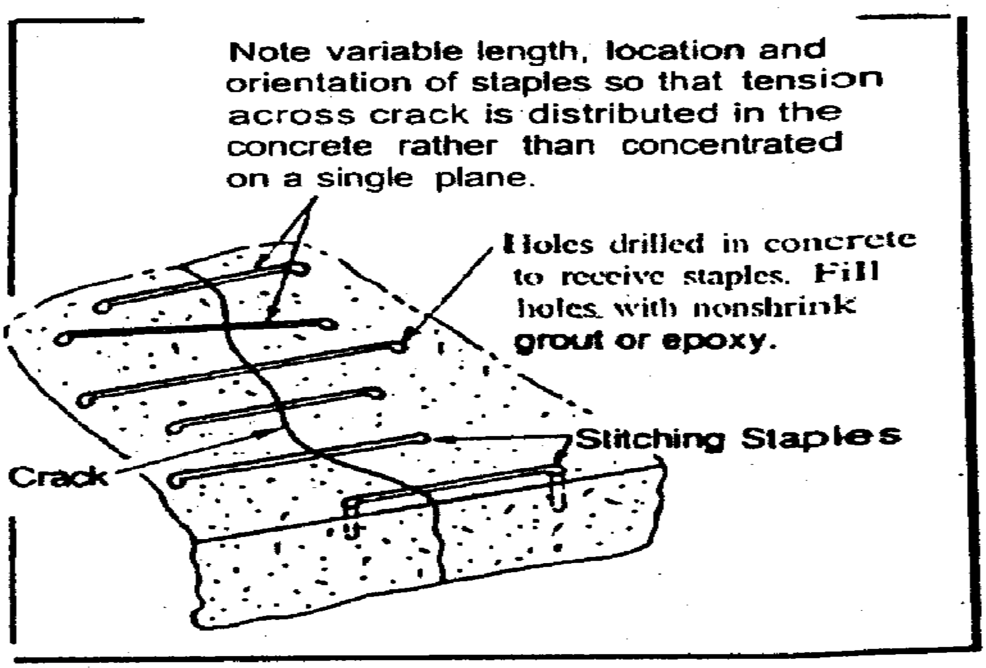


Fig (3) shows crack stitching method.

3. Drilling and Plugging: This method is used where water is in touch with structure parts to prevent water from passing through cracks, for example, in swimming pools, fountains and reservoirs.

When cracks run in reasonable straight lines and are accessible at one end, drilling down through the length of the crack and grouting it to repair them, as it is the case in retaining walls. Drilling a hole should be wider a little bit than crack width (diameter of 50 to 75 mm) and with crack depth. Repair steps are:

- Crack is to be cleaned and filled with grout (grouting material must be of low modulus of elasticity).
- Place reinforcement bars (of predetermined sizes and lengths) in them to stitch across the cracks (see fig.4).

A Hole is to be drilledin the wall,centeredon anddown through the crack.Sizeof holedependson thewidthof thecrack.Use2”to 2-1/2”minimumdiameter.

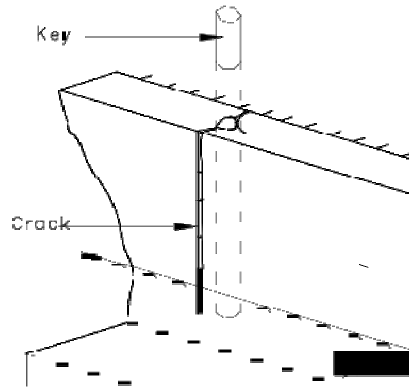


Fig (4) drilling and plugging.

4. Polymer Impregnation:it’s a costly method used in specific placessuch as tanks of chemicals. The process is impregnated polymer of low viscosity in cracks. By heating, the polymer will be strong, durable and elastic material which improves concrete properties. In this method, cracks must be dried.

The large voids can be filled by aggregate in the compression zone before impregnated the polymer.

5. Dry Backing:this method is used to seal the narrow cracks, not for active cracks. This method is:

- Widening the crack to 25mm and with depth 25mm before repair, crack is to be as (V) shape.
- Cleaning and drying the crack.
- Using mortar (1:1) or polymer. Then mortar (1:3) on condition that sand passes through sieve no. 16. Mortar water is to be minimized as much as possible. Mortar is to be put with pressing to bond it to old concrete.Sometimes, it is required to use bonding agents.

6 Flexible Sealing: this method is used with narrow cracks. Cracks width is changed with seasons. It can be used when there are cracks between two expansion joints. The method is:

- Cleaning the crack by water or compressed air, then filled by elastic material such as mastic. The crack is to be widened so as to be similar to the expansion joints.
- Isolated material is to be put in the bottom to let the mastic changes its shape without concentrating stresses in the bottom. The isolation material is not to be bondto mastic.

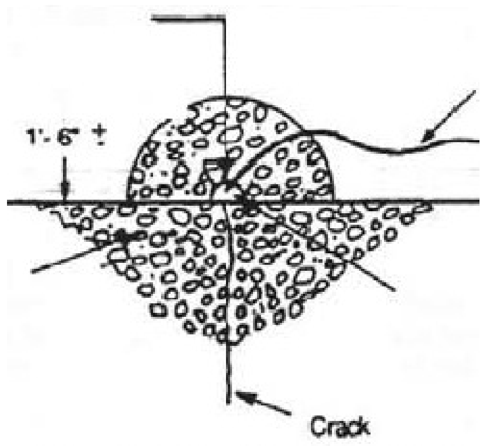
This is an economical method can be used in tanks, slabs and other areas which are not exposed to mechanical forces.

7. Cracks arresting: this method is used when a section is casted by more than one layer, or in mass concrete or road pavements, where cracks are horizontal and straight. The method is:

- The crack is to be cleaned. A 200 mm pipe is to be cut into two halves and fixed on the crack which is repaired by any means.
- A hole is drilled in the pipe to put grout through it then grouting continued till the pipe is filled with grouting material which is usually cementitious materials.

If there are many cracks, they are to be cleaned and repaired by any means then reinforcement mesh is put on the cracked areas so as to prevent stresses and cracks reflections from moving to the upper layer (this is often happens in floors).

Semicircular pipe (200)mm



Grout pipe

Holes drilled in the concrete to hold pipe in place.

Fig (5) shows crack arresting method.

<u>8. Autogenously healing:</u> it's a natural process to repair cracks when moisture is existed and very small cracks. The cracks are filled by cement hydration products (gel). Cracks may be filled by CaCO3 results from the reaction between $Ca(OH)_2$ from cement hydration and CO_2 from atmosphere. $CaCO_3$ precipitates with $Ca(OH)_2$ and they grow and fill the crack. This gains some strength to resist tensile stresses.

No healing for active cracks.As well as, no healing where there is flowing water, it washes calcium hydroxide and calcium carbonate.

<u>9. over lays and surface treatment:</u> when there are many cracks in a floor, the methods are either:

Neglecting the old concrete and consider it as a base then cast new concrete layer over it.

Or

Putting stress tensor layer then overlay thin layerso as the new and old layers act together as one unit.

10. Grouting:In structures such as dams and large foundations,wide and deep cracks may take place and extend deep in soil for long distances. The case is impossible to be solved by epoxy injection. Here, injection of cheap material is used, such as cement mortar or mud.

Note: there are many other methods.

Repair of R.C Columns Lec.13

R.C Columns are so important that the deterioration of any of them may cause total or partial failure. All sides (designer, maintenance team and users) must pay their attention to this fact.

R.C. Column Types:

A. Tied Column: square, rectangular or circular section, in which main reinforcement bars are fixed by separated ties.

B. Spirally Reinforced Column: circular section , in which main reinforcement bars are arranged on circle shape and surrounded by spiral tie.

There is another type called composite column. It consists of steel section with or without reinforcement bars to bear most of load and concrete to protect steel against fire.

The common defects in R.C. columns:

1. Superficial or deep cracks in concrete.

2. Deterioration in concretecover.

3. Cracks parallel to main reinforcement.

4. Partsof concrete separated due to buckling.

5. Edges crushing.

6. Others depend on column place.

Causes of defects and deterioration in columns:

1. Causes belong to design; reinforcement quantity, column dimensions, distance between stirrups and concrete designed strength.

2. Causes belong to execution; materials quality, perpendicularity, concrete quality and others.

3. Causes belong to use; overload moisture, steel corrosion and others.

4. Accidents; earthquake, fire, impact and explosion.

Repair of R.C. Columns:

The repair of R.C. Columns must be done quickly without delay. There are many methods to repair them. Each method must ensure:

1. Either to repair the column and make it efficient in function and appearance.

2. Or to repair the column and increase its efficiency for the new function and maintaining good appearance.

3. Removing the damaged concrete and evaluating the case.

4. Straightening the column that the deviation in column leads to change the level of beams and slabs.

5. Thinking in strengthened method. Strengthening may be done before or after repair process. In this example, strengthening is after repair.

Lec. 13

6. Cleaning of damaged concrete and adjusting steel reinforcement and cleaning cracks by steel brush, compressed air and water.

7. Cracks are to be repaired. The repair is often done by epoxy injection.

8. Casting new concrete to substitute the removed concrete, taking the following in consideration:

A.The same materials types are to be used (cement, aggregate).

B. the concrete mix is to be well designed so as to insure the needed compression strength.

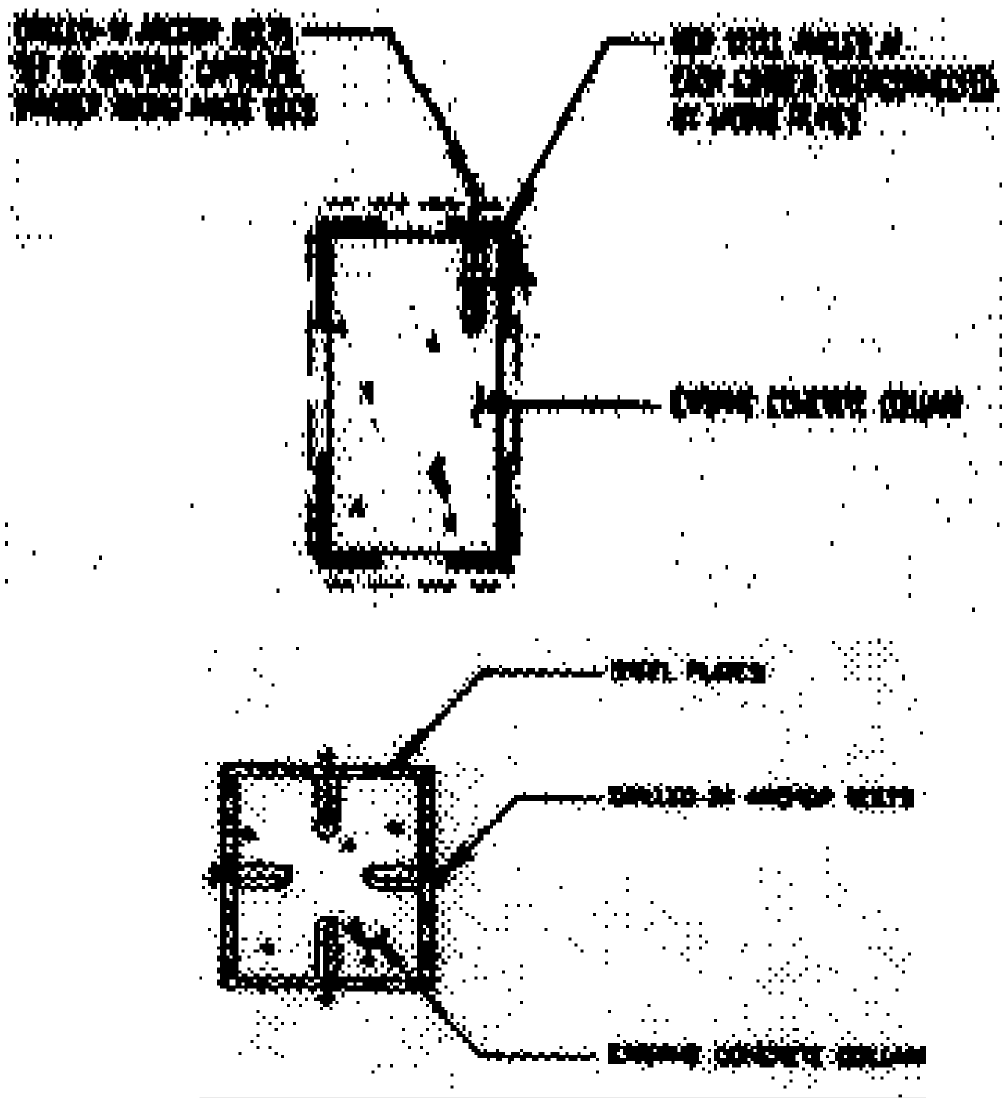
C. Small maximum aggregate size of gravel is to be used.

D. Admixture is to be used to insure good bond between new and old concrete.

E. Concreting is to start from the down of the column and up on stages.

F. Concrete curing.

9. Using steel sections (angle and plate) to surround the column and strengthen it.



Repair and strengthening of Defected R.C. Columns

Introduction:

Columns are very important in framed reinforced concrete structures . The deterioration of a column in a building ,for any reasons, may causes partial or complete failure of the building. So that it is required to take care about columns through the following stages:

*Design stage

*Execution stage

*Useful stage (building use)

*Maintenance stage

Concrete for columns erection also requires high care .It should be of a high quality and with a higher compressive strength compared with other parts of the building.

Common Defects in R. C. Columns

The main defects that could be commonly found in R. C. columns are:

*Different types of surface cracks.

*Deep cracks in different locations.

*Falling some parts of the concrete cover.

*Cracking the concrete along the main reinforcements of the columns.

*Buckling of reinforcement and falling some parts of the adjacent concrete.

*Crushing some parts of concrete in compression zone.

*Others which depend on location of columns and type reasons.

<u>Causes of Defects in R. C. Columns</u>

The main defects in R. C. columns are:

1-Designing causes include Insufficient or Incorrect of the following:

- Amount of reinforcement

-Column dimension

-Spacing of stirrups

-The specified compressive strength of concrete.

-Others.

2-Execution causes and defects , such as:

-Materials quality.

-Verticality and alignment

-Layout and accurate location of columns in site .

-Scaffoldings accuracy and tightness .

-Properties of concrete mixes .

-Casting , compaction , curing , …….etc.

3- Causes during the useful life of the building , such as :

-Applied loads .

-Environmental exposure .

-Water proofing problem .

-Thermal problem.

-Corrosion of reinforcement.

-Ignoring the maintenance as required.

4-Exccedental causes , such as :

-Fire.

-Earth quick.

-Explosions.

-Impacts.

-Others .

<u>Repair of R. C. Columns</u>

According to the importance of R.C. columns in framed structure it is required to investigate the causes of their defects . Then it is advisable to starting the repair procedure as quick as possible to avoid more complicated problems to the whole structure.

In any repair procedure it is required to insure the following :

*Either repair the column to be as before with respect to its function ,capacity and looking.

*Or repair the column and strengthening it to support higher loadings without affecting its general function.

<u>Case Study (Example) For Repair of R. C. Columns</u>

There are many cases and practical examples for defected reinforced concrete columns and their repair procedure. Some of them are discussed here.

Case Study 1

Repair of R. C. column subjected to loads higher than the designed loads:-

If a column is subjected to live or dead loads (or both) higher than the assumed design loads , some defects will appeared in this column immediately or with time. These defects could be one or more of the following:-

a-Crushing some parts of the concrete, if the applied compression stresses exceeds the loads which were considered in the design.

b-Buckling of longitudinal steel reinforcement, causing many defects in the column and the around area.

c- Cracks in the concrete surface of the column.

d-The general alignment , verticality and height of the column and the surrounding structural elements will be affected.

e-Others.

*suggested procedure to repair such type of defected column:-

1- Supported the column and the area around it with sufficient scaffolding for safety requirement.

2- Removing the five read as much as possible

3- Detection the deleted concrete and steel reinforcement and assessing the degree of damage.

4- Re-alignment the column and return it to its original position and level and according to that the position of the beams and slabs around the defected column will be as before to their normal position.

5-Then all cracks should be repaired as required according to the type of crack.

6- Also the existed steel should be repaired and straitened to its original position.

7-According to the high line load it is required to suggest any strengthening procedure for the column .There are many methods of strengthening such as:-

a- Increasing the cross section of the column.
b- Using structural steel sections.

c- Adding additional steel reinforcement for longitudinal and or stirrups.

d- Using new concrete materials:

*fiber concrete

*epoxy

*carbon strips

*Ferro cement

*other composite or hybrid materials

e- Adding new additional columns to reduce spans leading to reduce loading.

f- Others.

8- After that it is required to recompense the removed old concrete by new concrete, and the following should be considered :-

a- Using the same materials as possible (cement, aggregate …… etc.).
b- Design the concrete mix to produce the required strength and other properties.
c- For thin sections use mortar or concrete with small size of coarse aggregate.
d- Using bonding agent to ensure good adhesive between old and new concretes.
e- Casting the new concrete of the column with high skill.
f- Curing the new concrete efficiently.
g- Using the same finishing of the old column for appearance requirement.
h- Remove the scaffolding and reuse the repaired location.

i- After reusing the building check the adequacy of the repair with time.

Case study 2

A column in a cars park building exposed to accidental impact and the following defects are diagnosed:-

*Crushing some parts of the concrete.

*Cutting and buckling some of the reinforcements.

*Observing number of cracks in the column and falling some parts of the concrete cover.

*Small diversion (side sway) of the column.

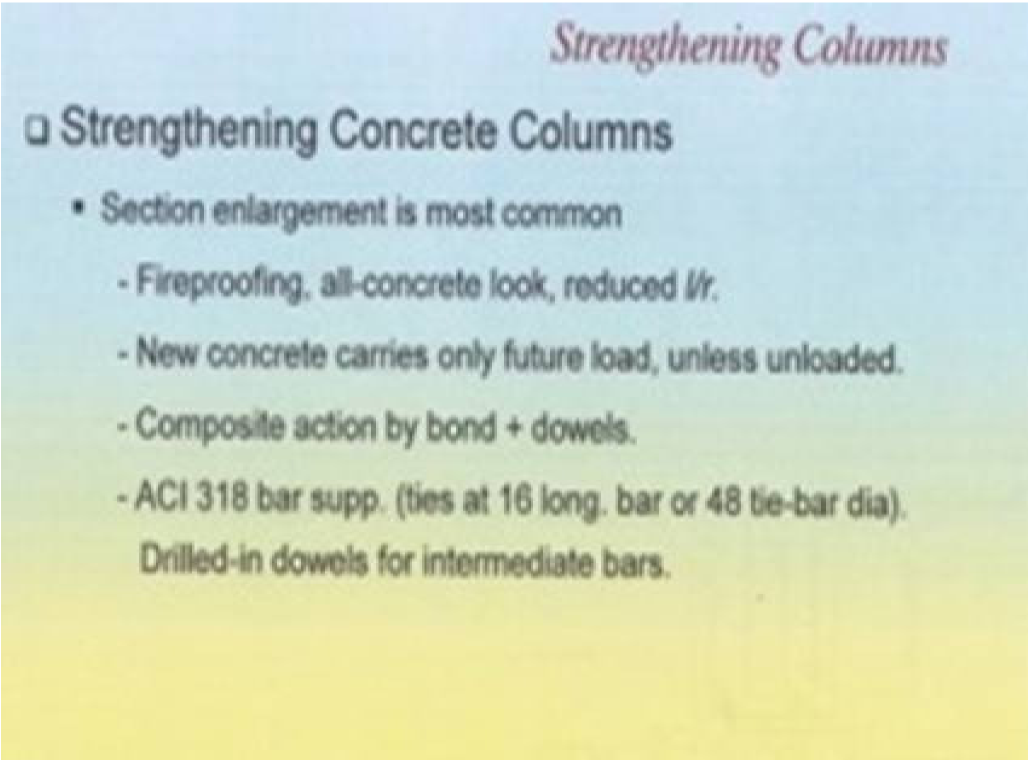
According to these defects the following procedures are suggested to repair the column:-

a- Support the column and the area around it.
b- Remove the live load as possible.
c- Clean the column and remove all the falling parts of the concrete.
d- Assess all defects of the column carefully.
e- Re-leveling the column in all directions to return it to its old position and elevation.
f- Ensure returning the adjacent slabs and beams to their original positions.
g- Repair all existing cracks as required.
h- Recompense the defected steel to ensure that the required steel reinforcements and stirrups are fixed .Special care is required for overlaps.
i- Then it is important to recompense the removed concrete by casting a new concrete mix as explained in case study 1 .
j- Execute the same old finishing of the column.
k- Reuse the location normally under regular observation.

Case study 3:-

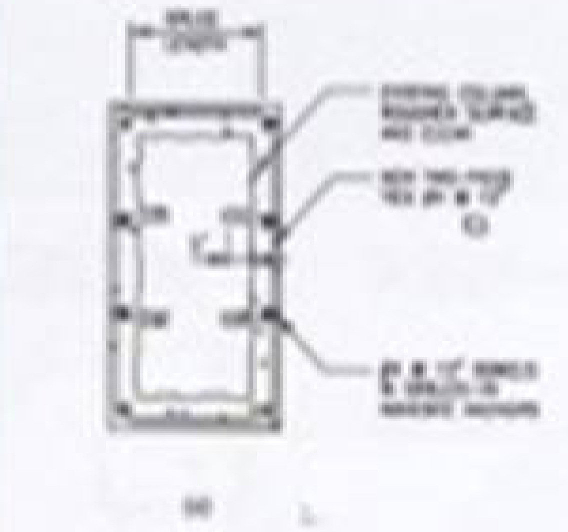
Examples for strengthening of columns:-

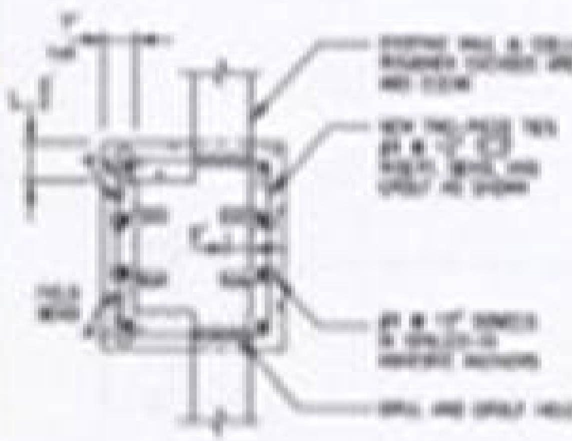
The followings are some proposals and suggested methods for strengthening of reinforced concrete columns:-



Strengthening Columns

- Concrete Columns, Cont'd
  - Biggest problem: drying shrinkage
    - Shrinkage-comp. cement.
    - Preplaced aggregate
      (grout pumped from bottom or thru pipes gradually withdrawn).
  - ACI 304.1 Guide for Use of Preplaced Aggregate Concrete



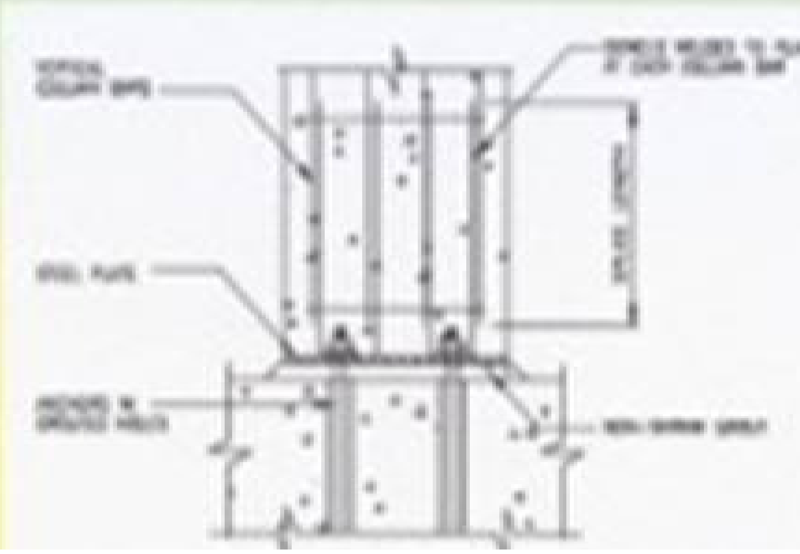


50

Strengthening Columns

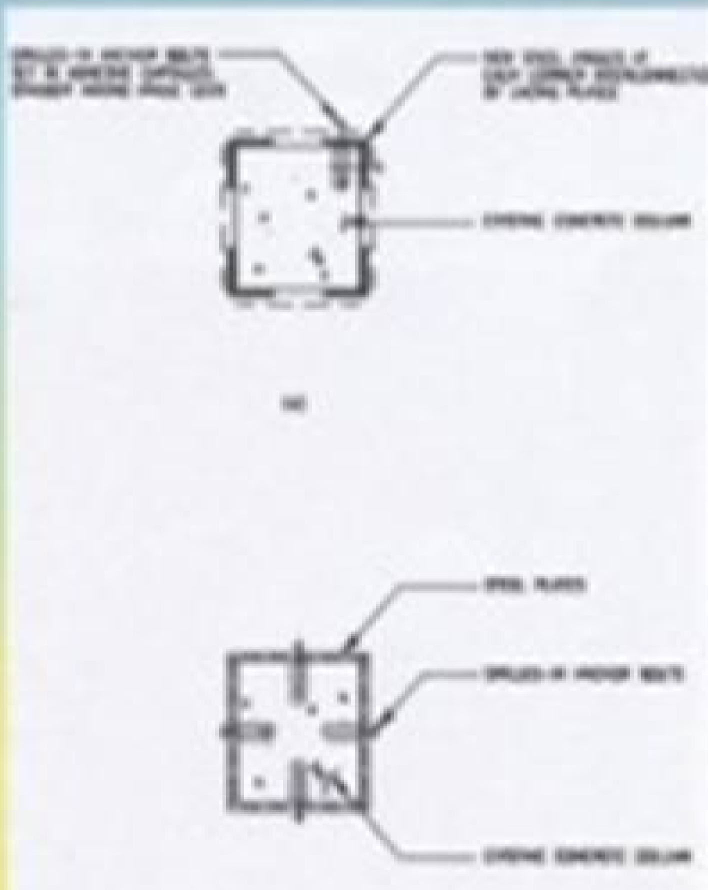
Concrete Columns, Cont'd

- Adding columns (separate or tied-in)
  - Concrete, steel (HSS), or concrete-encased W.
  - Best for one-sided beams and wide foundations.
  - NS grout for top gap.
  - Drill-in dowels for verticals or use steel bearing plate.



Strengthening Columns

- Concrete Columns, Cont'd
  - Reinforcing with structural steel
    - Four laced angles (a)
    - Welded steel-plate jacket (b) bolted-on or loosely fitted & grouted.
    - Design as concrete-filled HSS per ACI 318 or AISC LRFD (both conservative).



52

Strengthening Columns

- Strengthening Concrete Columns, Cont'd
  - Shorten length
    - Brackets?
    - Kickers?
    - Concrete cap?
  - Reinforcing with FRP wraps

Repair and strengthening of Reinforced Concrete Beams

Reinforced concrete beams are very important elements in framed structures. R. C. beam may be exposed to different types of defects due to many reasons. These reasons could be due to design deficiency, execution error, materials and/or bad using of building.

So that it is very important to investigate the causes of defects and its degree, then suggesting a suitable proposal to repair the defected beam.

Common Defects in R. C. Beams:-

There are many types of defects in R. C. Beams such as:-

1:-Cracks at the surface of the beam specially in the tension zones and concrete cover.

2:-Deflection higher than the accepted limit.

3:-Falling the concrete cover at different places.

4:-Diagonal deep cracks toward the depth of the beam near the supports.

5:-Different defects due to bad execution and quality control.

6:-Some defects due to bad use of the building.

Causes of Defects in R. C. Beams:

The main causes of defects in R. C. beams are:-

1:-The applying loads are higher than the designed loads.

2:-The steel reinforcement of the beam exposed to corrosion for many reasons.

3:-Some design errors.

4:-Execution and quality control errors.

5:-Chang in use of the structure leading to higher loading or for example heaver traffic across bridge.

6:-Accidents defects such as fire earth quick explosion …..etc.

Repair and strengthening of R. C. beams:-

There are different methods could be used for repair defected R. C. beams. Some methods are conventional and others are new with respect to technique and/or materials. In all cases the repaired beam should return to its original capacity, function and shape. Some time it is required to upgrade (Strengthening) the beam in addition to its repair.

The method of repair depends on type of defect and the required costs.

Examples (case study) for R.C. Beams repair:-

Case 1:-

A reinforced concrete beam exposed to a load higher than the designed load due to change in use of the building. A severe defects appear throughout the beam. Give proposal to repair this defected beam.

The following defects could be found in the beam:

1:- Successive deflection at the maximum moment of the beam.

2:- Cracks, relatively deep, through the concrete in the tension zone of the beam.

3:- Diagonal cracks could be found near the supports if the stirrup reinforcements are not adequate.

4:- Crushing parts of the concrete.

5:- Surface cracks throughout the whole beam and falling some parts of the concrete.

The following procedures are proposed to the repair and strengthening:-

A:- Support the beam safely with suitable scaffolding.

B:- Remove the live load as possible.

C:- Clean the defected area carefully and remove all the falling parts of concrete.

D:- Repair all cracks using a suitable method, for example use epoxy injection.

E:- Replace the removed concrete using the same old materials as possible with satisfied compressive strength and other properties.

F:- After that and due the change in use of the building it is required to strengthen the beam using any suitable method, such as:-

*- Adhering a steel plat to the tension area of the beam using special type of epoxy. The dimensions of the plat should be accurate to increase the capacity of the beam to the required value. This method requires a lot of care and skill to insure the upgrading.

*-Adding a frame of structural steel sections to form a composite beam with a higher capacity. A steel angle, channel and plats could be used for this purpose. Welding, bolts and shear connectors are required to complete the process accurately.

<u>Case 2:-</u>

A reinforced concrete beam exposed to successive corrosion, propose a suitable method to repair the defected beam.

According to the cumulative corrosion of the beam's reinforcement the following defects could be found:-

1:- Surface cracks throughout the beam specially along the main reinforcement due to the increase in the corroded steel bar volume.

2:- Falling some parts of the concrete cover.

3:- The effective area of steel bars may be reduced due to successive corrosion.

4:- The deflection of the beam may be increased.

5:- Others

To repair the defected beam the following procedures are suggested:-

*- Support the beam by using suitable scaffolding.

*- Remove the live load as possible.

*- Clean the area carefully and remove all loose pieces of concrete.

*- Clean the steel bars and remove the rust from it.

*- Then assess the existing reinforcement and the degree of deterioration in it.

*- Add new steel to compensate the losses amount due to corrosion.

*- Cast the new concrete with the required properties to compensate the fallen cover.

*- Cure the repaired beam sufficiently.

*- Execute the finishing using the same materials as before.

*- Reuse the location and regular observation is required.

Examples for beam strengthening:-

There are many proposals for beam strengthening, some of them are shown and discussed in this lecture:-

Strengthening Concrete Beams

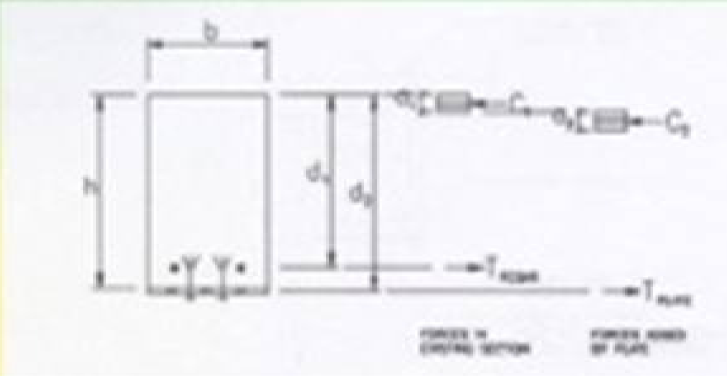
❑ Another Approach

- Calculate forces, depth of compression stress block "a" and M_{nom} in existing section using phi = 0.9.

Find $M_{req} = M_{max} - M_{nom}$ (all factored)

M_{req} is between plate and compression block below existing one.

Use phi of, say, 0.5 to account for lesser reliability of drilled-in anchors.

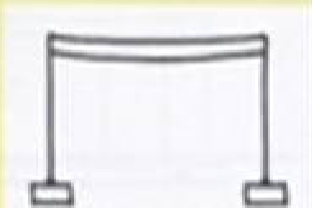


30

Strengthening Concrete Beams

❑ Strengthening Reinforcing Concrete Beams

- By analysis and testing (e.g., using USD, moment redistribution of ACI 318).
- Active methods (future and present loads) vs. passive (future only).



23

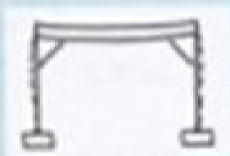
Strengthening Concrete Beams

General Methods of Strengthening

- Shortening span
- Adding members
- Replacement
- Post-tensioning (external prestressing)
- Enlarging section

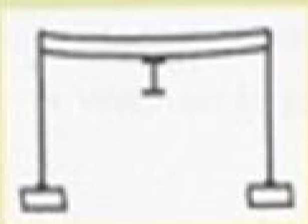
Strengthening Concrete Beams

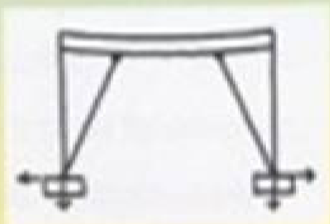
Shortening Span

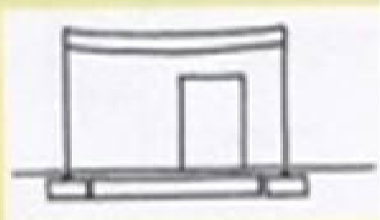


- Add columns, girders
- Add diagonal braces (not knee-braces)

  Check foundations or add new
- Add walls with openings



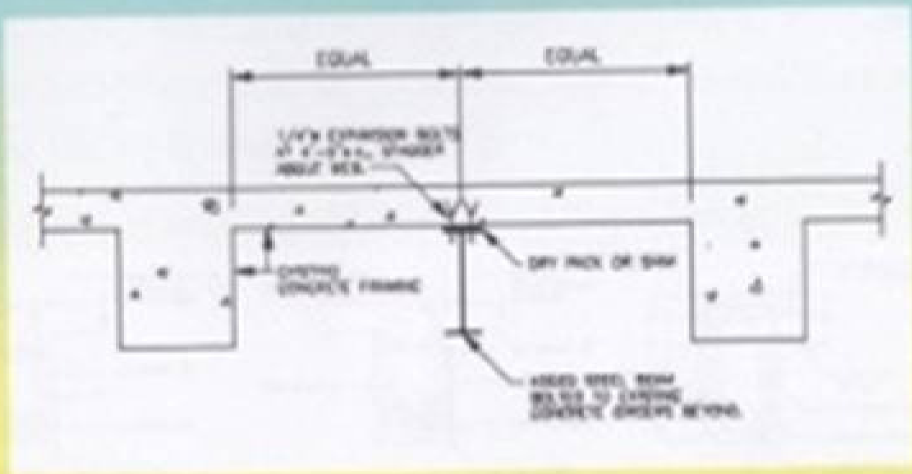




Strengthening Concrete Beams

❑ Adding Members Between or Alongside Existing

Maintain deformational compatibility; brace steel.

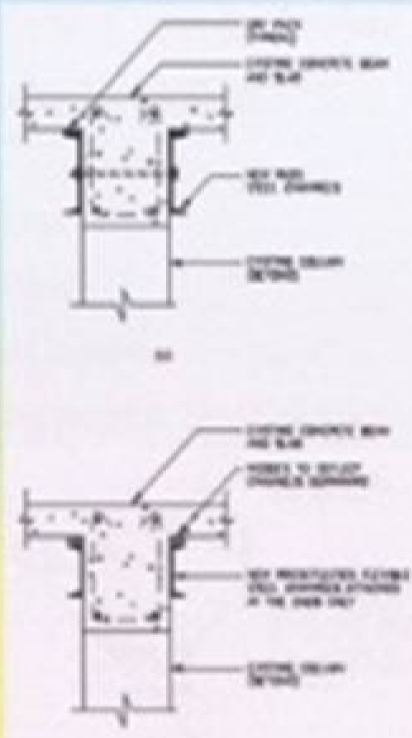


Strengthening Concrete Beams

❑ Flexural Strengthening RC Beams by Steel Channels

- Cordon off area above to remove LL.
- Rigid through-bolted channels (passive)

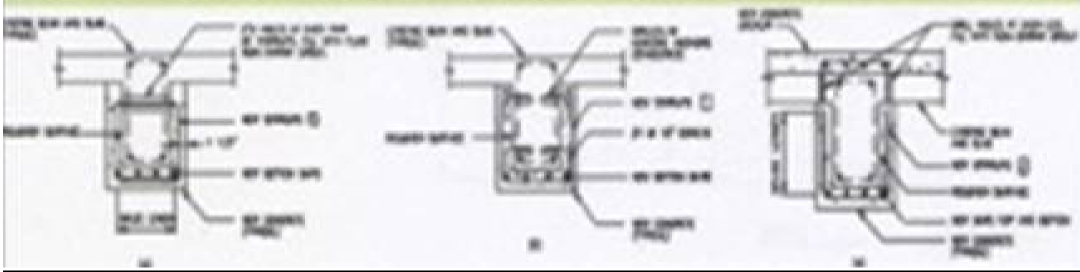
  vs. flexible pre-deflected attached only at the ends (active).
- Channels laterally braced by concrete.
- Watch out for pipes, conduits at sides.



Strengthening Concrete Beams

❑ Flexural Strengthening by Enlarging Section

- Use if a look of concrete or if fireproofing is desired.
- Unload the beam; roughen surface, remove contaminants.
- Shrinkage: Use nonshrink repair material or preplaced aggregate to reduce tension stresses in existing concrete from shrinkage of new, leading to cracking, debonding.
- Corrosion of new bars and dowels in existing concrete.

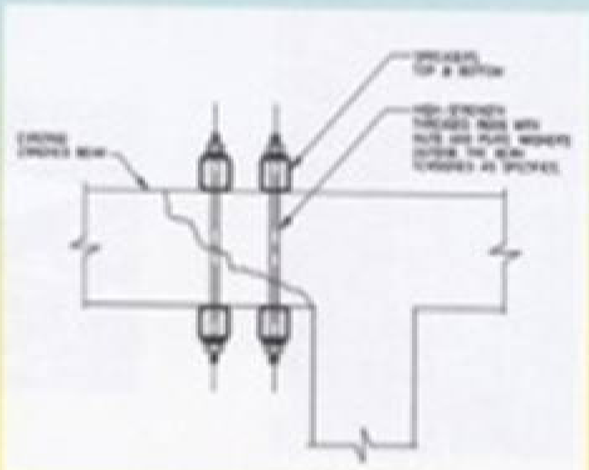


Strengthening Concrete Beams

❑ Increasing Shear Capacity of Beams, Cont'd

- For damaged ends, clamping and epoxy filling can help, or use steel end brackets bolted to columns
- Shorten span...

  or FRP wrapping



41

Strengthening Concrete Beams

Some Problems of Using FRP

- Design standards lacking… alkalis in cement can damage FRP (fibers not alkali-resistant; resin only few mm thick)
- Epoxy adhesives soften with temperature

  - If T > the glass transition point (70-170 °F for most), strength & stiffness quickly decrease, creep occurs. When T < again, properties return, but damage done…

  - Fireproofing FRPs by drywall or intumescent coatings expensive.

Strengthening Concrete Beams

Some Problems of Using FRP, Cont'd

- CFRP plates & fabrics lose strength after long-term exposure to high humidity
- Biggest concern: delamination
- CFRP wrapping for flexure and shear:

  Use as "supplemental reinforcement"?

Strengthening Concrete Beams

❑ Bonded Steel Plates, Cont'd

- Some problems:
  - Complete reliance on workmanship
  - At exterior, plate rusting at interface, leading to loss of bond.
    (But coatings interfere with adhesion.)
  - In corroding members, adds galvanic cell, conceals signs of corrosion
  - Fire resistance issues.

Strengthening Concrete Beams

❑ Flexural Strengthening by Bonded FRP Plates

- Fiber-reinforced plastics used today
  - GFRP: corrosion-resistant, but low E (1/5 of steel).
  - Aramid: Strong in tension, poor in compression, expensive.
  - CFRP: (+) strong, corrosion-res't, $E \sim$ steel.
    (-) conducts electricity => a galv. cell.
    F_t up to 270 ksi, but limited by bond or contact area => surface prep. critical.

Defects and Repair of Reinforced Concrete Slabs

Introduction:

Slabs in reinforced concrete structures are very important elements. They hold or engaged a large surface area in any building. The normal thicknesses of these structural elements are ranged from 12 to 20 cm. Generally slabs are reinforced with a mesh of steel bars to resist the applied loads. Due to their small thickness and large area, slabs may expose to some defects and deterioration. So that it is useful for any engineer to know the common defects of slabs and their causes. After that defected slabs should be repaired as soon as possible to increase the useful life of the building.

Common Defects in R. C. Slabs:

One or more of the following defects could be found in reinforced concrete slabs:

1- Cracks distributed randomly throughout the slab .
2- Cracking of the concrete cover, mainly along the steel reinforcements.
3- Deep cracks could be occurred in the tension zone of the slab.
4- Falling parts of concrete fragments from the slab.
5- Problems in thickness, level, alignment, dimensions and others.

Causes of Defects in R. C. Slabs:

The main causes of defects in R. C. slabs are:

*- Causes due to design:

1- Mistake in the amount of reinforcement and spacing.

2- The slab thickness and concrete cover are not adequate.

3-Using unsuitable design strength or specifications.

4-using unsuitable design live and dead loads.

*-Causes due to execution:

1-Non efficient scaffolding.

2-Leveling problems.

3-Not applying the design sheets accurately.

4-Not achieving the specified properties for concrete mixes and their constituents.

5-Non efficient casting and compaction.

6-Non efficient curing.

*-Causes due to uses:

1-Applying loads higher the design loads due to change in use.

2-Corrosion of reinforcement due to water leakage and bad use.

3-Accedents such as fire, explosions, earthquakes……etc.

Repair of Defected Reinforced Concrete Slabs

There are many methods could be used to repair defected or deteriorated slabs. The choose method depends on type of defect and its causes cost and importance of structure…..etc.

However any chosen method should be efficient and suitable to repair the slab and returning it to its original case in everything; shape, function, strength and durability.

In some cases it is required to strengthen the slabs to resist any new loading higher than the original design load.

Before starting the repair procedure it is required and very important to diagnose the main causes of the defects and preventing them to be occurred again.

<u>Suggested Method for Repair a Reinforced Concrete Slab Exposed to Accidental Fire</u>

The very high temperature (due to fire) affects the concrete and the steel reinforcement significantly. The concrete starts to deteriorate at exposure temperature 300 Degree Celsius and higher. The strength of concrete reduces with the increase of temperature (from 300 to 800 Degree Celsius) . For temperature higher than 800 Degree Celsius the normal concrete loses all its mechanical properties due to de-hydration phenomena.

At 550 Degree Celsius and higher the steel reinforcement starts to lose its mechanical properties. So that the defects of a R. C. slab exposed to fire depend on many factors such as; degree of exposure, duration of exposure, location of exposure, …..etc. However all slab defects should be diagnosed during the preliminary and detailed inspections.

The following procedure could be used to assess and repair the defected slab;

1- Support the slab efficiently by suitable scaffoldings to prevent any sudden failure during repair.
2- Remove all the deteriorated concrete and clean the area to diagnose the defects accurately in concrete and steel bars.
3- Assess the degree of deterioration in concrete and steel bars and the location of cracks.
4- Repair the cracks by adopting any suitable technique.
5- Recompense the defected steel by adding additional steel reinforcement to be sufficient to return the slab to its original capacity.
6- Recompense the removed concrete and the concrete cover to be sure that slab section returns to its original thickness and shape. During casting the new concrete be sure to use the same old materials, bonding agent, the required strength and dimensions with a very high skill of labors.

7- New concrete should be cured to the required age to be strong enough to resist the applied loads.
8- Use the same old finishing materials to return the structure to its original function and shape.
9- Remove the scaffolding and re-use the building with regular observation**.**

Strengthening of Reinforced Concrete Slabs

In some applications it is required to strengthen the defected slab in addition to its repair. There are many methods could be used for R. C. slab strengthening. Bellow Figures show some details and suggestions for strengthening:

Strengthening Slabs

- Strengthening Two-Way Slabs
  - Beams or bolted plates at intersections – better to cover the whole slab?
  - Two-way slabs rarely fail in bending (in theory)
  - Membrane action (Study: design ultimate 188 psf, carried 490 psf); only effective after large deformations - damages finishes.

Strengthening Slabs

- Strengthening Sagging Cantilevers
  - Top bars rust, damaged, drilled through, placed too low…
  - Active vs. passive methods… elegant and $$ vs. basic & cheap

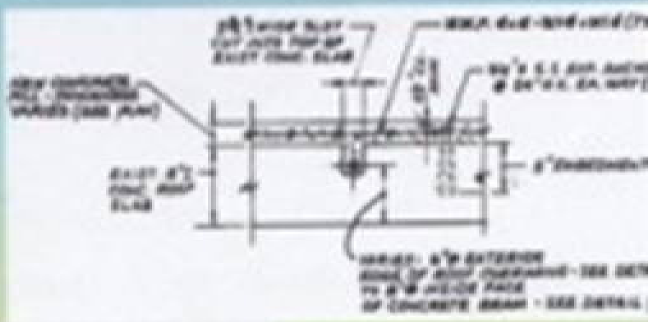
43

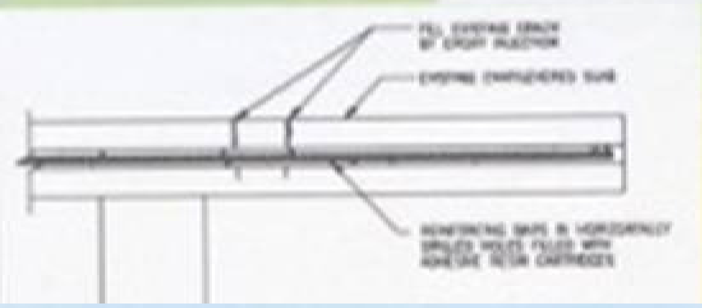
Frank Lloyd Wright was warned in 1936 in Fallingwater.

Strengthening Slabs

Strengthening Sagging Cantilevers, Cont'd

- Drilling-in bars
- PT tendons with overlay





Strengthening Slabs

Strengthening Sagging Cantilevers, Cont'd

- Adding steel brackets, braces, beams + columns.
- Remove/shorten cantilevers.