INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

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REHABILITATION AND RETROFITTING OF STRUCTURES

Course Code: A80151

Regulation- R15 JNTUH

B. Tech. Course: Year IV, Semester II

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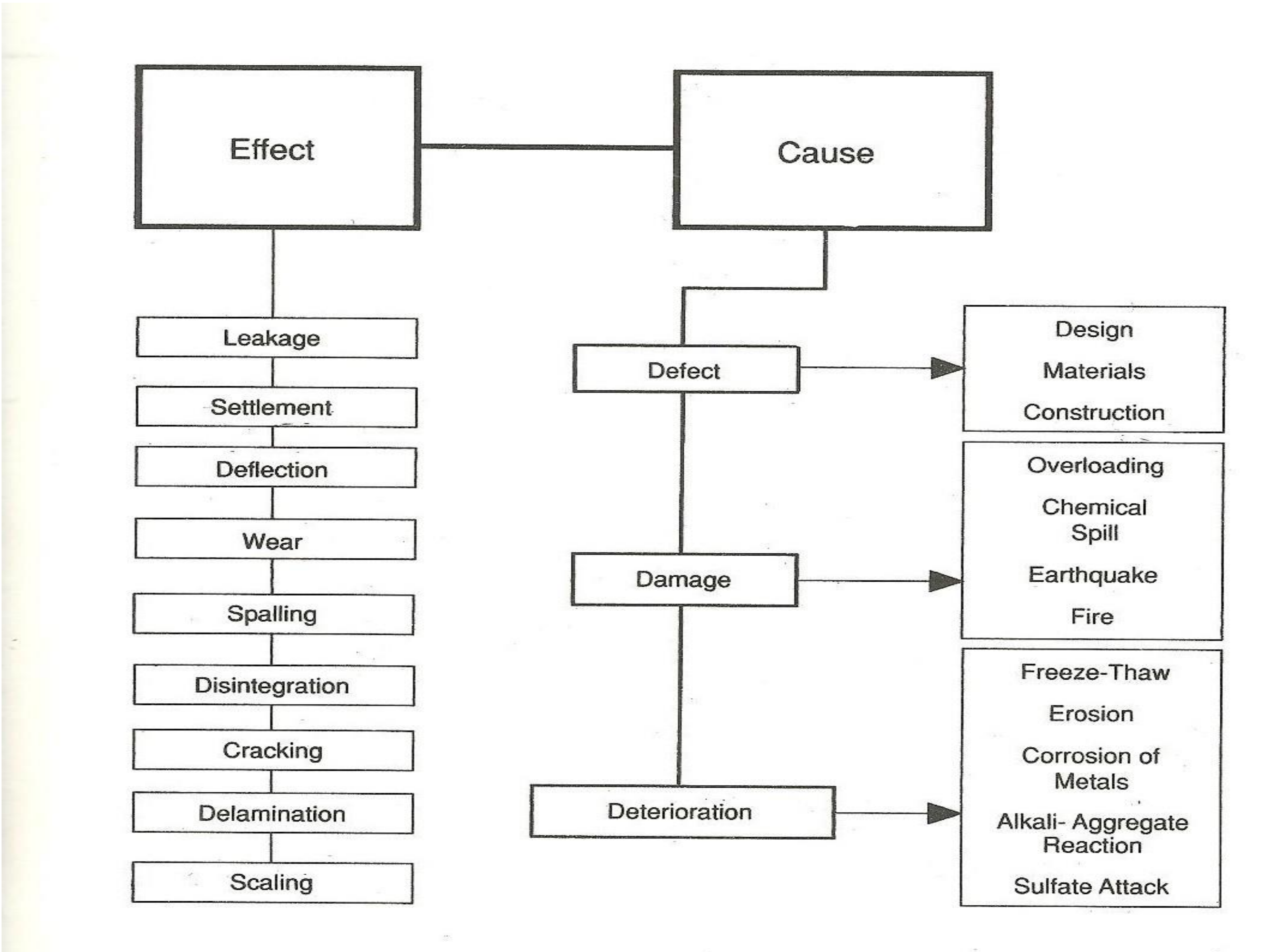
UNIT 1: DETERIORATION AND DISTRESS IN STRUCTURES

- Introduction
- Deterioration in Structures
- Distress in Structures
- Causes and Prevention

Introduction



Types of Structural Distress and Deterioration

Leakage

Examples of roof leakage and water seepage

Distress in Structures

Structural

- Caused by faulty design, faulty construction and/or overloading.
- Endangers building safety.
- Needs immediate attention.

Non-Structural

- Caused by internally induced stresses in components
- Looks unsightly
- Indirectly leads to structural weakening

Factors Causing distress

External

- Overloads due to dead load, live load, wind load, seismic loads, etc. which are not accounted in the design.
- Differential settlements in the foundation.

Internal

- Dimensional changes induced by
  - moisture penetration
  - temperature changes
  - horizontal shifts of building components
  - volume changes due to chemical action
- Weakness in tensile and shear stresses

Deterioration of Structures
- Causes and Prevention

Possible causes of deterioration/defects

- Pre-construction stage
- Construction stage
- Post-construction stage

PRE-CONSTRUCTION STAGE DEFECTS

CAUSES

- Poor design
- Poor design detailing
- Poor deflection estimations
- Faulty design of rigid joints in precast elements
- Faulty design estimations at changes in sections

CONSTRUCTION STAGE DEFECTS

SWELLING OF FORMWORK

CAUSES

- Formwork absorbs moisture from concrete or the atmosphere, which results in swelling of form.
- Crushing of wale in the formwork also causes movements of forms
- These result in cracks in the concrete while setting

PREVENTION

- Coating of the formwork with moisture resistant material.
- Using unyielding lateral ties with good end anchorage

CONSTRUCTION STAGE DEFECTS

III. INTERNAL SETTLEMENT OF CONCRETE

CAUSES

- Differential settlement between the surface and the interior volume of the concrete suspension causes surface cracks.
- Concrete on the surface sets faster than the interior suspension

PREVENTION

- Surface cracks can be cured and closed by delayed finishing.
- Curing of concrete must start immediately after casting to delay setting of the surface concrete.
- Good compaction will also help prevent this defect.

CONSTRUCTION STAGE DEFECTS

IV. SETTING SHRINKAGE OF CONCRETE

CAUSES

- While setting the concrete shrinks giving rise to surfacial cracks resembling the scales of the alligator.

PREVENTION

- Good and timely curing will help avoid this type of damage.

Deterioration of Structures

CONSTRUCTION STAGE DEFECTS

V. PREMATURE REMOVAL OF SHORES

CAUSES

- **Premature removal of shores from freshly poured concrete causes re-distribution of stresses on formwork, causing movements and cracking of concrete.**

PREVENTION

- **Shores must be removed only after the concrete has gained sufficient strength.**

CONSTRUCTION STAGE DEFECTS

VI. VIBRATIONS INDUCED DAMAGES

CAUSES

- Vibrations due to indiscreet walking over concrete and dumping construction materials, etc., can also lead to cracking

PREVENTION

- Workers have to be trained in avoiding such carelessness

Deterioration of Structures

POST-CONSTRUCTION STAGE DEFECTS

IV. WEATHERING ACTION

CAUSES

- Shock waves
  - Shock waves could be mechanical or thermal
  - Concrete is heterogeneous - different constituents have different wave transmission rates
- Erosion

PREVENTION

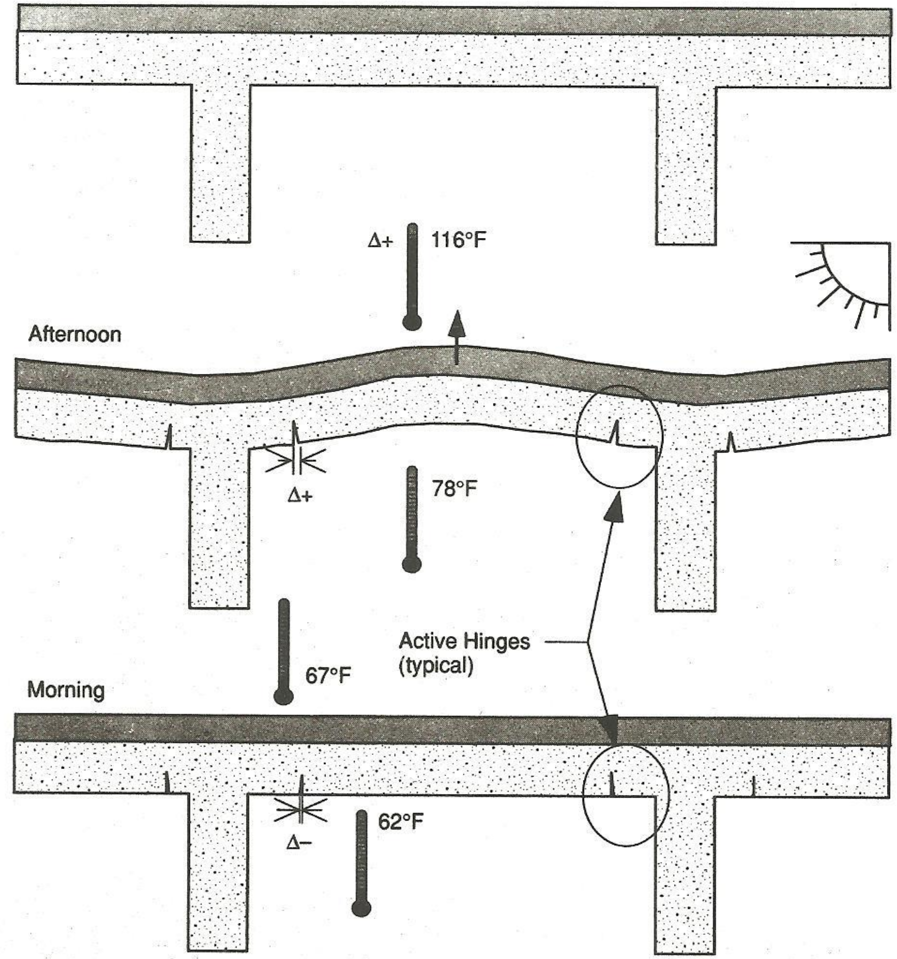
- Providing sufficient reinforcement is said to an excellent resistance to shock waves.
- Use of high-strength concrete
- Proper curing
- Proper finishing

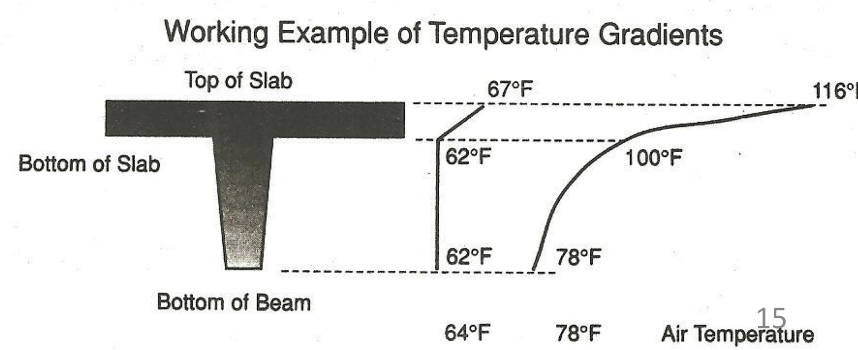
Thermal Cause:
(B) Temperature Variation

Diurnal Solar Heating effects the structure based on its configuration.

In simple span structures only up and down deflections take place and the joints are free to rotate.

In continuous span structures, hinges may form due to joint rotation being restrained. These hinges open and close with daily temperature.





DAMAGE IN HARDENED CONCRETE

TYPE 3:THERMAL CAUSE

(C) Early Thermal Cracking in Fresh Concrete

DAMAGE IN HARDENED CONCRETE

Thermal Cause: (C) Early thermal contraction

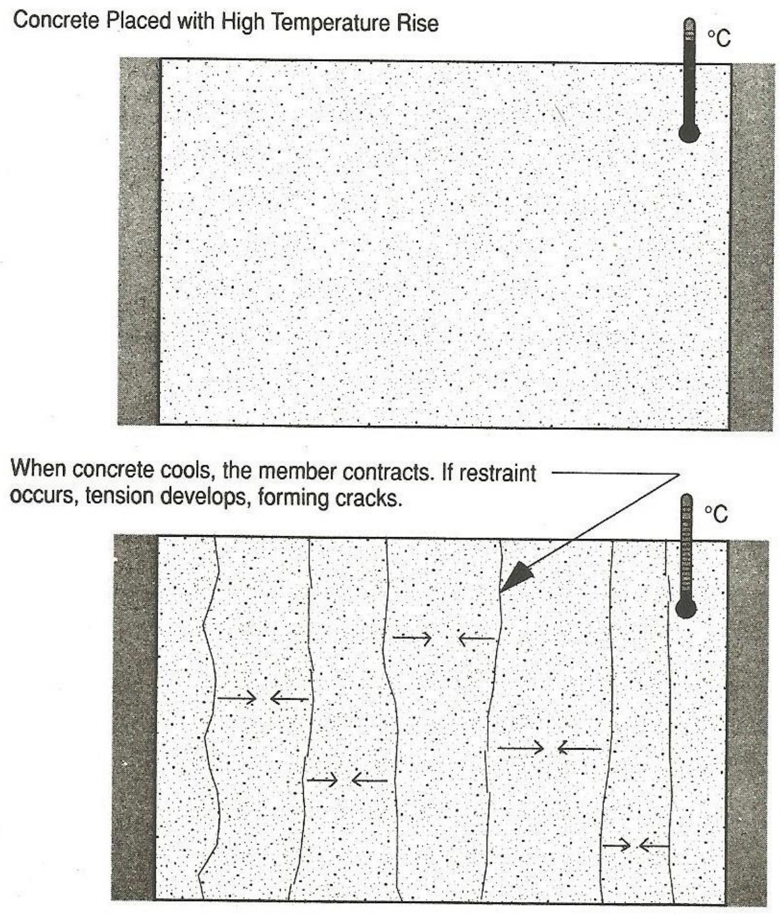
Fresh concrete undergoes temperature rise due to cement hydration.

When concrete is cooling to the surrounding ambient temperature in a few days, the concrete has very little tensile strength.

Weak tensile strength + thermally contracting concrete = tension cracks

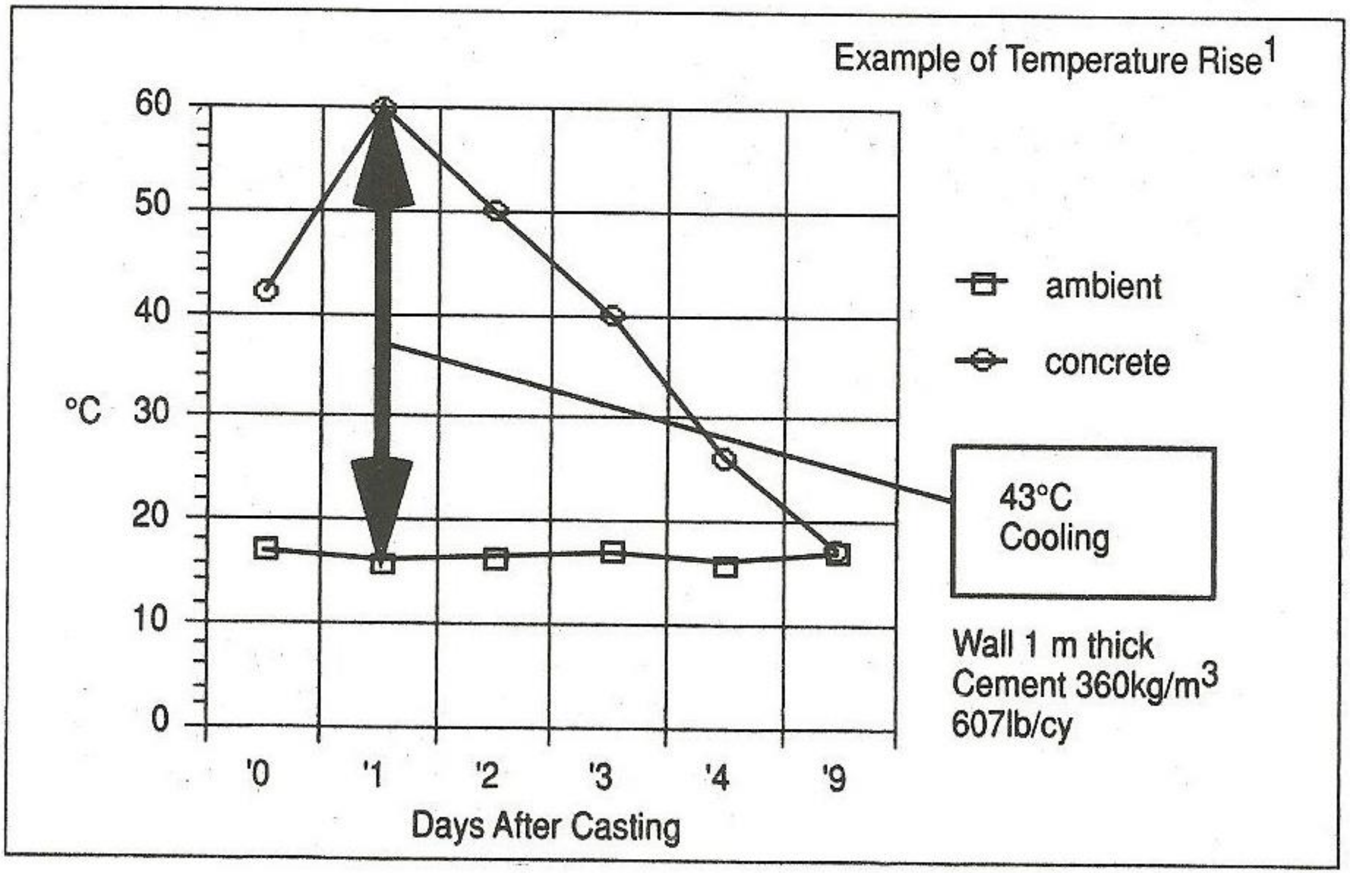
DAMAGE IN HARDENED CONCRETE

Thermal Cause: (C) Early thermal contraction



DAMAGE IN HARDENED CONCRETE

Thermal Cause: (C) Early thermal contraction



Thermal Cause: (C) Early thermal contraction

Factors affecting early temperature rise in fresh concrete

1. **Initial temperature of materials:** Warm materials lead to warm concrete. Aggregate temperature is most critical.
2. **Ambient temperature:** Higher ambient temperature leads to higher peaks
3. **Dimensions:** Large sections generate more heat.
4. **Curing:** Water curing dissipates the build-up of heat. Avoid thermal shock.
5. **Formwork removal:** Early removal of formwork reduces peak temperature.
6. **Type of formwork:** Wood form produces higher temperatures than steel forms.
7. **Cement Content:** More cement in the mix means more heat.
8. **Cement Type:** Type III cement produces more heat than most other cements
9. **Admixtures:** Fly ash reduces the amount of heat build-up

DAMAGE IN HARDENED CONCRETE

TYPE 4: STRUCTURAL CAUSE

(A) Accidental Overload

Unit II:

Corrosion of Steel Reinforcement

- Causes
- Mechanisms
- Prevention

Embedded Metal Corrosion Process

Concrete is a high alkaline - pH of fresh concrete is between 12 and 13.

In this range of alkalinity, embedded steel is protected from corrosion by a passivating film bonded to the reinforcing bar surface.

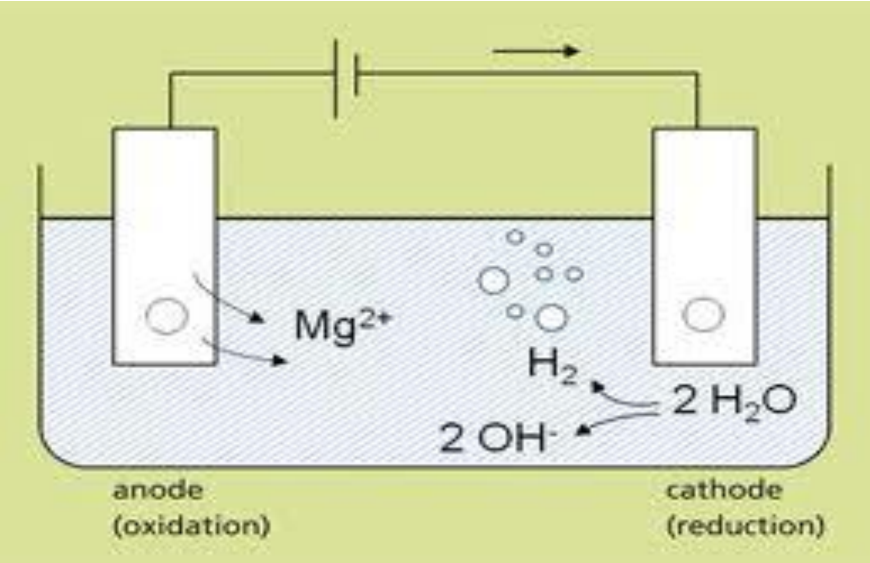
However, when the passivating film is disrupted, corrosion may take place.

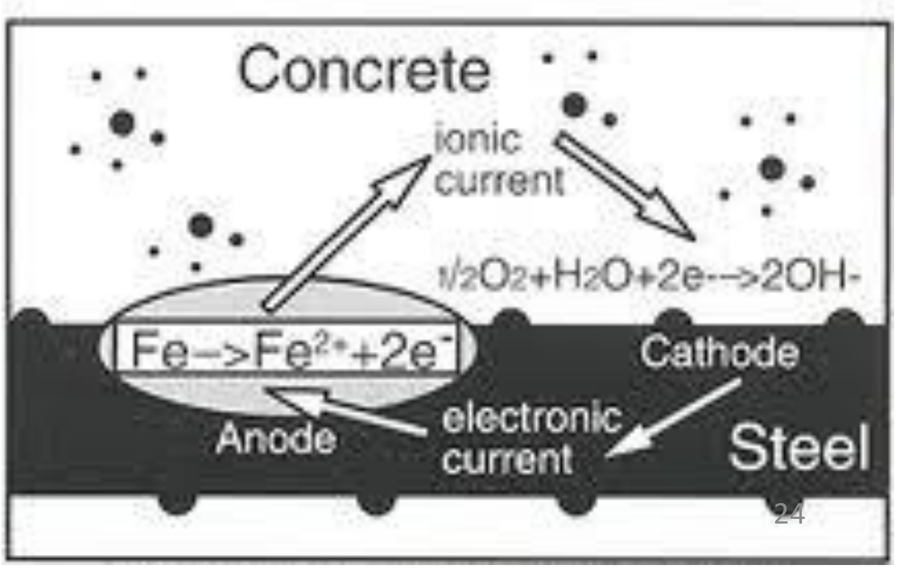
Embedded Metal Corrosion Process

- An Electrochemical Process

An electrochemical process requires an anode, cathode and an electrolyte.

Moist Concrete forms an Electrolyte.
Steel reinforcement provides anode and cathode.





Effects of Rebar Corrosion

- Cracking and Spalling

In good quality concrete the corrosion rate will be slow.

Accelerated corrosion will take place if

- the pH (alkalinity) is lowered (carbonation)
- if aggressive chemicals or dissimilar metals are introduced into the concrete
- presence of stray electrical currents and concentration cells caused by an uneven chemical environment.

Embedded Metal Corrosion

- Induced by Chloride Penetration

Source of Chlorides:

Environments containing chlorides, such as sea water or de-icing salts.

Penetration rate of chlorides into concrete depends on:

- The amount of chlorides coming into contact with concrete.
- The permeability of the concrete.
- The amount of moisture present.

Embedded Metal Corrosion

- Chloride Penetration Mechanism

The concentration of chlorides in contact with the reinforcing steel will cause corrosion when moisture and oxygen are present. As the rust layer builds, tensile forces generated by the expansion of the oxide cause the concrete to crack and delaminate.

Spalling of the delamination occurs if the natural forces of gravity or traffic wheel loads act on the loose concrete. When cracking and delamintaion progress, accelerated corrosion takes place because of easy access of corrosive salts, oxygen and moisture.

Corrosion then begins to affect rebars buried further within the concrete.

UNIT II

DAMAGE IN STRUCTURES DUE TO FIRE

DAMAGE IN STRUCTURES DUE TO FIRE

- PART 1: Fire Induced Damages in Structures
- PART 2: Fire Rating of Structures
- PART 3: Phenomenon of Desiccation

Part 1: Fire Induced Structural Damages

Effects of Fire on Concrete Structures

Uneven volume changes in affected members, resulting in distortion, buckling and cracking. The temperature gradients are extreme - from ambient 70°F (21°C), to higher than 1500°F (800°C) at the source of the fire and near the surface.

Part 1: Fire Induced Structural Damages

Effects of Fire on Concrete Structures

Spalling of rapidly expanding concrete surfaces from extreme heat near the source of the fire. Some aggregates expand in bursts, spalling the adjacent matrix. Moisture rapidly changes to steam, causing localized bursting of small pieces of concrete.

Part 1: Fire Induced Structural Damages

Effects of Fire on Concrete Structures

The cement mortar converts to quicklime at temperatures of 750°F (400°C), thereby causing disintegration of concrete.

Part 1: Fire Induced Structural Damages

Effects of Fire on Concrete Structures

Reinforcing steel loses tensile capacity as the temperature rises.

Once the reinforcing steel is exposed by the spalling action, the steel expands more rapidly than the surrounding concrete, causing buckling and loss of bond to adjacent concrete where the reinforcement is fully encased.

Part 1: Fire Induced Structural Damages

Effects of Fire on Concrete Structures

Concrete undergoes cracking, spalling, and experiences a decrease in stiffness and strength as the temperature increases.

Concrete has low thermal conductivity, which allows it to undergo heating for longer durations before the temperature increases significantly and damage occurs.

Part 1: Fire Induced Structural Damages

Effects of Fire on Concrete Structures

The concrete compressive strength starts decreasing rapidly after its temperature reaches approximately 400°C (750°F).

At temperatures of around 500°C (932°F), the concrete compressive strength is reduced to 50% of its nominal strength.

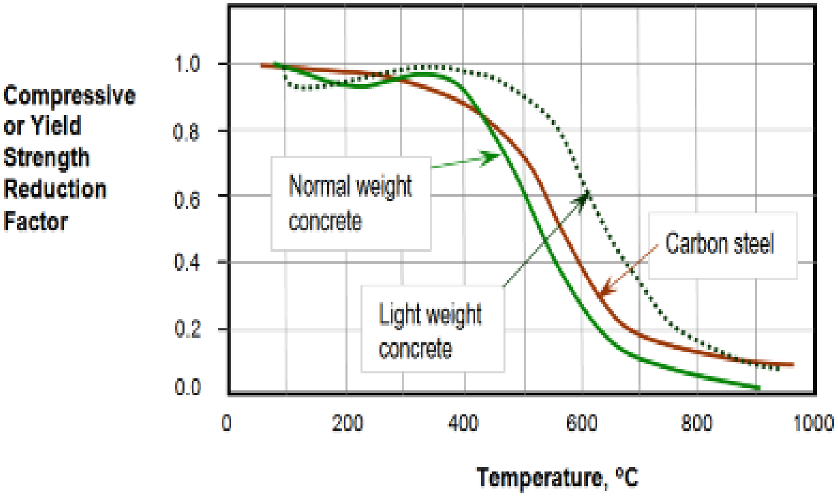


Figure 2.2. Reduction in concrete compressive strength with temperature (Astaneh-Asl et al. 2009)

PART 2: Fire Ratings of Structures

DAMAGE IN STRUCTURES DUE TO FIRE

PART 2: Fire Ratings of Structures

What is Fire Rating?

A fire rating refers to the length of time that a material can withstand complete combustion during a standard fire rating test. Fire testing of building materials and components of buildings -- such as joists, beams and fire walls -- is required in most places by building codes.

Other fire tests for things such as appliances and furniture are voluntary, ordered by manufacturers to use in their advertising. Wall and floor safes are examples of products for which fire resistance is a key selling point.

PART 2: Fire Ratings of Structures

What is Fire Rating?

With the required tests, the results are measured in either units of time, because the emphasis is on holding up under fire (literally) long enough for the occupants of a home or building to escape, or by classification designations. This does not mean, necessarily, that the components of every new structure have to be fire tested. In most cases, the fire rating has been already established by testing the product before it is even put on the market.

PART 3: Phenomenon of Desiccation

- Desiccation is a phenomenon referring to dryness of the material induced by the loss of moisture

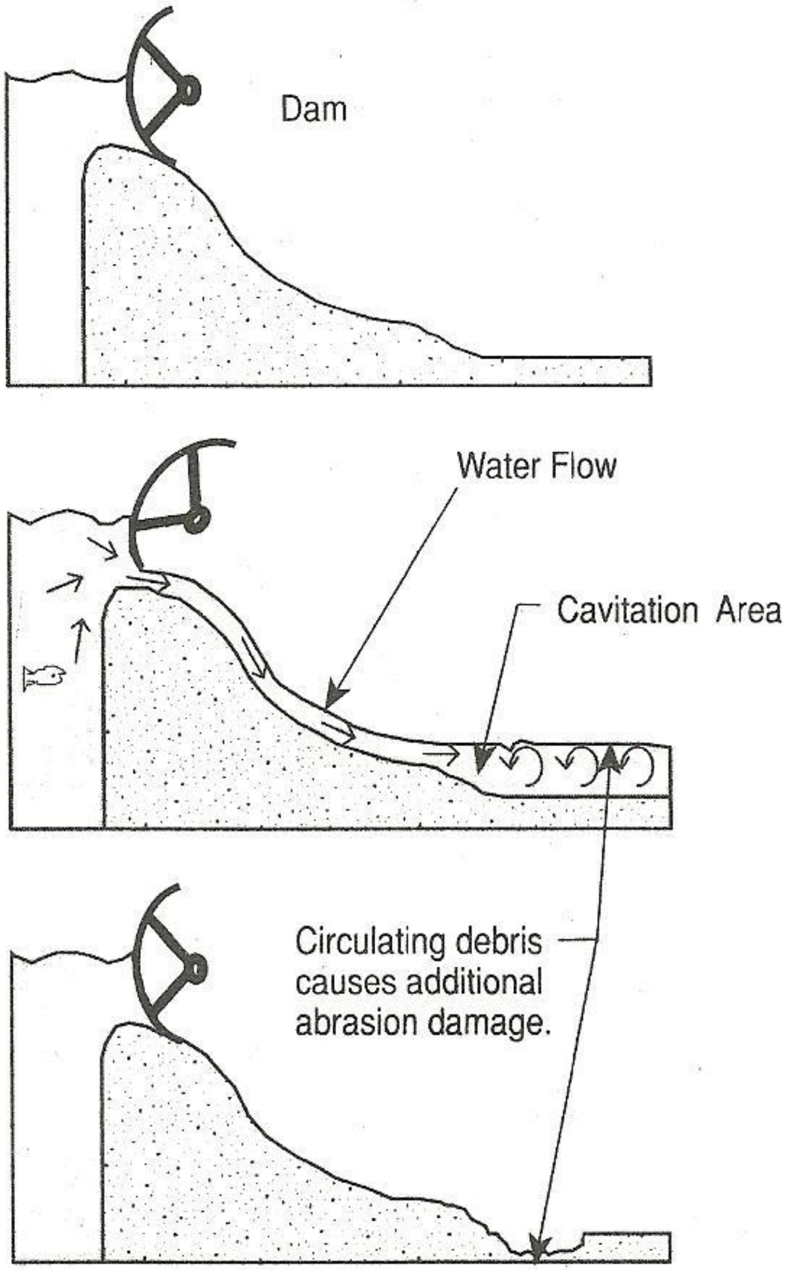
Erosion by Cavitation

Good-quality concrete shows excellent resistance to steady high-velocity flow of clear water; however nonlinear flow at velocities exceeding 40 ft/sec. may cause severe erosion of concrete due to cavitation.

CAVITATION

As water moves at a high velocity over a rough surface, vacuum bubbles or vapour bubbles form, due to pressure changes. These flow downstream and as they enter into a region of high pressure, they implode (collapse) with such a great force that they fracture the adjacent rock, thereby accelerating erosion.

The formation of vapour bubbles and they subsequent collapse is called cavitation.



Cavities are formed near the curves, offsets or at the centre of the vortices.

The imploding bubbles erode the cement matrix leaving the harder aggregate.

At high velocities, the forces of cavitation may be great enough to wear away large quantities of concrete

Prevention of Cavitation induced Erosion

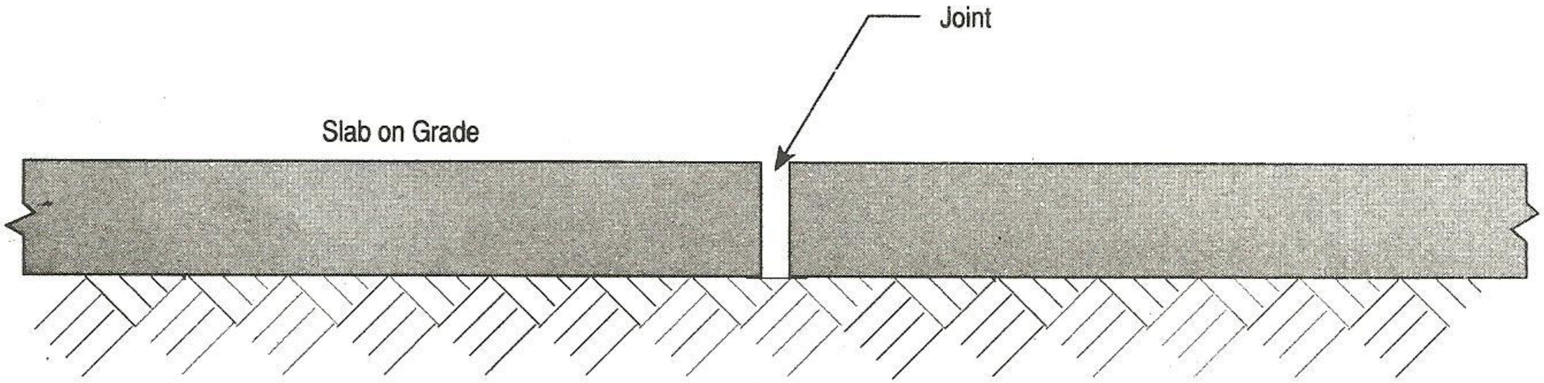
It is not enough to have a structural design in water retaining and irrigation structures , but it is equally important to consider the hydraulic design.

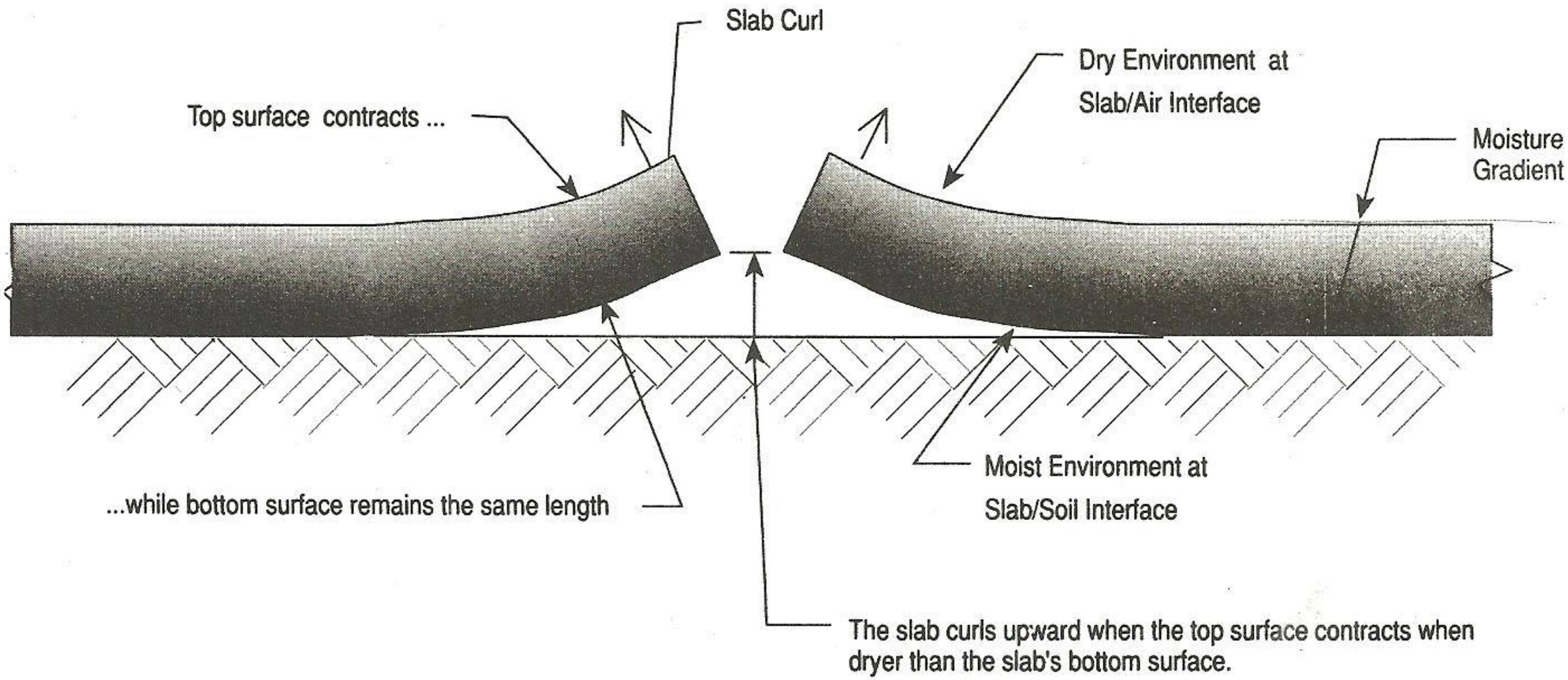
The structure should have smooth surfaces and must not have protruding obstructions to flow, surface misalignments and abrupt changes in slopes.

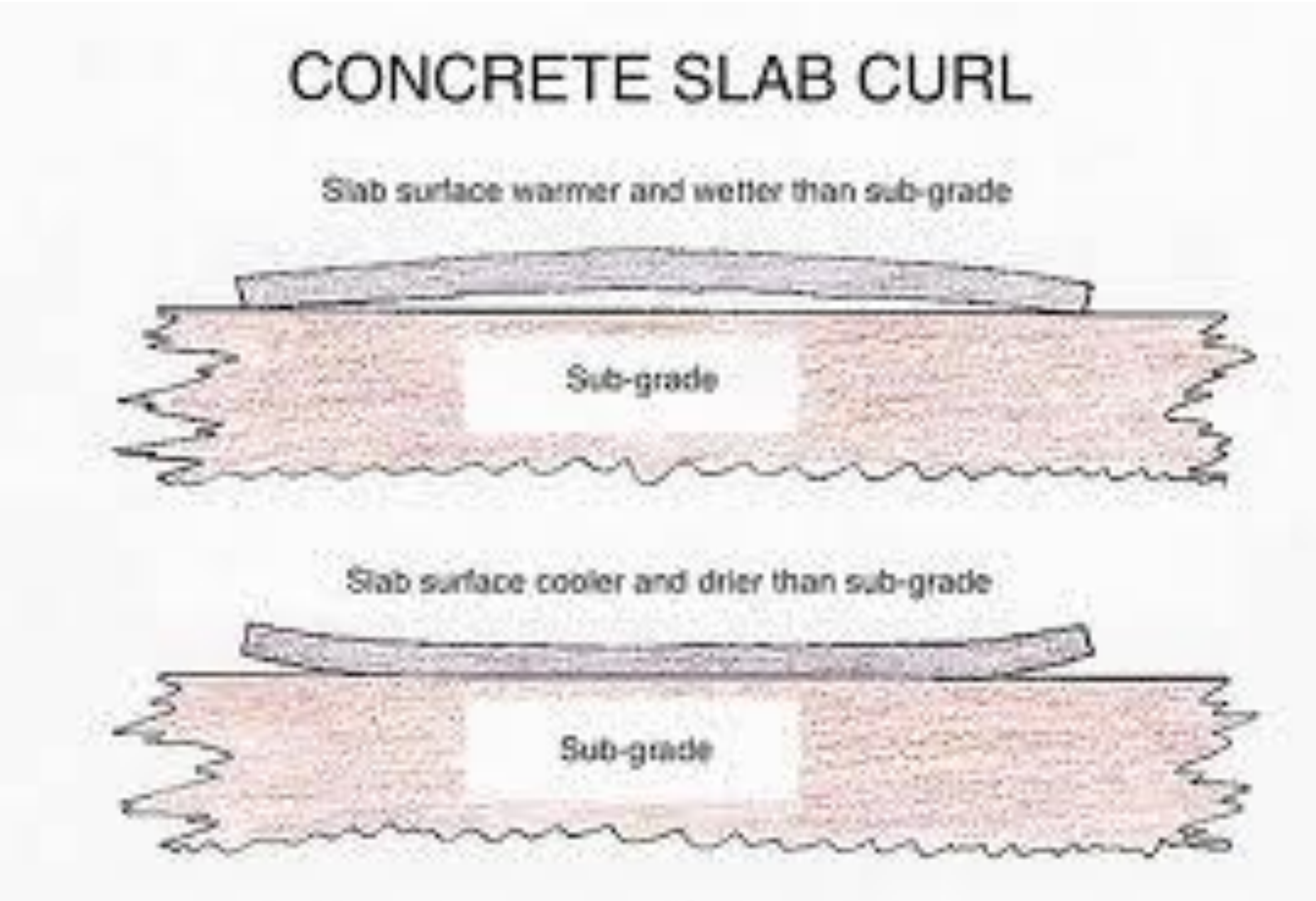
Curling

- **Effect of Moisture gradient:** **The top drier surface has a tendency to contract in length relative to the moist bottom surface. Stress releases by the slab curling upwards.**

- **Effect of Temperature gradient:** **Due to solar heating of the top surface the top surface has a tendency to grow in length as compared to the bottom surface. Stress releases by the slab curling downwards.**


Joint
Slab on Grade


Slab Curl
Dry Environment at
Slab/Air Interface
Top surface contracts ...
Moisture
Gradient
...while bottom surface remains the same length
Moist Environment at
Slab/Soil Interface
The slab curls upward when the top surface contracts when
dryer than the slab's bottom surface.


CONCRETE SLAB CURL
Slab surface warmer and wetter than sub-grade
Sub-grade
Slab surface cooler and drier than sub-grade
Sub-grade

UNIT III

INSPECTION AND TESTING

INSPECTION AND TESTING

- Testing Methods
- Visual Inspection
- Non-Destructive Testing and Evaluations
- Semi-Destructive Tests

INSPECTION AND TESTING

Testing Methods

Condition Survey Procedure

1. **Visual Inspection**
2. **Review of Engineering Data**
3. **Condition Survey**
4. **Final Evaluation Analysis**
5. **Condition survey Report**

Visual Inspection
- a vital step to evaluation

Components

1. Tools and Equipment
2. Familiarization with the Engineering Data
3. Walk-through: What to look for?
4. Sketches
5. Mapping of deficiencies
6. Recommendations
    1. Sampling and Testing
    2. Non-destructive testing

Visual Inspection
- a vital step to evaluation

For Details:

1) Refer to NDT handbook - Chapter 2

TESTING METHODS

Mechanical Properties

- **Semi-destructive Tests**
- **Non-destructive Tests**

Testing For Mechanical Properties

Compressive Strength	Core testing, Windsor probe test, Rebound hammer test, Pull-out test
Quality of Concrete	Ultrasonic Pulse Velocity test
Tensile Strength	Pull off test, Splitting tensile test
Flexural Strength	Centre-point & third-point load test
Abrasion Resistance	Sand blasting test
Bond Strength	Pull off testing

Testing For Mechanical Properties

Already Discussed in Detail:

Detailed References:

1) Main Text book: Part 2
   Concrete Repair and Maintenance Handbook –
   P H Emmons and Sabnis
2) Concrete Technology – A R Santhakumar
   Chapter 25 **(Particularly see – Semi-destructive tests)**
3) NDT Handbook - Chapter 4, 7 and 11

TESTING METHODS

Chemical Properties

NDTs

Electrochemical Activity

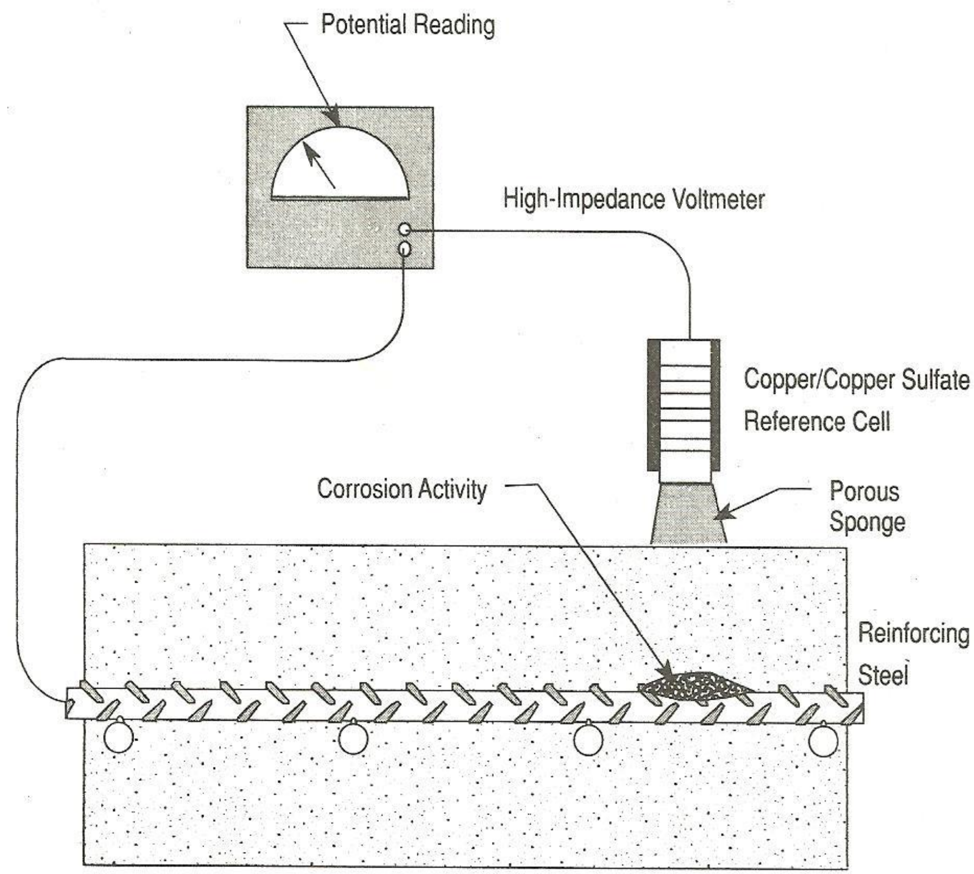
I. Half Cell Potential Method

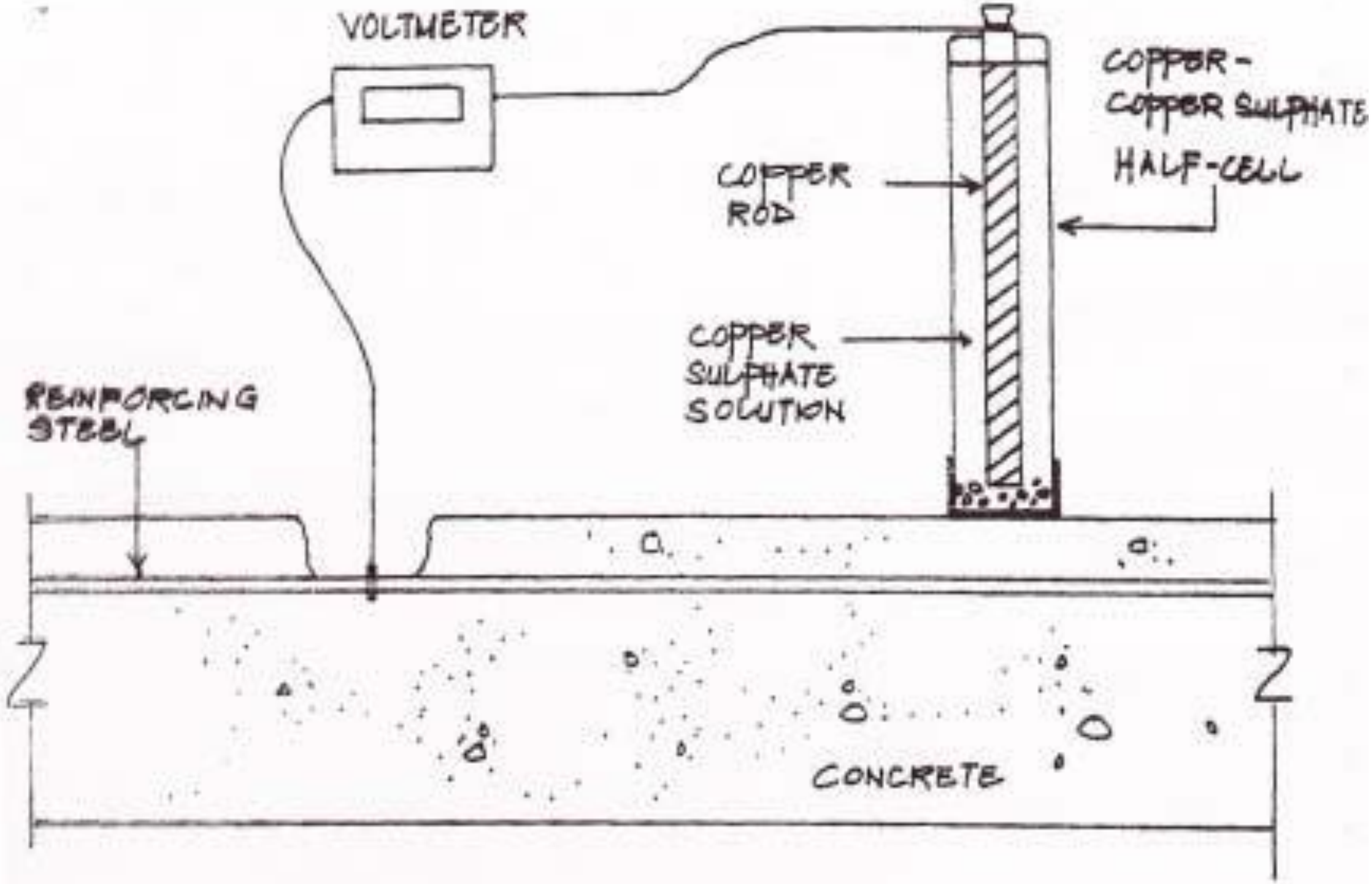
(also called Open-Circuit Potential Measurement Technique)

The half-cell is usually a copper/copper sulphate or silver/silver chloride cell.

The concrete functions as an electrolyte.

The risk of corrosion of the reinforcement in the immediate region of the test location is related empirically to the measured potential difference.





COPPER-COPPER SULPHATE
HALF-CELL CIRCUITRY

Electrochemical Activity

II. Electrical Resistivity

Whilst the half cell potential measurement is effective in locating regions of corrosion activity, it provides no indication of the rate of corrosion. Electrical resistivity measurements give further insight into corrosion.

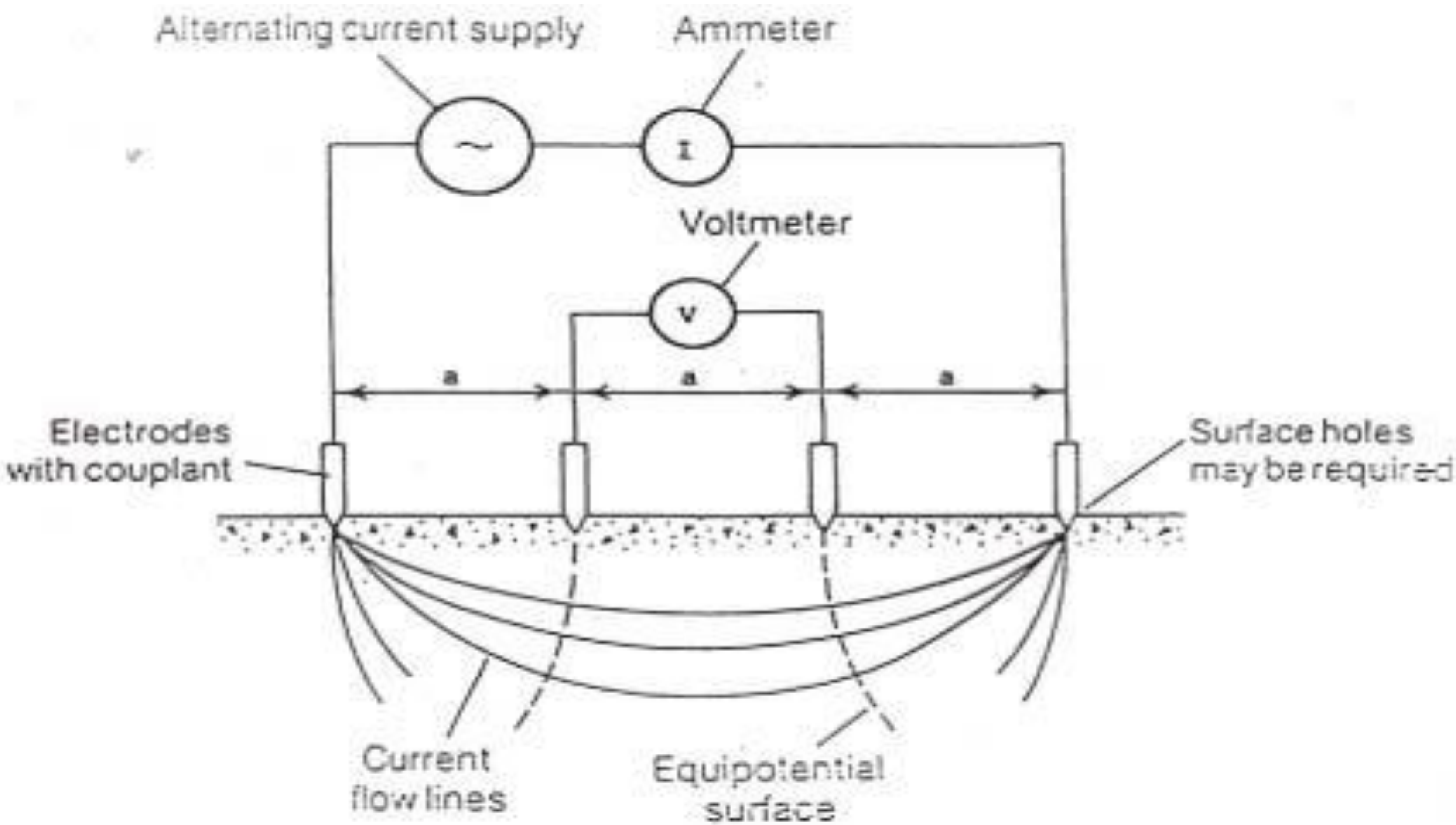
PRINCIPLE:

A low resistance path between anodic and cathodic sites would normally be associated with a high rate of corrosion than a high resistance path. Electrical resistivity measurements determine the current levels flowing between anodic and cathodic portions, or the concrete conductivity over the test area, and are usually used in conjunction with the half-cell potential technique. This is an electrolytic process as a consequence of ionic movement in the aqueous pore solution of the concrete matrix.

Electrochemical Activity

II. Electrical Resistivity

EQUIPMENT: Wenner 4 Probe Resistivity Meter



Electrochemical Activity

II. Electrical Resistivity

EQUIPMENT: Wenner 4 Probe Resistivity Meter

The equipment consists of four electrodes (two outer current probes and two inner voltage probes) which are placed in a straight line on or just below the concrete surface at equal spacings. A low frequency alternating electrical current is passed between the two outer electrodes whilst the voltage drop between the inner electrodes is measured.

The apparent resistivity (ρ) in "ohm-cm" may be expressed as:

$$\rho = 2\pi aV/I$$

where
V is voltage drop,
I is applied current,
a is electrode spacing.

Electrochemical Activity

II. Electrical Resistivity

Spacing of probes in the Resistivity Meter

The spacing of the four probes determines the regions of concrete being measured. It is generally accepted that for practical purposes, the depth of the concrete zone affecting the measurement will be equal to the electrode spacing. If the spacing is too small, the presence or absence of individual aggregate particles, usually having a very high resistivity, will lead to a high degree of scatter in the measurement. Using a larger spacing may lead to inaccuracies due to the current field being constricted by the edges of the structure being studied. In addition, increased error can also be caused by the influence of the embedded steel when larger spacings are employed. A spacing of 50 mm is commonly adopted, gives a very small degree of scatter and allows concrete sections in excess of 200 mm thick to be measured with acceptable accuracy.

TESTING FOR CHEMICAL PROPERTIES

CARBONATION DEPTH MEASUREMENT

Carbonation Depth Measurement
I. Acid Base Indicators

Principle:

Carbonation of concrete occurs when the carbon dioxide, in the atmosphere in the presence of moisture, reacts with hydrated cement minerals to produce carbonates, e.g. calcium carbonate. The carbonation process is also called depassivation, as it reduces the pH value of the concrete matrix.

Carbonation penetrates below the exposed surface of concrete extremely slowly. The time required for carbonation can be estimated knowing the concrete grade and using the following equation:

$$t = (d/k)^2$$

where
t is the time for carbonation,
d is the concrete cover,
k is the permeability.

Carbonation Depth Measurement
I. Acid Base Indicators

TABLE 5.1. PERMEABILITY VALUES VERSUS CONCRETE GRADE

Concrete Grade	Permeability
15	17
20	10
25	6
30	5
35	4
40	3.5

Carbonation Depth Measurement
I. Acid Base Indicators

Method to Measure the Depth of Carbonation:

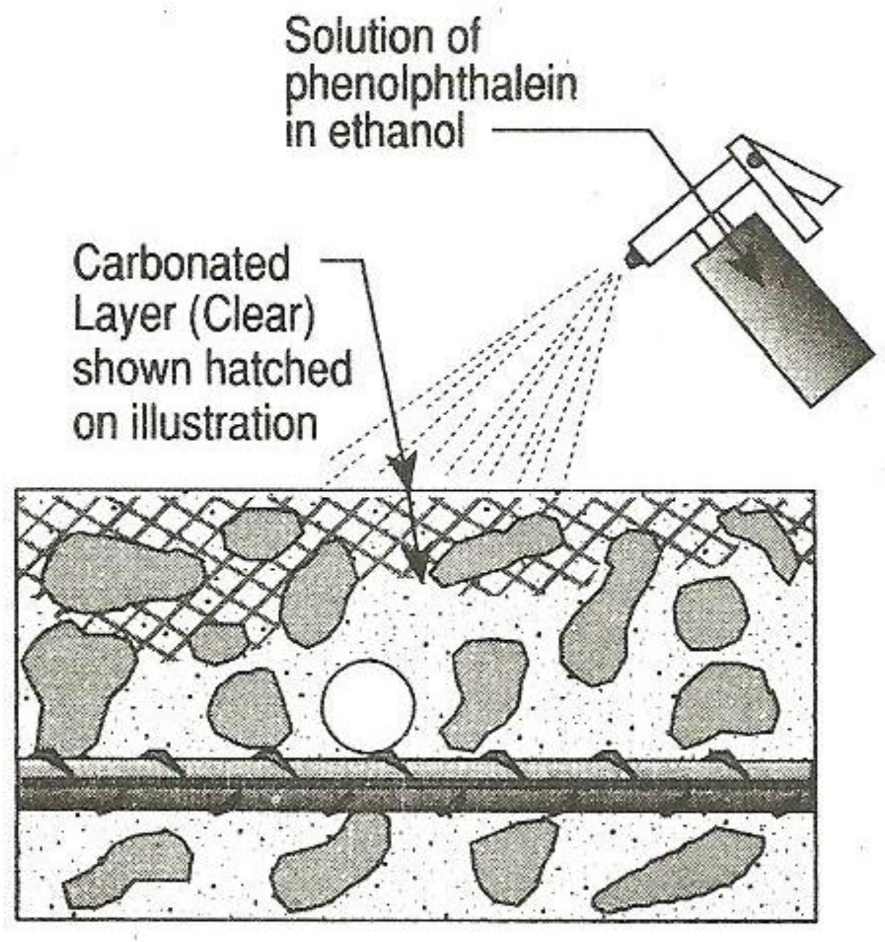
The 1% phenolpthalein solution is made by dissolving 1gm of phenolpthalein in 90 cc of ethanol. The solution is then made up to 100 cc by adding distilled water. On freshly extracted cores the core is sprayed with phenolphthalein solution, the depth of the uncoloured layer (the carbonated layer) from the external surface is measured to the nearest mm at 4 or 8 positions, and the average taken. If the test is to be done in a drilled hole, the dust is first removed from the hole using an air brush and again the depth of the uncoloured layer measured at 4 or 8 positions and the average taken.

If the concrete still retains its alkaline characteristic the colour of the concrete will change to purple (pink). If carbonation has taken place and pH lowers below 10 there will be no colour change.

Carbonation Depth Measurement

I. Acid Base Indicators

Method to Measure the Depth of Carbonation:



Carbonation Depth Measurement

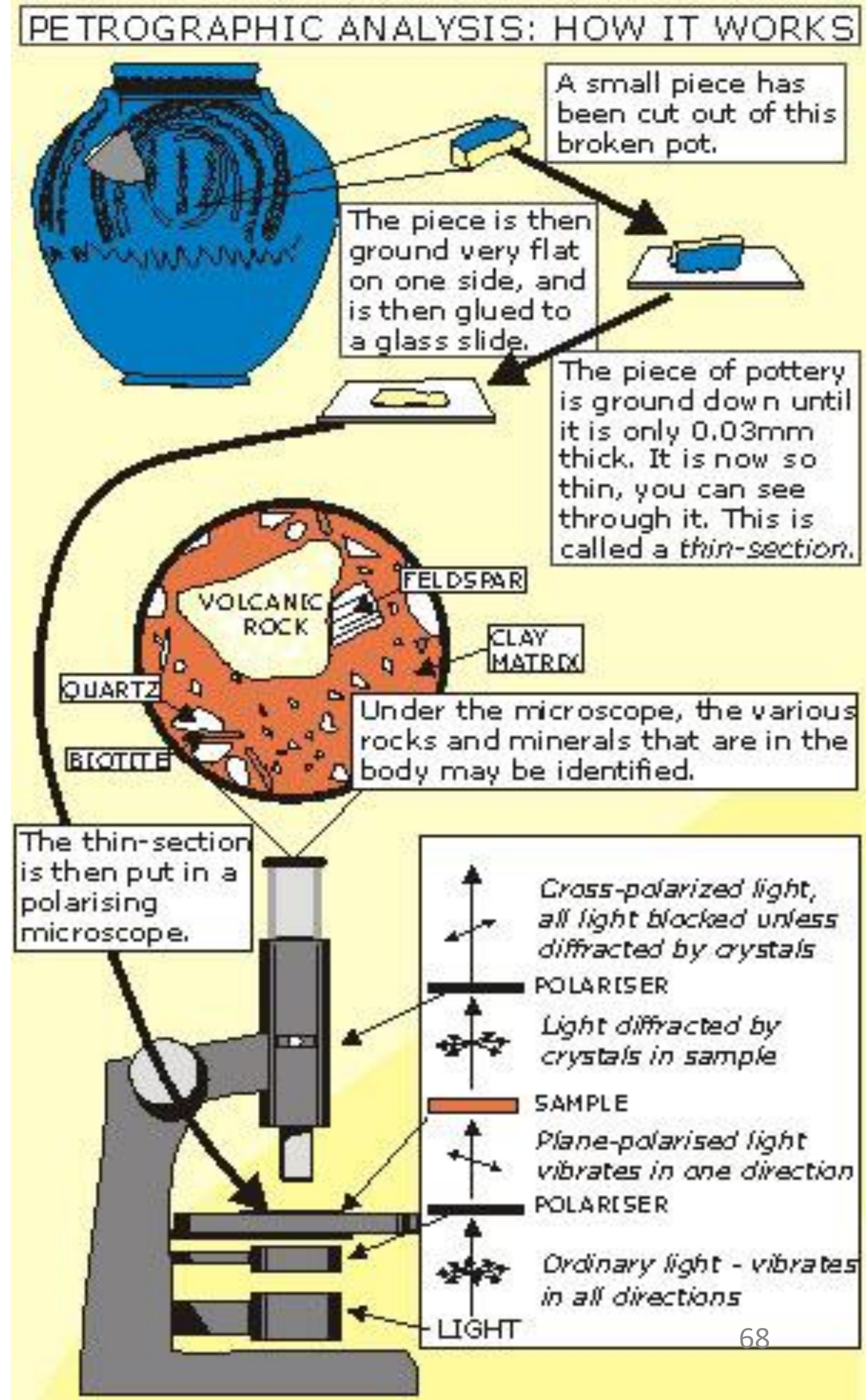
II. Petrographic Analysis

What is Petrographic Analysis?

Petrographic analysis is a technique developed in the earth-sciences for observation of rocks and minerals. It involves creating a "thin-section" of the material being studied. Once the thin-section is made it is viewed through a polarising microscope, which has two polarizing filters oriented at right-angles to each other, thereby blocking out any light . However, a sample containing minerals may diffract the light, so that they are visible in cross-polarized light. The degree of diffraction is a key characteristic enabling identification of the crystals.

Illustration

The petrographic examination helps to improve the extrapolation from test results to performance in situ. Together with various other concrete tests, petrographic analysis helps to determine why this concrete in situ behaved in the way it did, and how it may behave in the future.



Carbonation Depth Measurement
II. Petrographic Analysis

To perform this type of analysis, concrete specimens are taken from the structure and are prepared by either polishing or etching a surface of the specimen. Petrographic examination includes identification of mineral aggregates, aggregate-paste interface, assessment of the structure, and integrity of the cement paste.

Petrographic examination helps determine some of the following mechanisms:

1) Freeze-thaw resistance
2) Sulfate attack
3) Alkali-aggregate reactivity
4) Aggregate durability
5) Carbonation

TESTING FOR CHEMICAL PROPERTIES

ALKALI-AGGREGATE REACTION, SULPHATE ATTACK BY PETROGRAPHIC ANALYSIS

Source: http://www.fhwa.dot.gov/pavement/concrete/pubs/hif09004/asr11.cfm

Source: http://alkalisilicareaction.blogspot.in/

TESTING FOR CHEMICAL PROPERTIES

CHLORIDE CONTENT

Chloride Content Measurement

A sample of powder is obtained by drilling and careful quartering. Then an accurately weighed 3 gr. sample is dissolved in 20 ml of extraction liquid which consists of a precise, measured concentration of acid. For sampling wet concrete a 3 gr. sample of mortar is used.

The chloride ions react with the acid of the extraction liquid in an electrochemical reaction. An electrode, with integral temperature sensor, is inserted into the liquid and the electrochemical reaction measured. A uniquely designed instrument converts the voltage generated by the chloride concentration. The instrument automatically applies the temperature correction and it shows the chloride concentration on a LCD display in either lbs. per cu. yd. or percentage by weight. Once the sample is obtained, test results can be determined and read in less than five minutes.

Chloride Content Measurement

For more details of how the chlorimeter probe works:

Look at Section 25.4.9 : Quantab Test

From Concrete Technology
- A. R. Santhakumar

TESTING METHODS

Physical Condition Monitoring

NDTs

TESTING FOR PHYSICAL CONDITION

UNIFORMITY OF CONCRETE

UNIFORMITY OF CONCRETE

TESTING METHODS:

- Petrographic Analysis
- Ultrasonic Pulse Velocity Method
- Winsor Probe Method
- Rebound Hammer Test
- Core Examination and Testing

TESTING FOR PHYSICAL CONDITION

DELAMINATION AND VOIDS

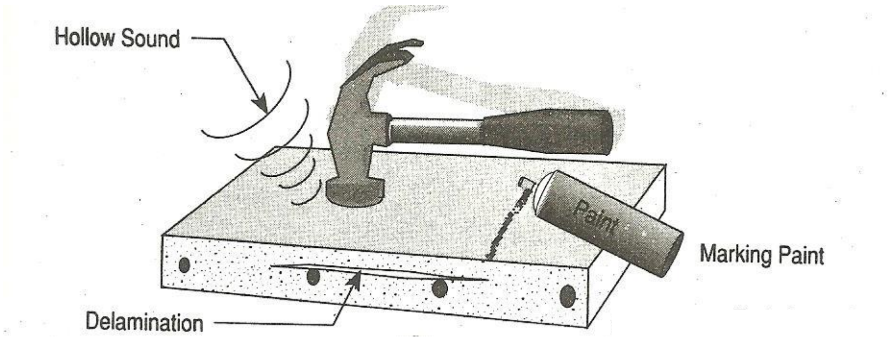
DELAMINATION / VOIDS DETECTION

TESTING METHODS:

- Hammer Sounding
- Chain Drag
- Impact Echo
- Pulse Velocity
- Exploratory Removal
- Remote Viewing (TV, borescope)
- Infrared Thermography

Refer to NDT Handbook for details

DELAMINATION / VOIDS DETECTION
I. Hammer Sounding



When striking the areas of delamination the sound of the hammer changes from solid sound ("ping") to a hollow sound ("pluck").

Low-cost accurate method but highly time consuming. Not possible to access all location.

TESTING FOR PHYSICAL CONDITION

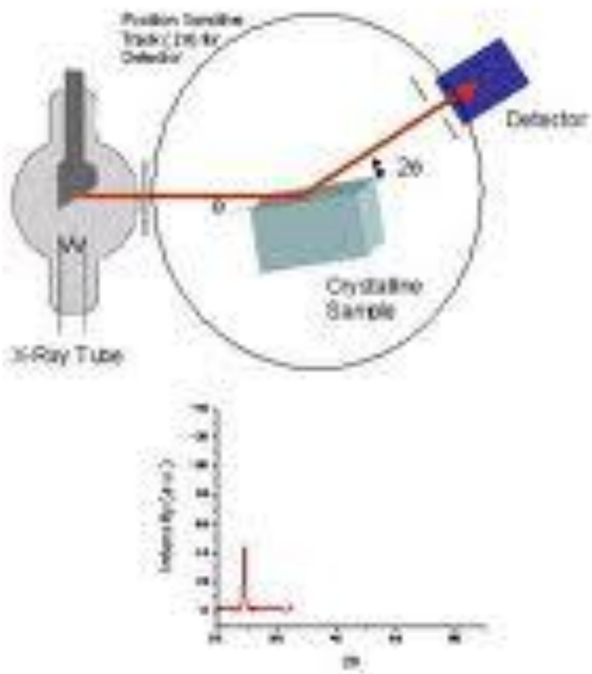
HYDRATION CHARACTERISTICS OF HARDENED CONCRETE

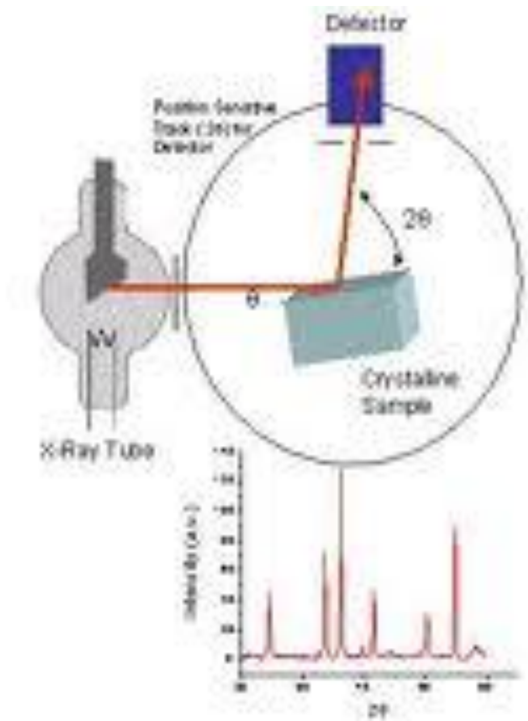
(A) X-ray diffractrometry (XRD)
(B) X-ray fluorescence spectroscopy (XRF)
(C) Differential Thermal Analysis (DTA)

HYDRATION CHARACTERISTICS

I. X-ray Diffractrometry (XRD)

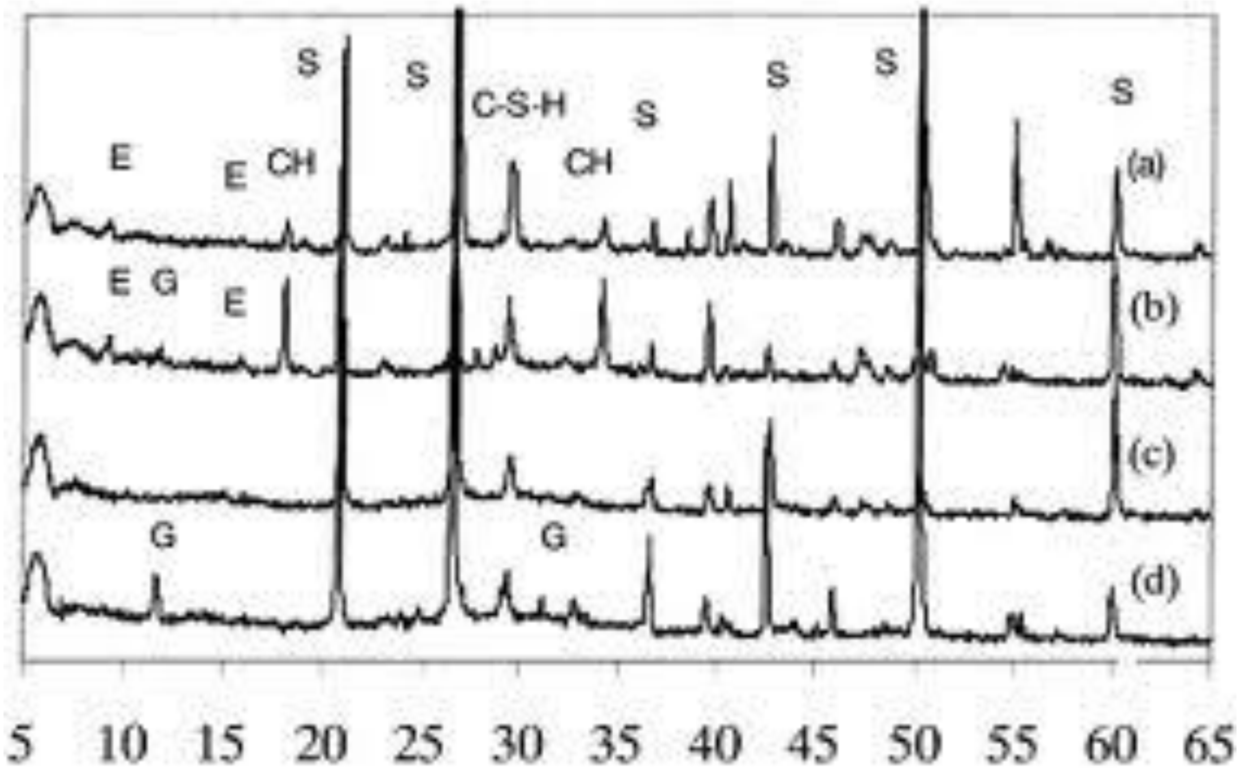
A powdered sample of concrete is bombarded with high-energy X-rays. Different mineral constituents refract through different angles on incidence of X-rays. The presence of various mineral ingredients are detected by examining an XRD pattern.





HYDRATION CHARACTERISTICS

I. X-ray Diffractrometry (XRD)



The XRD pattern shows the intensity of the X-ray plotted against the angle of the reflected beam. The peaks generally indicate calcium hydroxide, calcite, calcium silicate hydrate, etc. in concrete.

HYDRATION CHARACTERISTICS

II. X-ray Fluorescence (XRF) Spectroscopy

A sample of concrete is bombarded with high-energy X-rays and the fluorescent emission so caused is collimated into a parallel beam, directed on to the analysing crystal within a spectrometer and reflected into a detector.

The wavelength and the density of the fluorescent emission measured give the properties of the constituent materials. This method is a comparative one and the results obtained are compared with samples of known properties.

HYDRATION CHARACTERISTICS
III. Differential Thermal Analysis (DTA)

DTA uses the rate of change of temperature of a sample when heated at a constant rate of heat input. It involves heating a small sample of powdered concrete in a furnace together with a sample of inert material. The DTA graph shows a series of peaks at particular temperatures, which are characteristic of minerals in the concrete sample under test.

This test is useful for assessment of exposed temperatures for a fire damaged concrete structures and can also for assessment of the depth of affected concrete.

TESTING FOR PHYSICAL CONDITION

CRACKS AND SPALLS

CRACKS AND SPALLS DETECTION

TESTING METHODS:

- Hammer Sounding
- Infrared Thermography
- Impact Echo Testing
- Pulse Velocity Method
- Remote Viewing (TV, Borescope)
- Exploratory Removal

UNIT IV: REPAIR IN STRUCTURES

Syllabus Description

- Common Types of Repairs
- Repairs in Concrete Structures
- Repairs in Underwater Structures

  (Guniting, Shotcrete, Underpinning)

SYNOPSIS

- **Repair and Rehabilitation of Structures**
  - **Broad Classification**
- **Repair Materials**
  - **Material Requirements**
  - **Material Types**
- **Types of Surface Repairs**
  - **Repair of Cracks**
  - **Repair of Spalling and Disintegration**

Repair and Rehabilitation of Concrete Structures

BROAD CLASSIFICATION

BROAD CLASSIFICATION

Repair and Rehabilitation

SURFACE REPAIRS

- Repairing Cracks
- Repairing Deteriorations
  (spalling & disintegration)

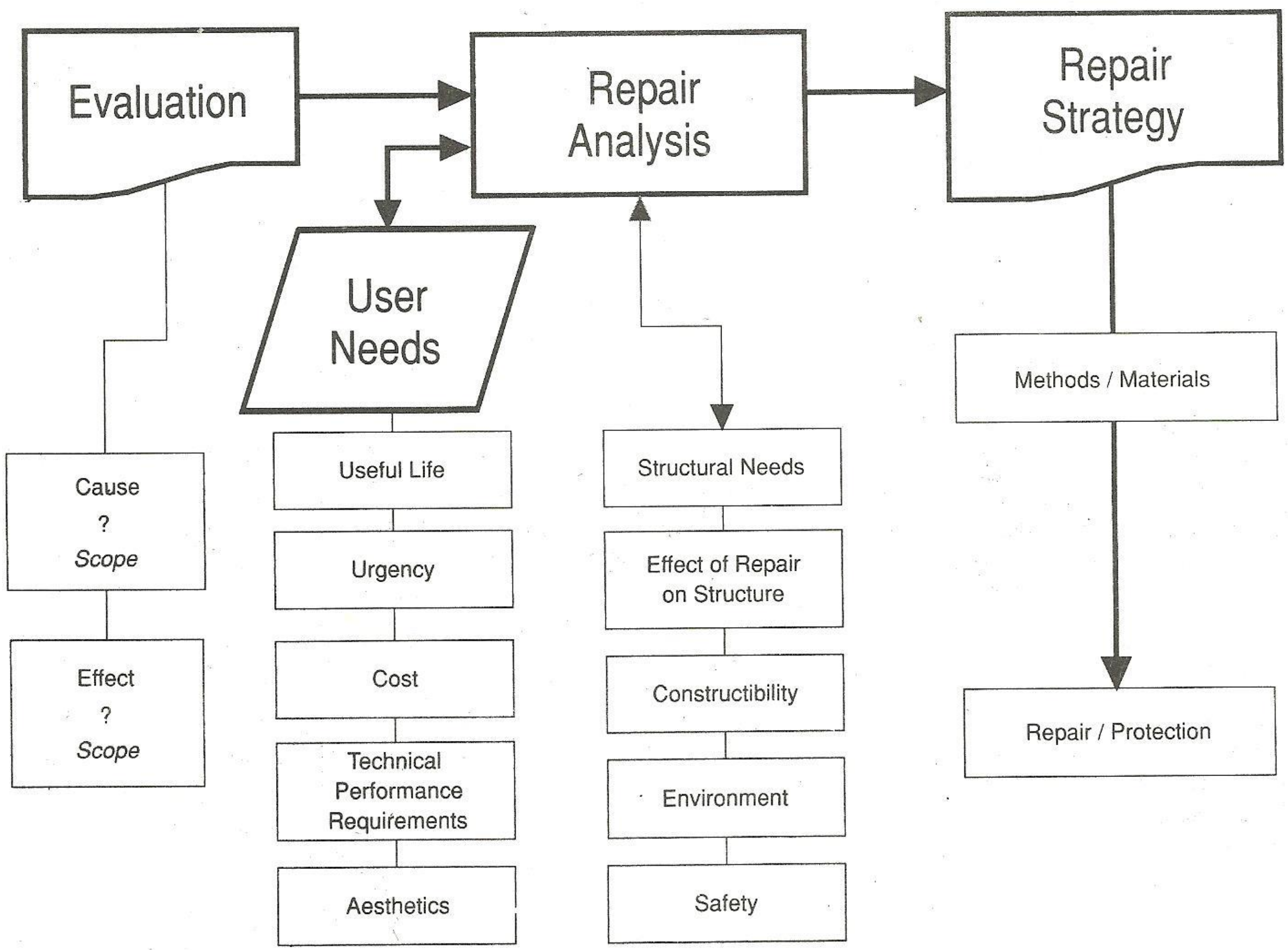
STRENGTHENING OF STRUCTURAL COMPONENTS

- Enlargements
- Composite Construction

In this session we are focusing on surface repairs

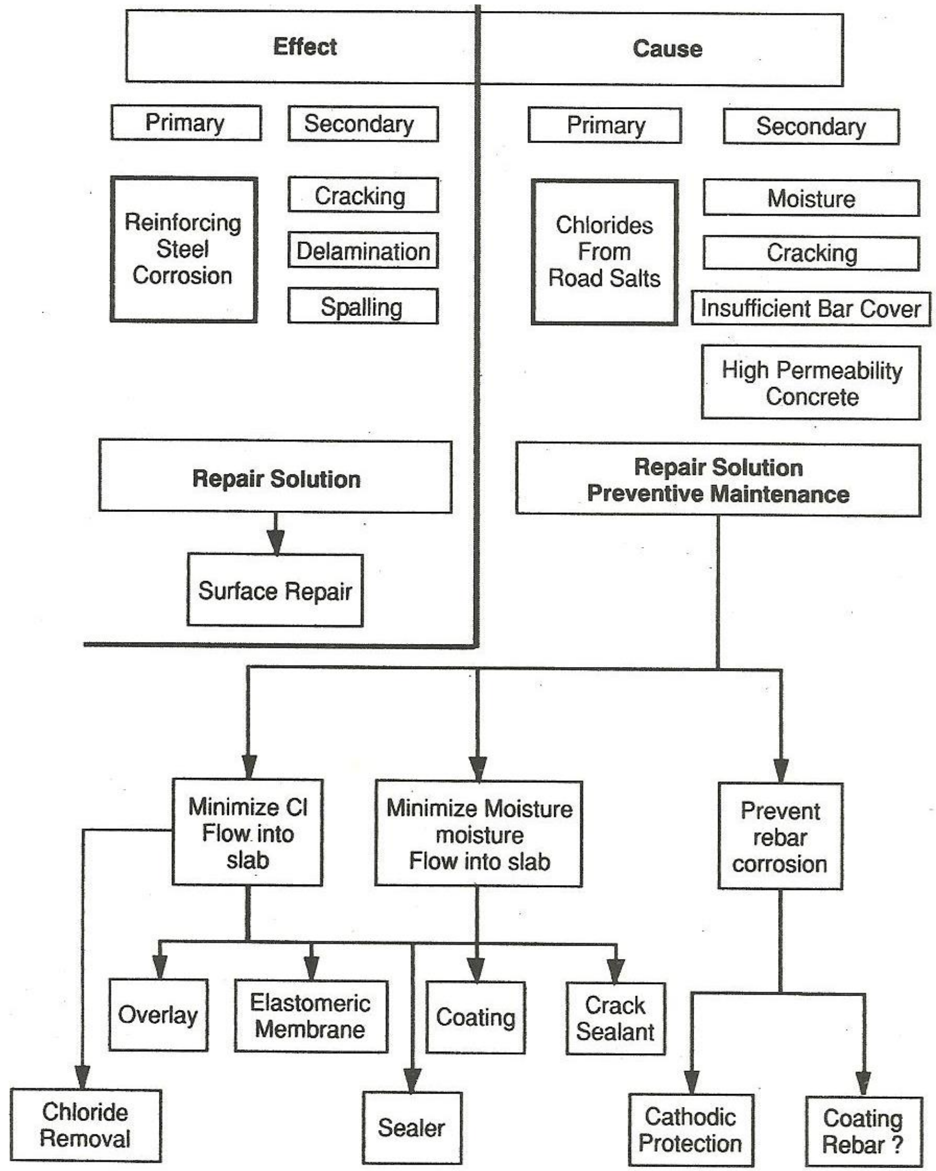
SURFACE REPAIRS

EVALUATION – ANALYSIS - STRATEGY



EVALUATION – ANALYSIS – STRATEGY

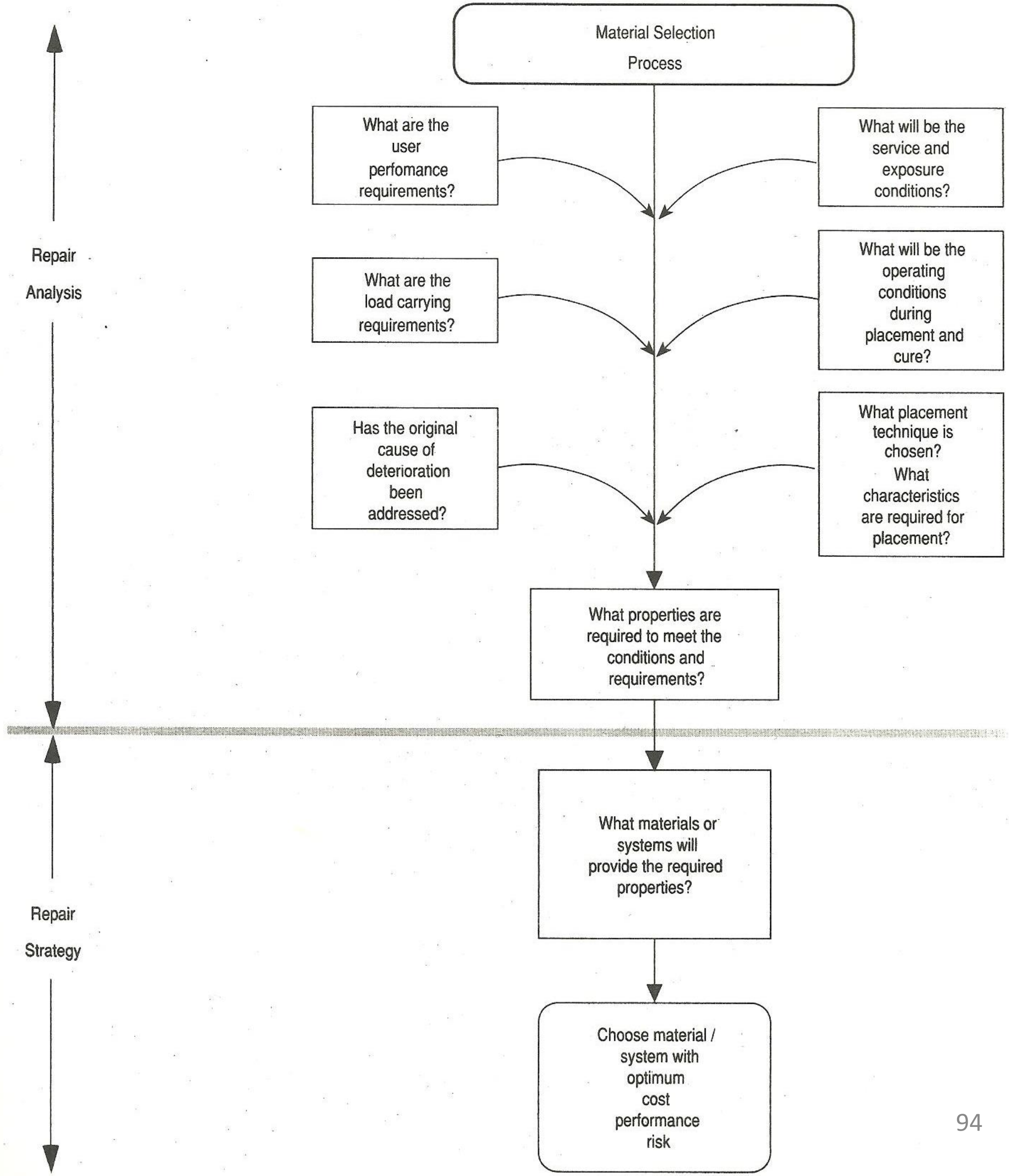
Example of Spalling due to Corrosion



REPAIR MATERIALS

- MATERIAL REQUIREMENTS
- MATERIAL TYPES

MATERIAL SELECTION PROCESS



REPAIR MATERIALS

- MATERIAL REQUIREMENTS

MATERIAL REQUIREMENTS

DESIRED PROPERTIES OF REPAIR MATERIALS

1. **Engineered materials with high performance, high durability and low maintenance**
   - Composites
   - Polymers
   - High performance concrete
2. **Materials must be easy to use, have high productivity and reduce construction cycle time**
   - High flow self-levelling concrete/mortar
   - Setting time controlling materials
   - Materials with wide applicability for varied substrate and environmental conditions
3. **Safe for the workers and users, environment friendly: which do emanate toxics or irritating fumes during application or service**
4. **Materials that do not add to the dead weight of the repaired component or the structure**

MATERIAL REQUIREMENTS

MATERIALS PROPERTIES AS PER REPAIR REQUIREMENTS

CHOICE OF THE MATERIAL HAS A CHEMICAL ANGLE
- Not just chemical composition but its performance characteristics

Selection of the Repair Material is guided by

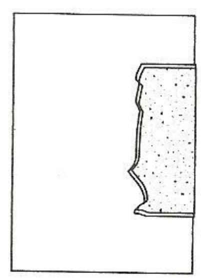
- Type of the structure
- Type of the service conditions and environment
- Nature of the deterioration
- Extent of the deterioration
- Appearance
- Economic considerations

MATERIAL REQUIREMENTS

MATERIALS PROPERTIES AS PER REPAIR REQUIREMENTS

LOAD CARRYING PROPERTIES

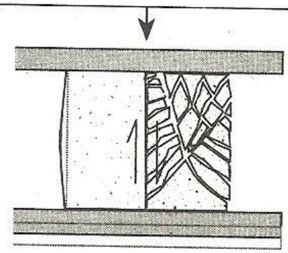
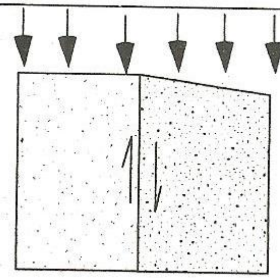
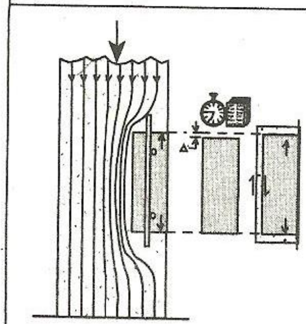
Load-Carrying Properties

Goal (performance requirements)	Results if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
Bond to substrate	 Loss of bond, delamination, detachment of repair from substrate	Tensile bond, low internal stress	High internal stress caused by thermal incompatibility, drying shrinkage*

MATERIAL REQUIREMENTS

MATERIALS PROPERTIES AS PER REPAIR REQUIREMENTS

LOAD CARRYING PROPERTIES

Goal (performance requirements)	Results if the wrong material is selected (undesirable response)	Look for these properties	Avoid these!
Load carrying as intended by the engineer	 Does not carry loads as anticipated, overstressing either substrate or repair material	Equal modulus of elasticity with substrate	Low or high modulus of elasticity compared to substrate
	 Carries loads initially, but over time, the repair relaxes under creep deformation.	Extremely low compression creep	High compression creep
	 Drying shrinkage causes material to lose volume, reducing its ability to carry compressive loads.	Extremely low drying shrinkage*	Shrinkage*

MATERIAL TYPES

GENERAL CLASSIFICATION OF REPAIR MATERIALS

1. Portland cement based materials
2. Polymer modified concrete
3. Resin based mixtures
4. Substitute materials/Recent products

MATERIAL TYPES

1. PORTLAND CEMENT BASED MATERIALS

1. Portland cement mortar
2. Portland cement concrete

- The commonly used cement mortar or concrete with similar properties as the substrate.
- General observation is that problems such as shrinkage, cracking or even eventual failure of the repair work occurs

MATERIAL TYPES

2. POLYMER MODIFIED CONCRETE PRODUCTS

1. Polymer modified cement
2. Polymer modified mortar
3. Polymer modified concrete
   - also called Latex Modified Concrete (LMC)
4. Polymer and fibre-modified mortar
5. Polymer mortar
6. Polymer concrete (PC)
7. Polymer impregnated concrete (PIC)

MATERIAL TYPES

2. POLYMER MODIFIED CONCRETE PRODUCTS

- Polymer products have better durability under long-term exposure to UV radiation.
- In cement mortar or concrete, the polymer can be used as a second binder to the mix.
- Polymer mortars form matrix with cement in two-phase systems
  1. In the cementitious water phase, fine polymer particles of 0.1 – 0.2 μm are dispersed
  2. With cement, polymer particles join to form chain link reinforcement matrix increasing the tensile and flexural strength.

  Matrix achieves greater plasticity and reduces shrinkage stress.

MATERIAL TYPES

2. POLYMER MODIFIED CONCRETE PRODUCTS

Polymer Concrete (PC) is formed by polymerizing a mixture of a monomer and aggregate (no other bonding material is present)

Latex-Modified Concrete (LMC) is also known as Polymer Portland Cement Concrete. It is conventional concrete made by replacing part of mixing water with a latex.

Polymer-Impregnated Concrete (PIC) is produced by impregnating or infiltrating a hardened concrete with a monomer and subsequently polymerizing the monomer in-situ.

Both PC and LMC have been in commercial use since the 1950s.
PIC was developed and has been in use since the 1970s.

MATERIAL TYPES

2. POLYMER MODIFIED CONCRETE PRODUCTS

Polymer Concrete (PC)

Polymer concrete (PC) is a mixture of aggregates with a polymer as the sole binder. To minimize the amount of the expensive binder, it is very important to achieve the maximum possible dry-packed density of the aggregate.

Commercial products are available with a variety of formulations, some capable of hardening to 105 MPa within a few minutes without thermal treatment.

Due to good chemical resistance and high initial strength and modulus of elasticity, industrial use of PC has been mainly in overlays and repair jobs.

Thermal and creep characteristics of the material are usually not favourable for structural applications of PC.

MATERIAL TYPES

2. POLYMER MODIFIED CONCRETE PRODUCTS

Latex Modified Concrete (LMC)

The materials and the production technology for concrete in LMC are the same as those used in normal portland cement concrete except that latex, which is a colloidal suspension of polymer in water, is used as an admixture.

A latex generally contains about 50 % by weight of spherical and very small (0.01 to 1 m in diameter) polymer particles held in suspension in water by surface-active agents.

Earlier latexes were based on polyvinyl acetate or polyvinylidene chloride, but these are seldom used now because of the risk of corrosion of steel in concrete in the latter case, and low wet strengths in the former.

Elastomeric or rubberlike polymers based on styrenebutadiene and polyacrylate copolymers are more commonly used now.

TYPES OF SURFACE REPAIR

- Repair of Spalling and Disintegration

Repair of Spalling and Disintegration

1) Placement of repair material
    - Form and Cast in place
    - Form and pump
2) Dry Packing
3) Prepacked concrete (Grout Preplaced Aggregate)
4) Pneumatically Applied Mortar
    - Dry Mix Shotcrete (Guniting)
    - Wet Mix Shotcrete
5) Replacement of concrete (Full depth repair)
6) Overlays
7) Protective surface treatments
8) Hand-applied treatment

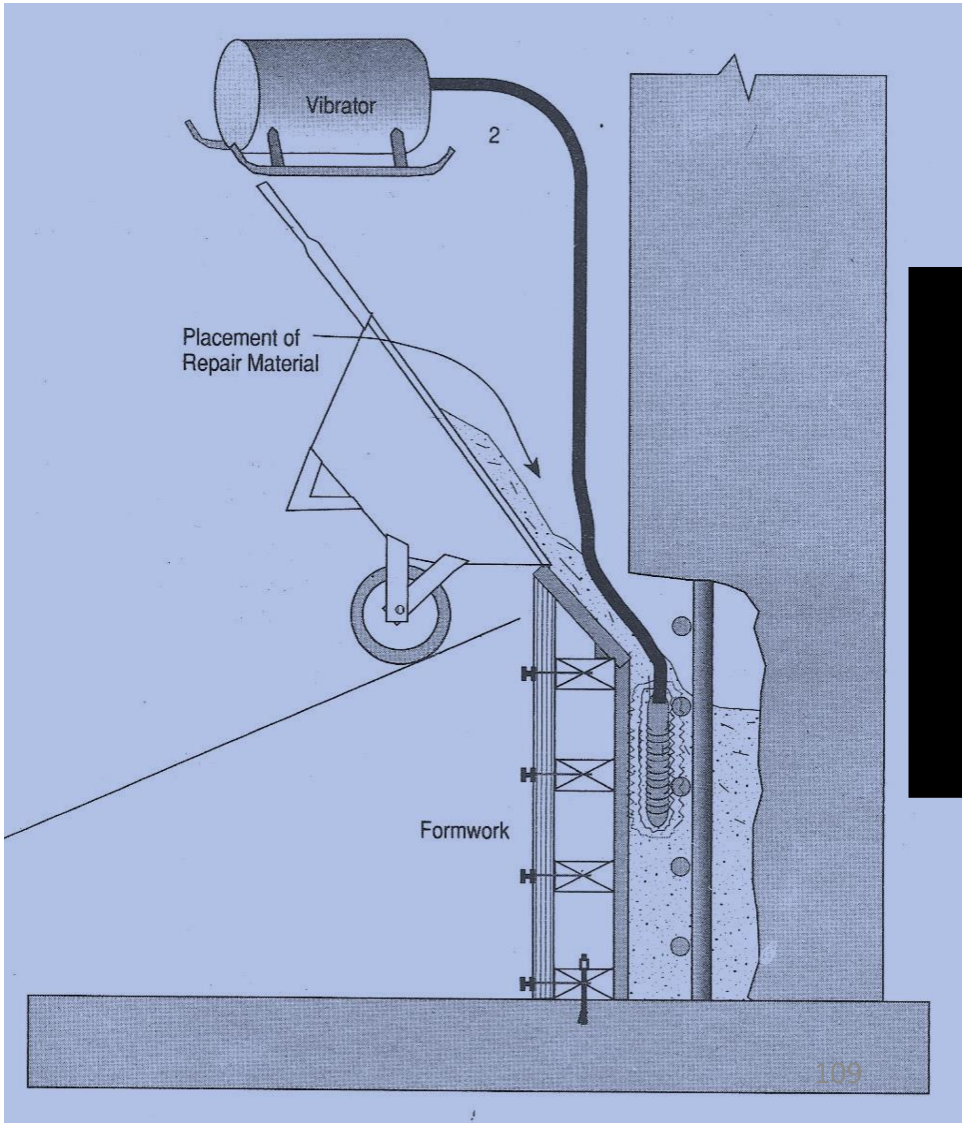
Repair of Spalling and Disintegration

1) Placement of Repair Material : (A) Form and Cast-in-Place

One of the most common methods of surface repair of vertical and, in some cases, overhead locations is the placement of formwork and casting of repair material into the prepared cavity.

Formwork facilitates the use of many different repair materials, selected on the basis of in-place performance vs. constructibility. The repair material must be of low shrinkage and provide the necessary flowability.

Placement of repair materials follows normal placement practice. Rodding or internal vibration is necessary to remove air and provide intimate contact with the existing concrete substrate.



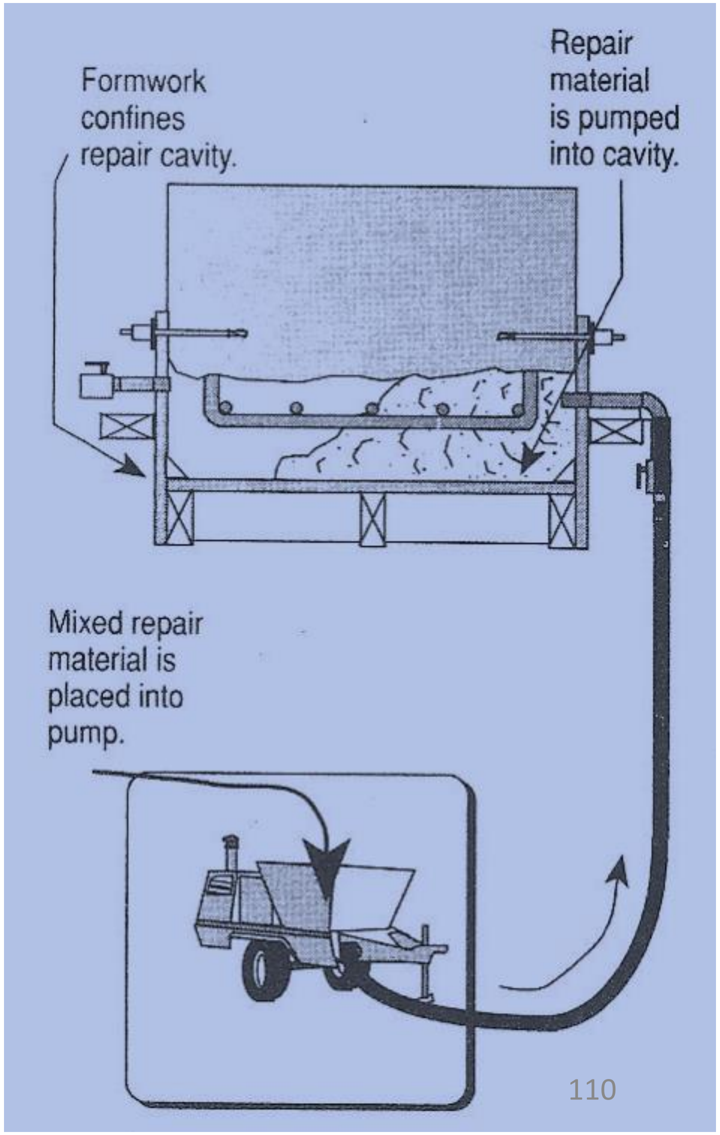
Repair of Spalling and Disintegration

1) Placement of Repair Material : (B) Form and Pump

The form and pump repair method is a two-step process of constructing formwork and pumping repair material into the cavity confined by formwork and existing concrete.

The form and pump technique allows the use of many different repair materials. The necessary requirement for material selection is pumpability.

Various pumps are used, depending upon the mix design (particularly the aggregate size). Prior to construction of formwork, any surfaces that may cause air to become trapped during the pumping process must be trimmed, or vent tubes installed.

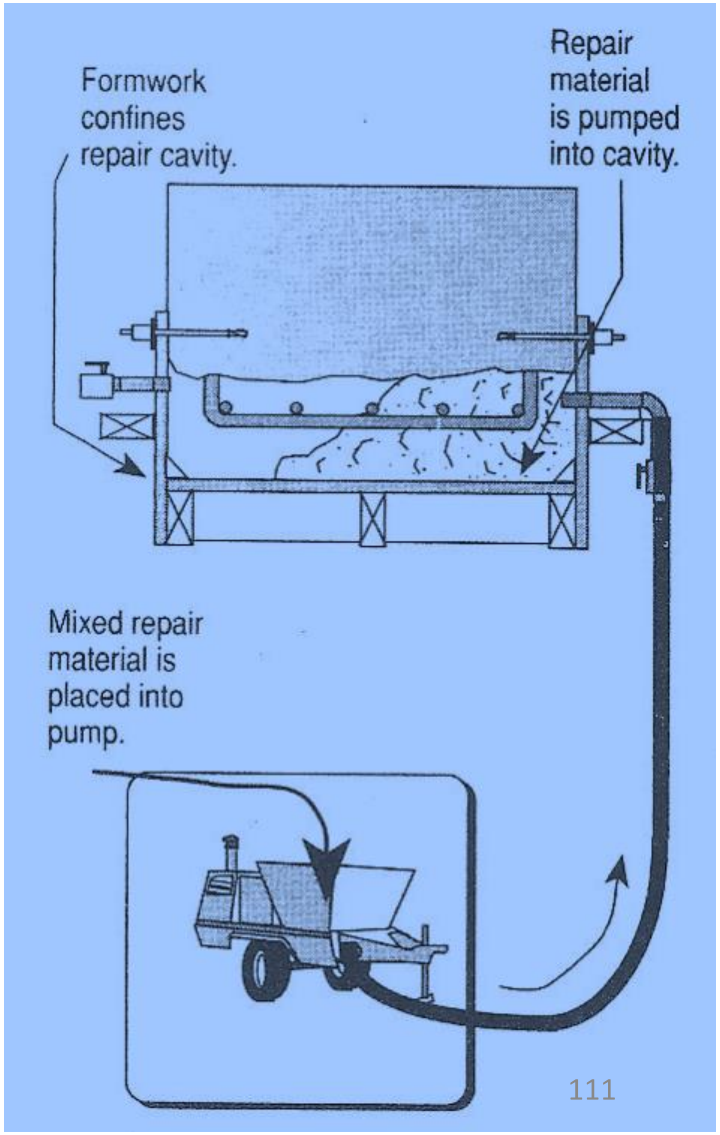


Repair of Spalling and Disintegration

1) Placement of Repair Material : (B) Form and Pump

Repair materials are mixed and pumped into the confined cavity. The sequence of pumping is from low points to high points and when performed overhead, from one extremity to the other. Large areas may require bulk-heading to separate placements into manageable areas.

When the cavity is full, pump pressure is exerted on the form, causing the repair material to consolidate and make intimate contact, and effect bonding with existing concrete surfaces.



Repair of Spalling and Disintegration

(B) Advantages of Form and Pump Technique

Form and pump technique offers many advantages to alternative techniques, such as shotcrete, hand-placement, and preplaced aggregate. Advantages include:

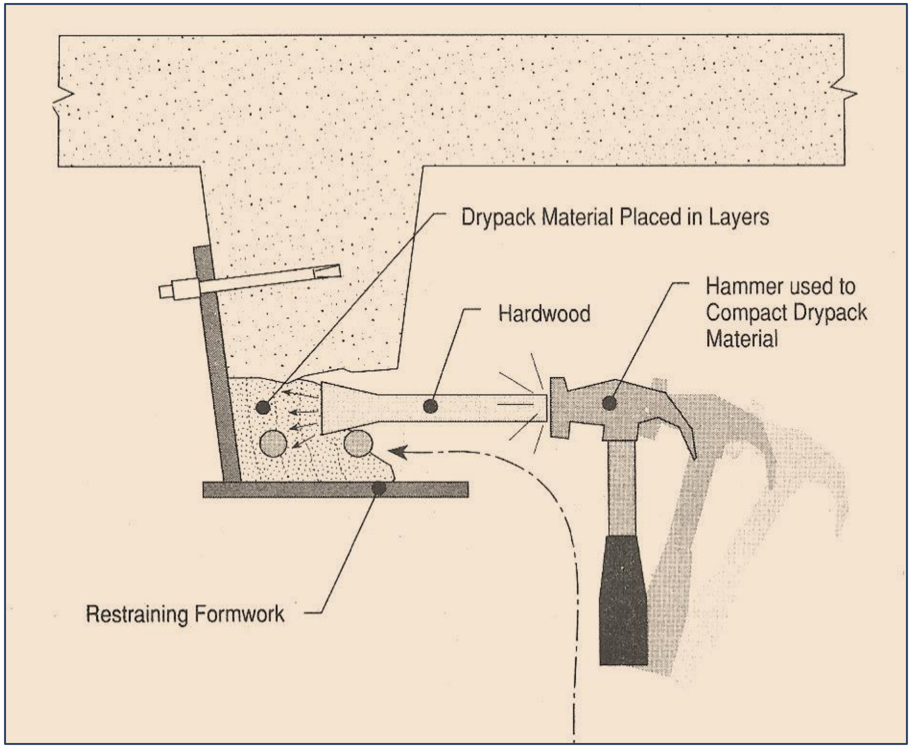
- The use of almost any repair material from fine grained mortars to coarse aggregate concrete, including polymers and hydraulic cement materials.
- Placement is not limited by depth of repair or by size or density of exposed reinforcement.
- Repair materials are premixed and placed to provide a uniform cross section without segregation or intermediate bond lines.
- The process does not depend on fighting the forces of gravity; all materials are supported by formwork during the placement and curing process.
- The pressurization process consolidates the repair material, providing for full encapsulation of exposed reinforcing steel.
- The formwork protects the repair material during the curing process.
- The process is less subject to individual operator error.
- Quality assurance of the in-place repair is easier to provide.

Repair of Spalling and Disintegration

2) Dry Packing

Dry packing is a method of placing zero-slump, or near zero-slump, mortar or concrete, by ramming, into surface cavities.

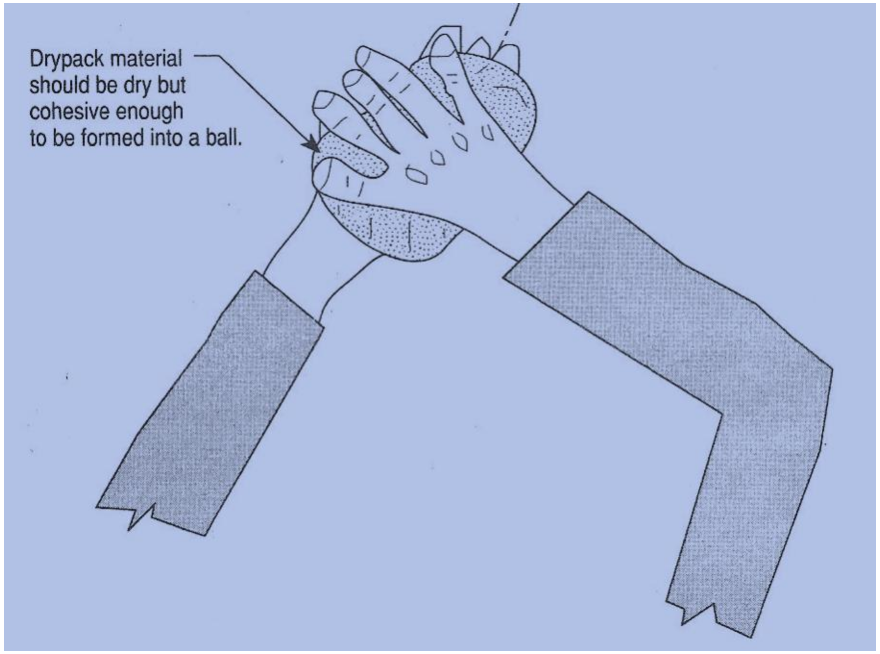
Dry packing techniques can be used in all locations: overhead, vertical and flat. Best applications are generally small cavities such as tie holes, small areas of surface honeycomb or rib bottoms (shown in illustration).



Each dry pack mortar repair is placed in layers. Compaction is achieved with a hardwood stick to prevent polishing of the surface. Curing is accomplished with a continuous 7-day moist cure.

Repair of Spalling and Disintegration

2) Dry Packing



The consistency of dry pack mortar must be such that it can be molded into a ball without excessive bleeding. Compaction densifies the mortar and provides the necessary intimate contact with the existing concrete for achieving bond.

Repair of Spalling and Disintegration

3) Prepacked concrete (Grout Preplaced Aggregate)

Grouted preplaced aggregate is a two-step process.

The first step involves aggregate placement into the cavity during the erection of formwork. The aggregate is gap-graded and washed of all fines. The void ratio of the cavity after the aggregate is placed, ranges from 40% to 50%.

The second step involves pumping a highly flowable grout through the formwork and into the preplaced aggregate. Grout flow fills the lower voids and progressively fills the cavity, eventually flowing to higher elevation ports.

After grout flows from adjacent ports, the grout hose is disconnected from the port being pumped, and reconnected to the port showing new flow. The process continues until the cavity is full and pressurized.

4) Pneumatically Applied Mortar

For a more detailed analysis between

Gunite Vs Shotcrete

(Dry Mix Shotcrete Vs Wet Mix Shotcrete)

Click at the object below

Source: http://www.mortarsprayer.com/shotcrete-gunite/

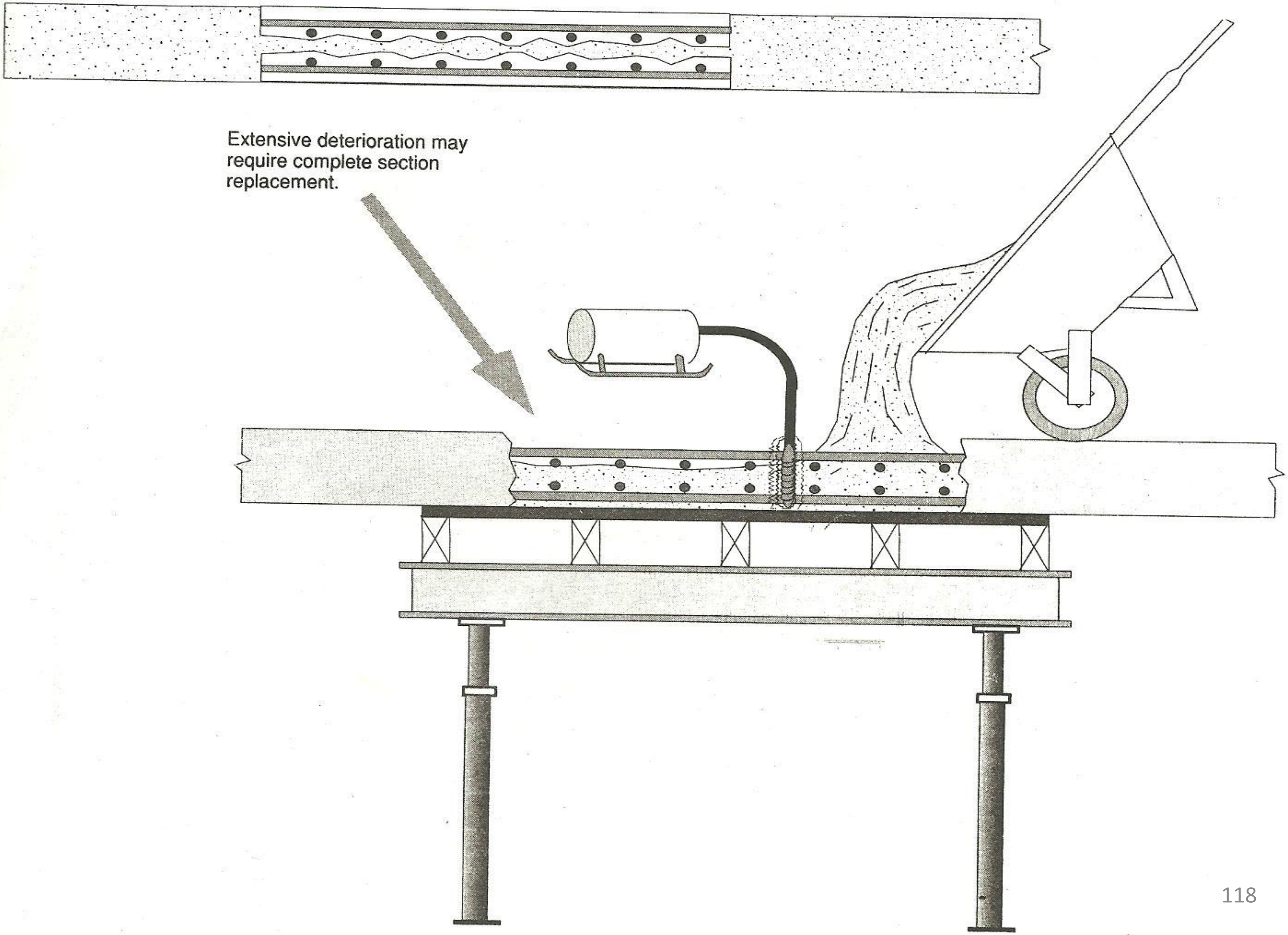
Microsoft Word Document

Repair of Spalling and Disintegration

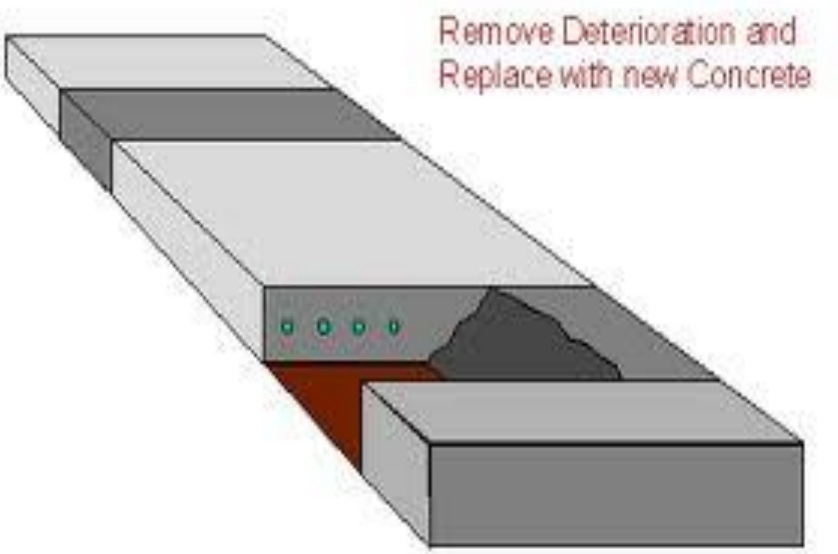
5) Replacement of Concrete: Full depth repair

In certain situations, surface repair may be better served by full depth repair. For example, when concrete surfaces have extensive surface damage, it may be more economical and provide for longer lasting repairs if the affected part of the member is removed and reconstructed. Consideration should be given to minimizing the restrained perimeter drying shrinkage. After placement of the new concrete, drying shrinkage results, causing tension within the newly reconstructed member and at the bond between new and old. In most cases, if tension stresses are not addressed, unplanned cracking may result. Low shrinkage concrete mixes should be used to reduce shrinkage stresses.

5) Replacement of Concrete: Full depth repair



5) Replacement of Concrete: Full depth repair



6) Overlays

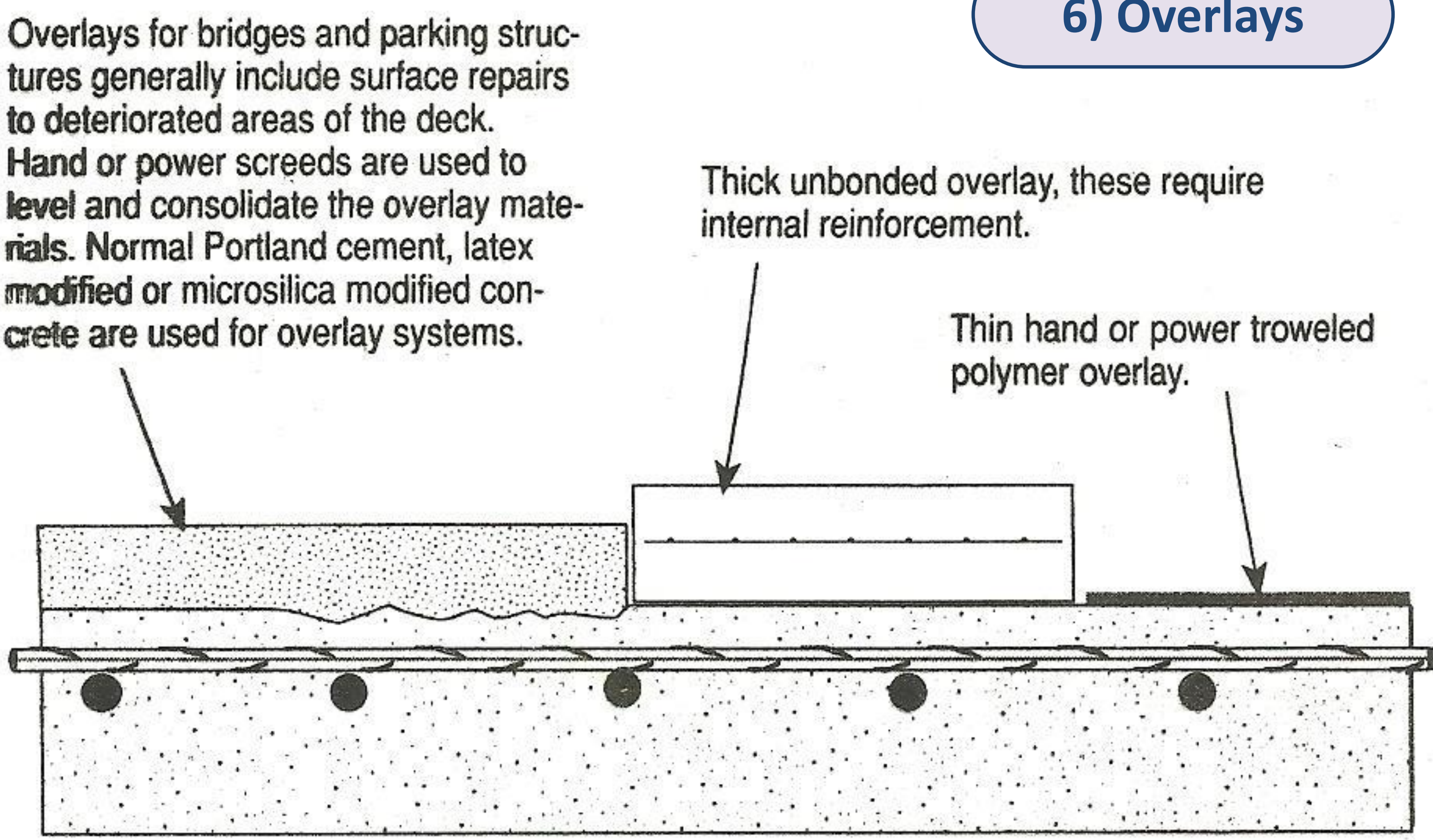
WHY USE OVERLAYS ?

Overlays are used to repair concrete structures as a remedy for a variety of concrete problems. They may be used to improve drainage, rideability, or load carrying capacity; to increase skid resistance; or to protect underlying concrete from aggressive environments. Many overlays also address underlying surface deterioration problems.

Overlays can be constructed of different materials from very thin (3mm) to very thick.

Repair of Spalling and Disintegration

6) Overlays



6) Overlays

7) Protective Surface Treatments

Durability of concrete can be substantially improved by preventive maintenance in the form of weather-proofing surface treatments. These treatments are used to seal the concrete surface and to inhibit the intrusion of moisture and/or chemicals.

Materials used for this purpose are

- Oils such as, linseed oils, petroleum oils, etc.
- Silicons used to seal concrete and masonry structures against moisture
- Epoxies

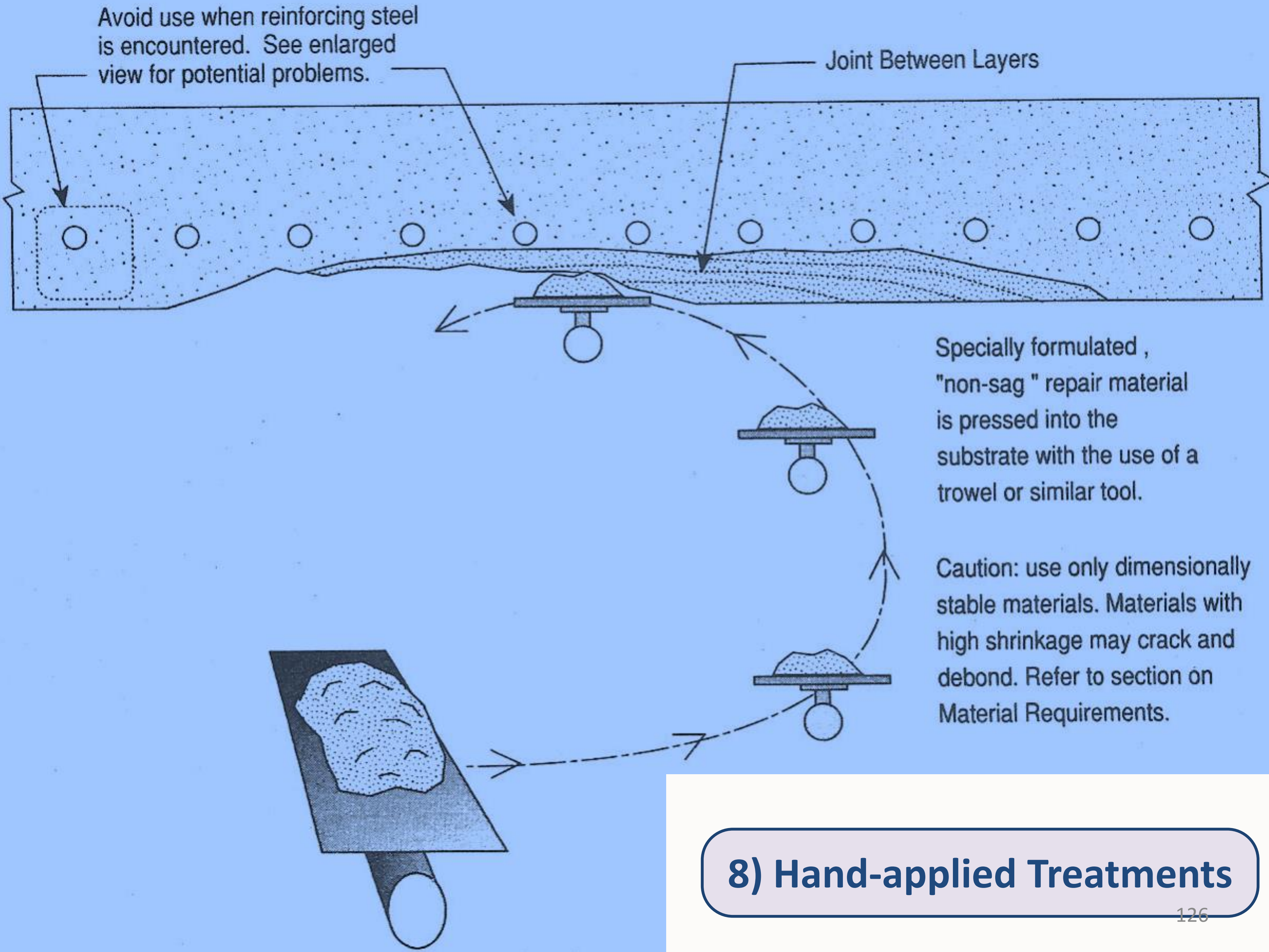
Repair of Spalling and Disintegration

7) Protective Surface Treatments

Repair of Spalling and Disintegration

8) Hand-applied Treatments

Hand-applied techniques are used to place non-sag repair materials on vertical and overhead locations. Most hand-applied materials are special blends of cement, finely graded aggregates, non-sag fillers, shrinkage compensating systems, and water. The mixed material is applied to the prepared surface with either a trowel or by hand. The applied pressure drives the repair material into the pore structure of the exposed concrete. The repair material is designed to "hang" in place until subsequent layers are added. Each layer is roughened to promote bond with the next layer.

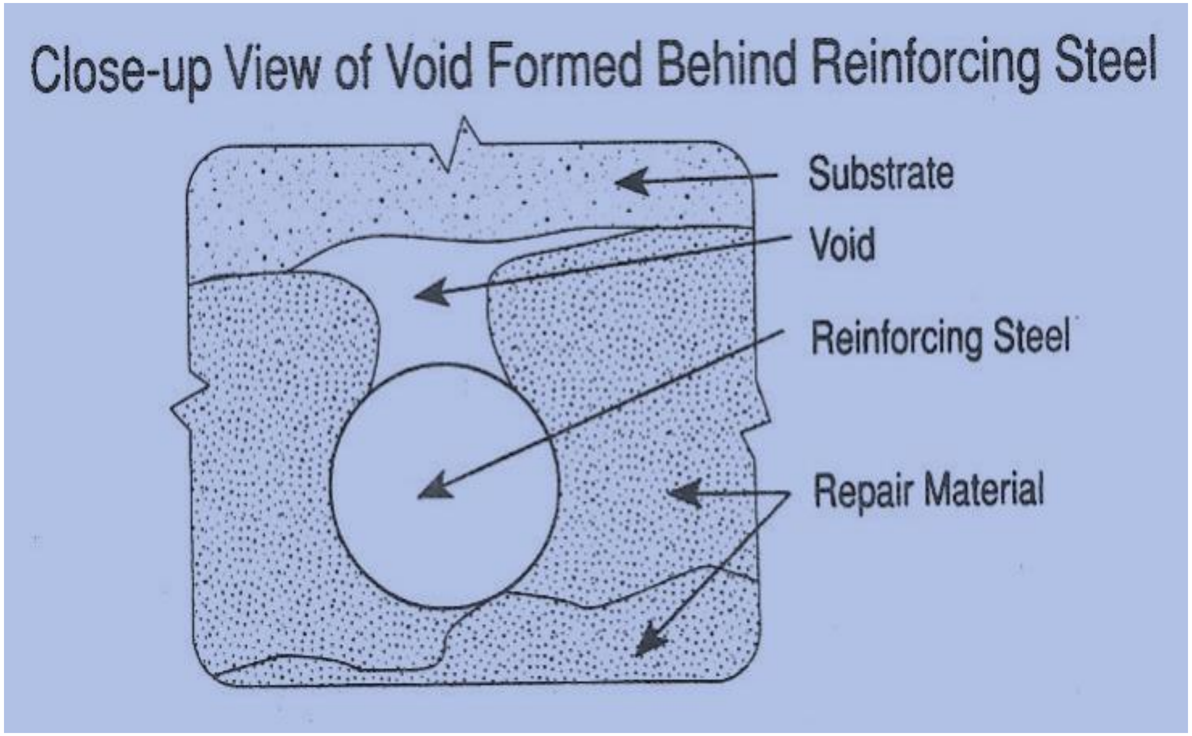


8) Hand-applied Treatments

8) Hand-applied Treatments

Repair of Spalling and Disintegration

8) Hand-applied Treatments

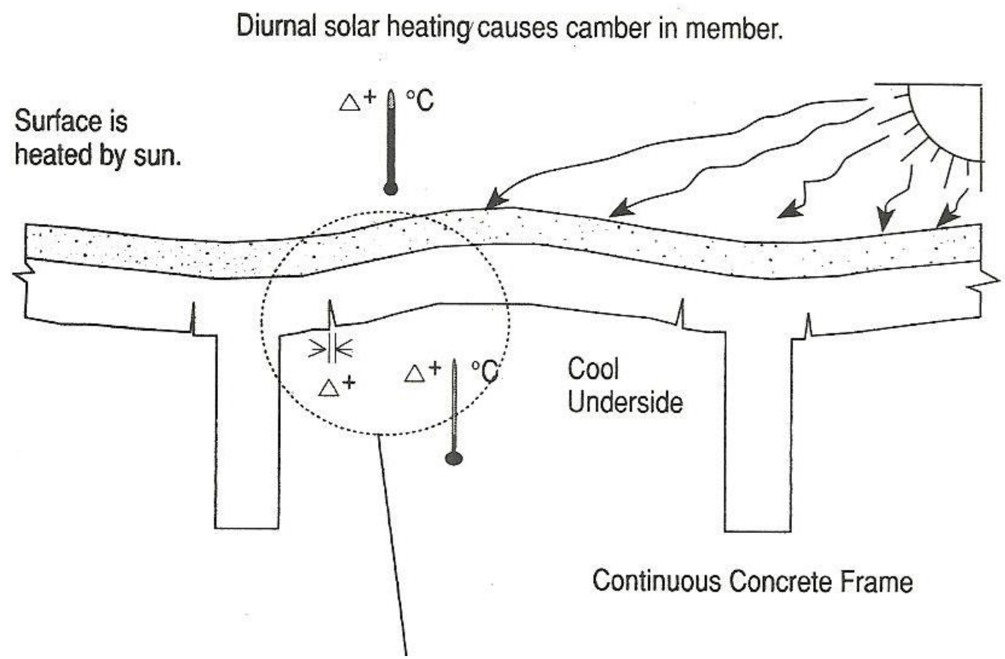


The best use of this technique is for topical cosmetic repairs not involving reinforcing steel. When reinforcing steel is encountered, it is very difficult to consolidate and provide for complete encapsulation of the reinforcing steel. Problems associated with this technique involve poor bond between layers and voids around embedded reinforcing steel.

Beam Shear Capacity Strengthening at Moving Hinge

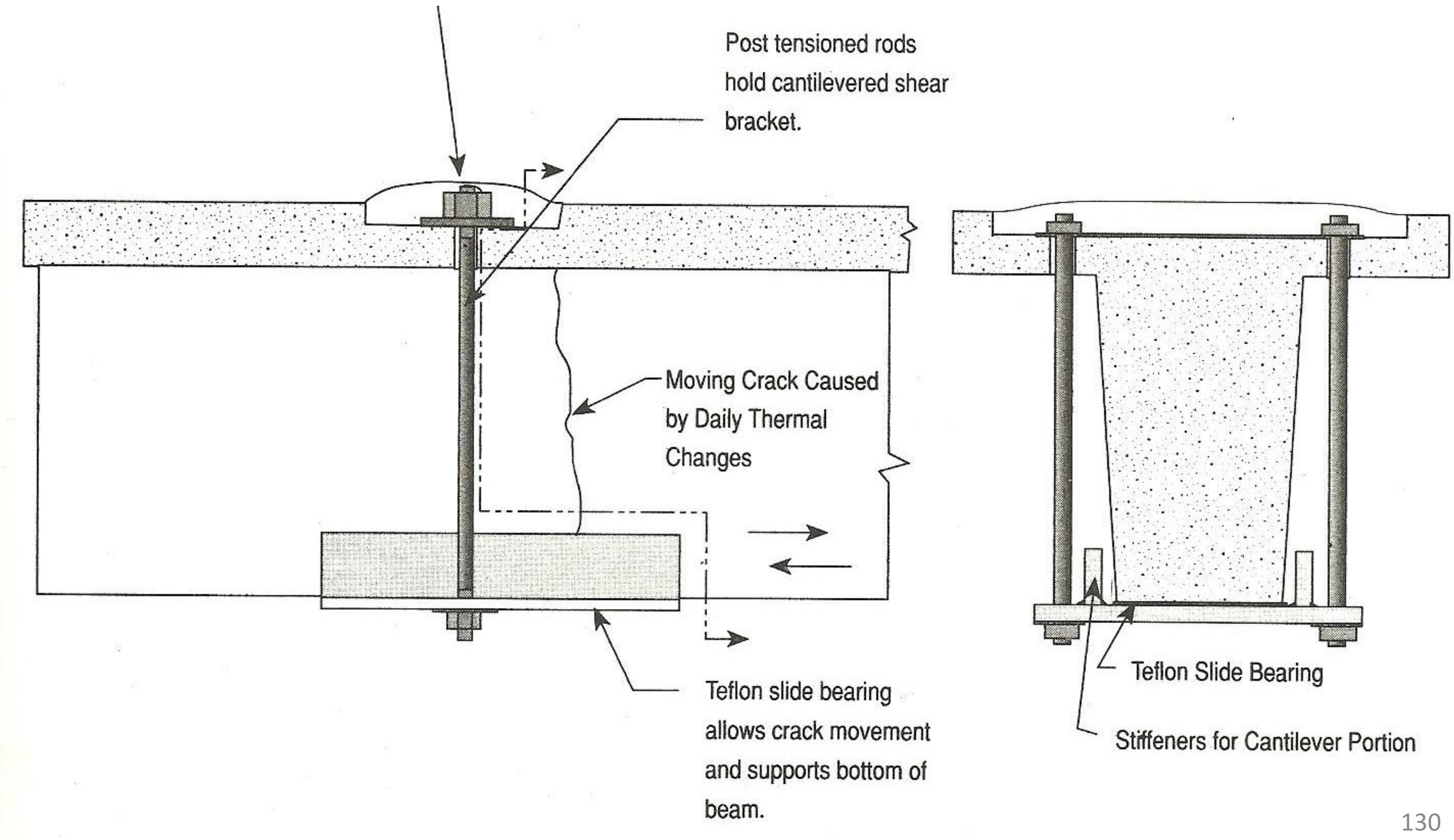
If a significant thermal gradient exists, in combination with insufficient tensile capacity in the bottom of the member, a hinge may form. Hinges may occur randomly in newly formed cracks, or may form in construction joints near the columns. Hinges open and close with daily temperature changes.

Cracks can be a cause for structural concern, since they sometimes identify insufficient shear capacity. When strengthening the member by repairing cracks, consideration must be given to the need for providing movement of the hinge. Generally any repair of a moving crack by bonding it with epoxy will fail.

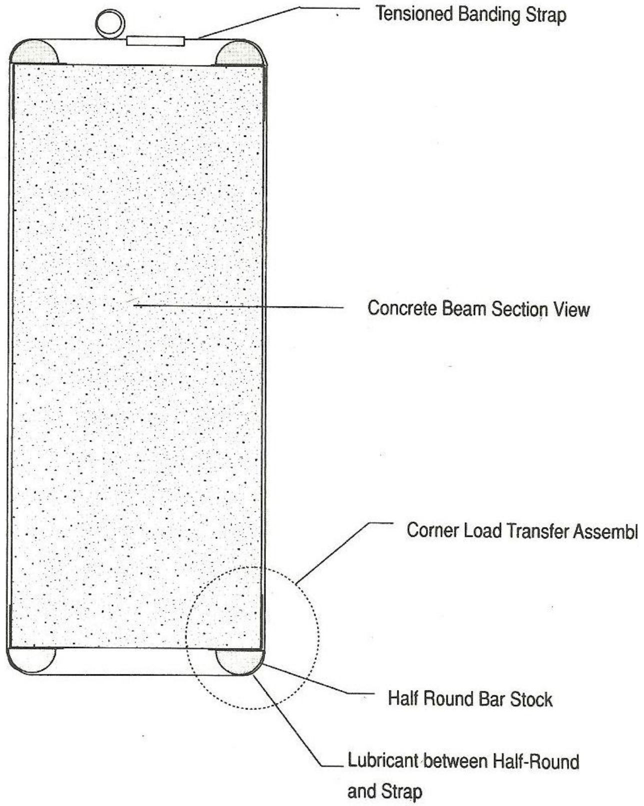


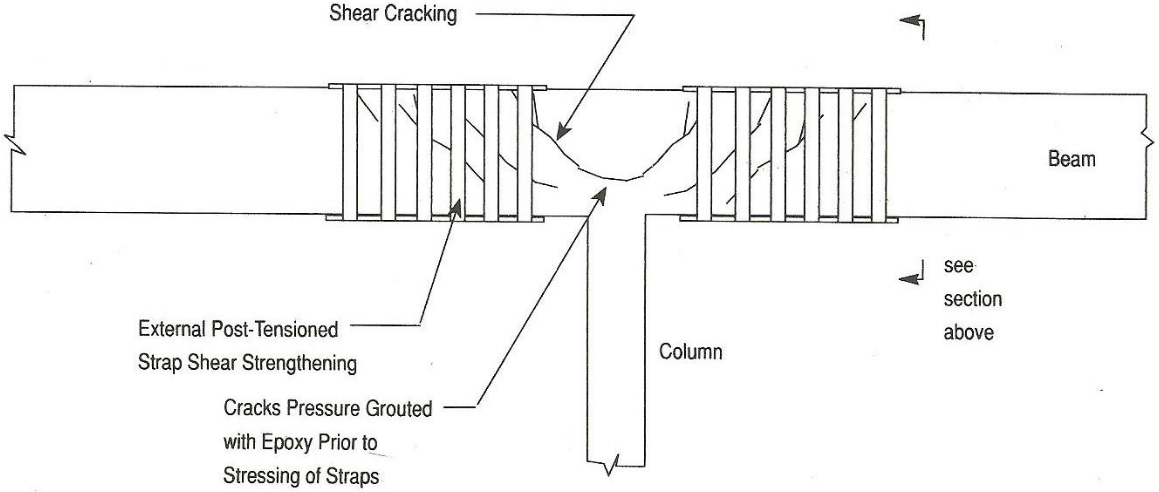
Beam Shear Capacity Strengthening at Moving Hinge

An effective method: the installation demonstrates how to strengthen a cracked beam with a post-tensioned shear clamp and a teflon slide bearing allowing for hinge movement.



External Post-Tensioned Straps



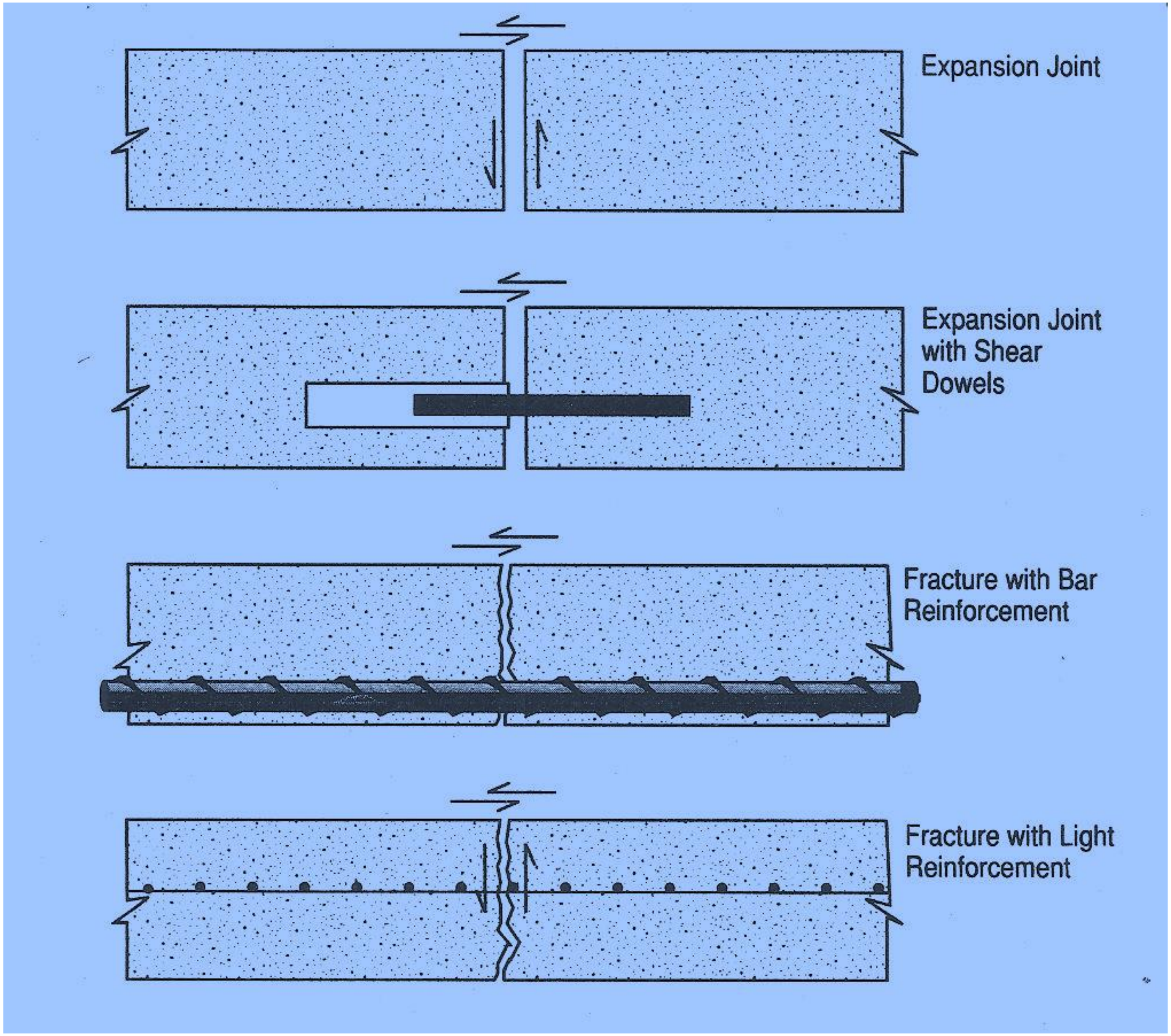


II. SHEAR TRANSFER STRENGTHENING BETWEEN MEMBERS

Shear Transfer Strengthening between members (Introduction)

1) Dowel Shear Device
2) Drilled Hole Shear Transfer Device
3) Grouted Subgrade
4) Cantilever Shear Arm

Types of junctions between members



III. STRESS REDUCTION TECHNIQUES

1) Installing New Expansion Joint
2) Lateral Ground Movement Isolation
   (Seismic Isolation)

III. Stress Reduction Techniques

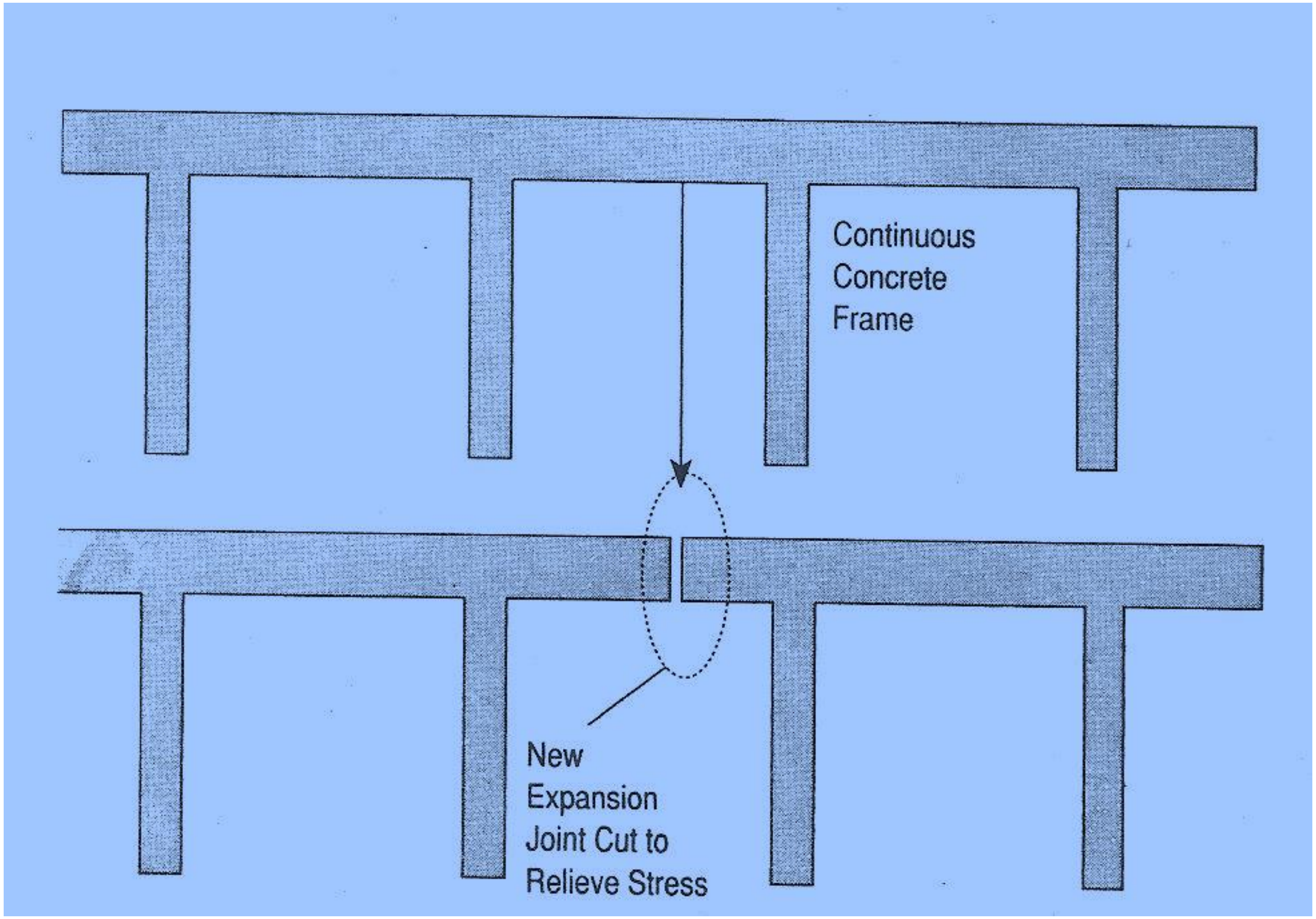
(1) Installing New Expansion Joint

Overstressing in members and structures can be repaired utilizing stress reduction techniques. Stress can be reduced by either reducing the load applied to the structure, or by modifying the behaviour of the structure.

III. Stress Reduction Techniques

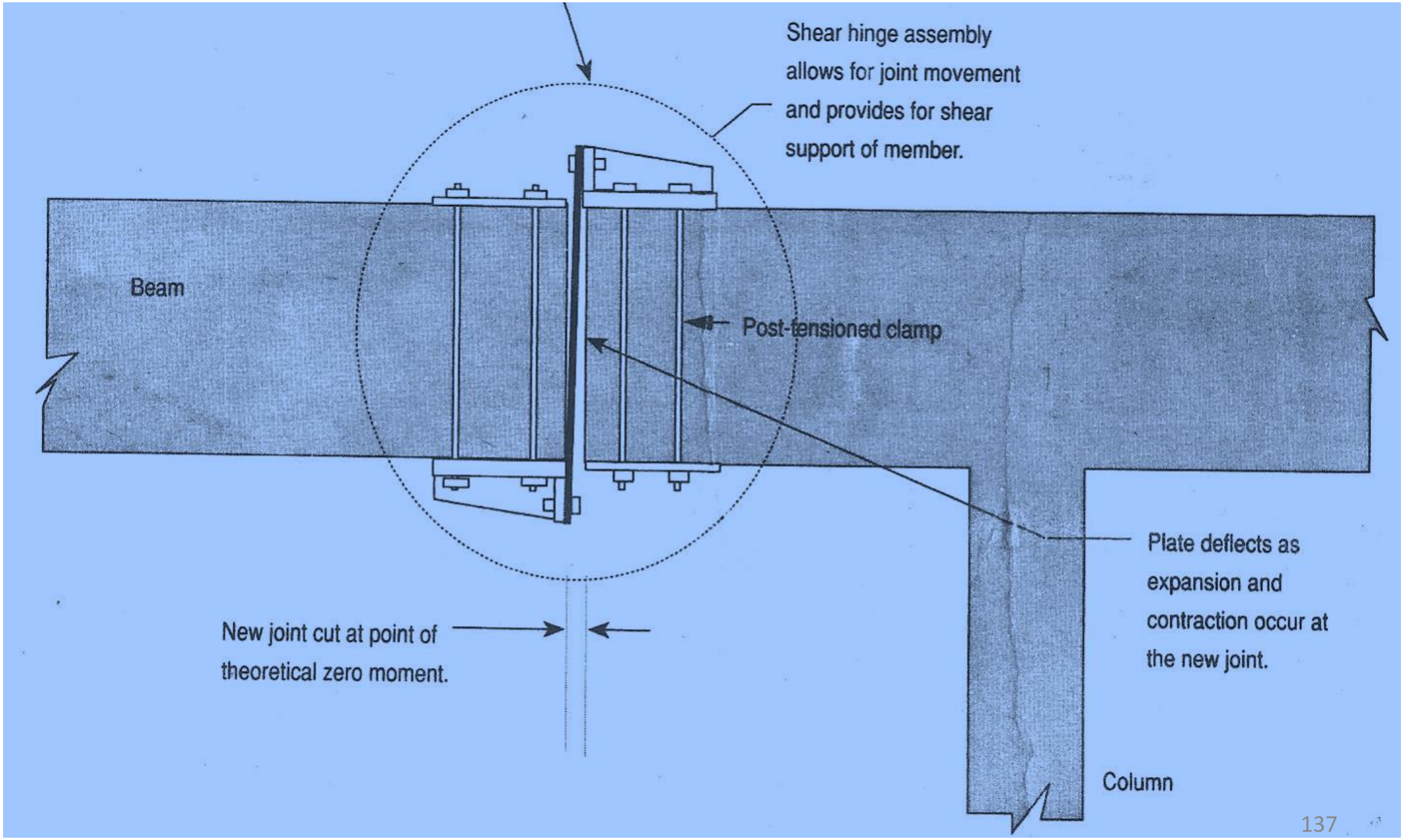
(1) Installing New Expansion Joint

An example of a continuous concrete frame in which stress is relieved by installing a new expansion joint.



III. Stress Reduction Techniques

(1) Installing New Expansion Joint



IV. COLUMN STRENGTHENING

1) Compressive Strengthening by Enlargement (Jacketing)
2) Shear Capacity Strengthening using Shear Collars
3) Beam-column Moment Capacity Strengthening
4) Confinement Strengthening

IV. Column Strengthening

(1) Jacketing: Section Enlargement

Enlarging the cross section of an existing column will strengthen the column by increasing its load carrying capacity. This is called Jacketing.

A column can be enlarged in various configurations.

However, the drying shrinkage effects in the concrete used to enlarge the column must be considered. Drying shrinkage, if restrained, will induce tensile stresses in the new portion of the column.

V. FLEXURAL STRENGTHENING

1) External Post-Tensioned Reinforcement
2) Span Shortening Techniques
3) Bonded Steel Plate Reinforcement
4) Correction of Deflected Member with Bonded Steel Plate
5) Concrete Overlay and Section Enlargement
6) Wall Strengthened

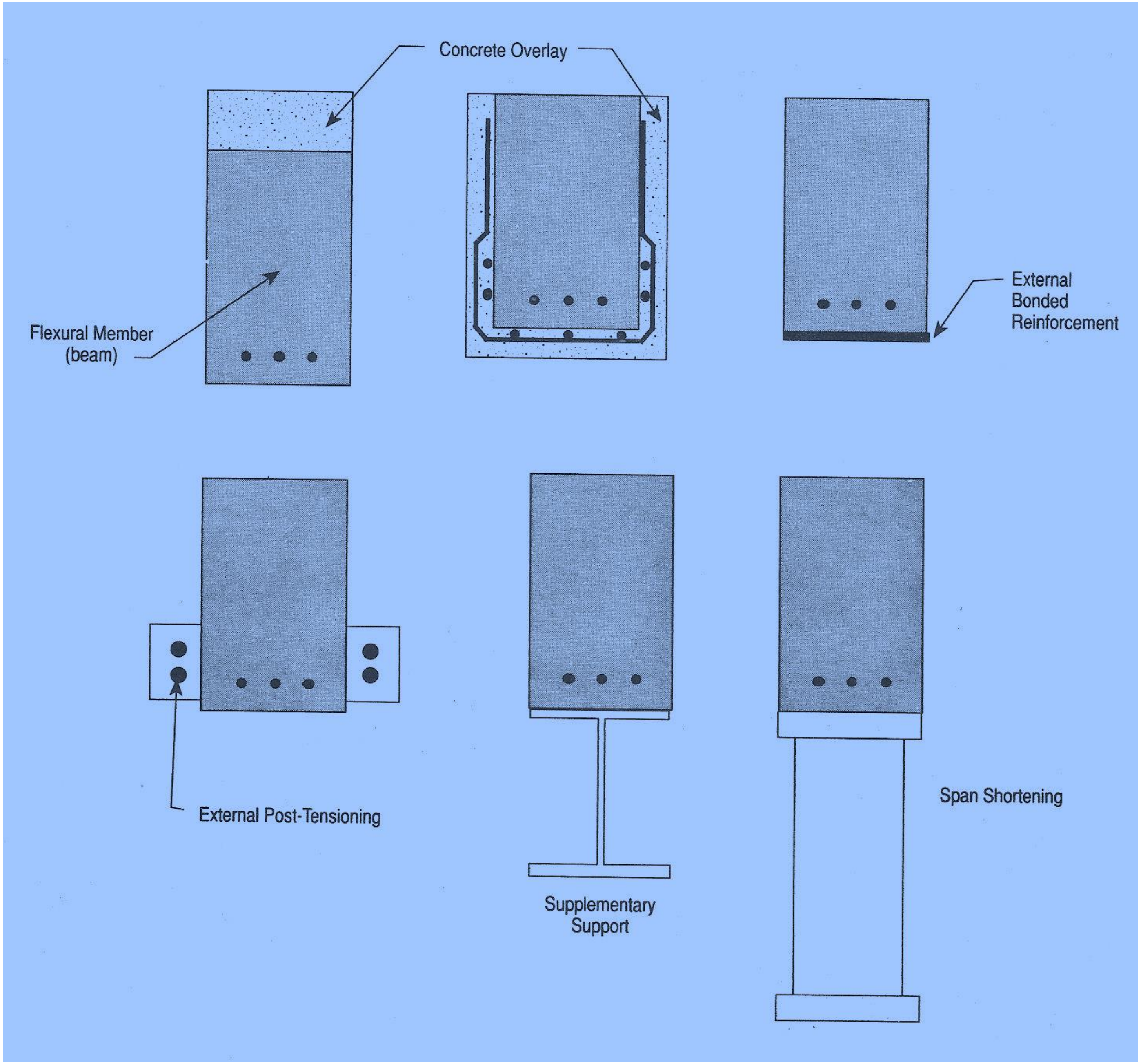
V. Flexural Strengthening

Beam and Slab Flexural Strengthening

The flexural capacity of concrete members requires an increase when either a design deficiency is found, excessive deflection occurs, or additional loads are anticipated. Various techniques used to increase flexural capacity include:

- **concrete encasement**
- **external post-tensioning**
- **externally bonded reinforcement**
- **concrete overlays**
- **span length shortening**
- **supplemental support**

Beam and Slab Flexural Strengthening



V. Flexural Strengthening

(1) External Post-Tensioned Reinforcement

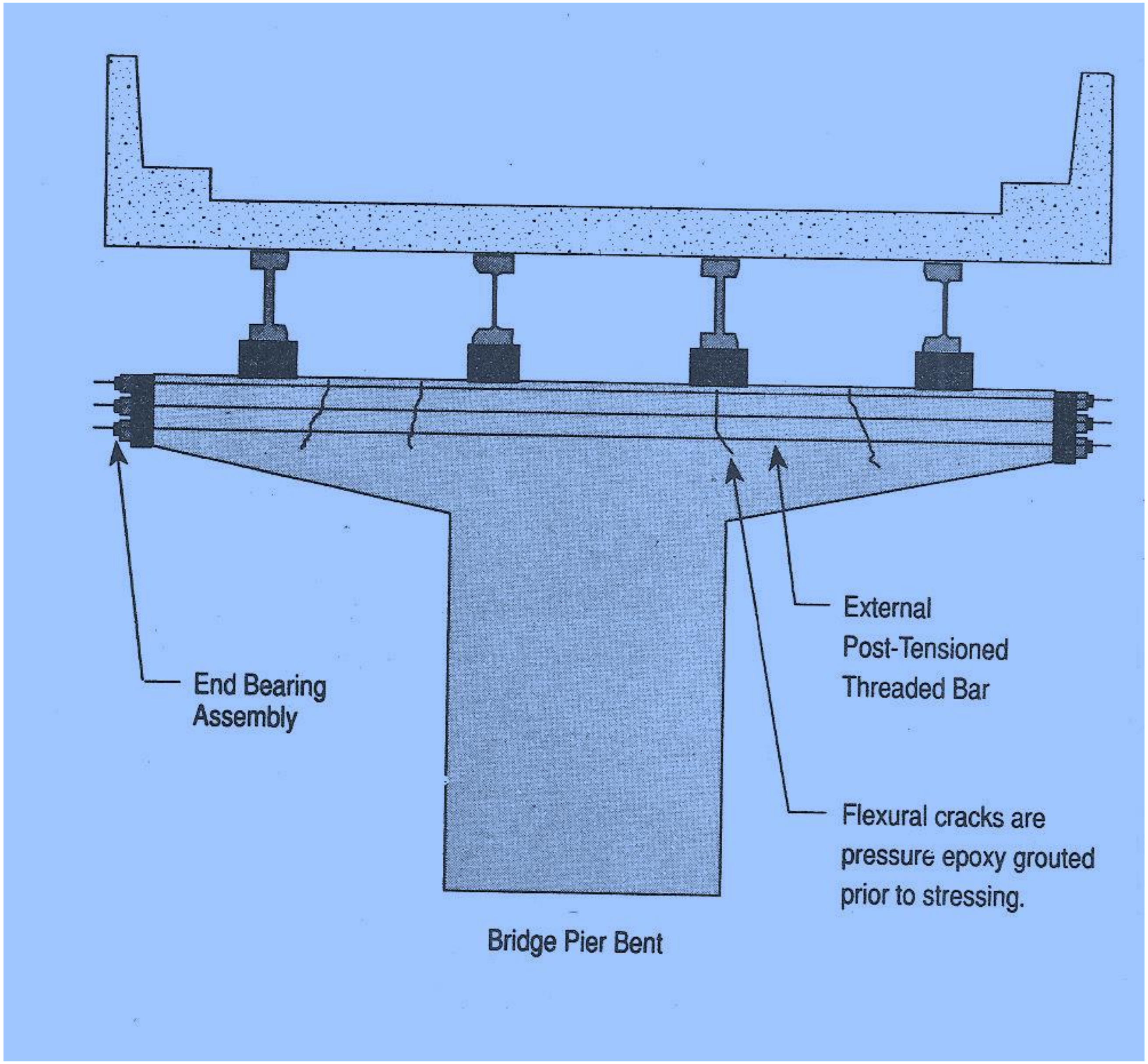
The use of external post-tensioned reinforcement is an excellent method of increasing flexural capacity or replacing damaged pre-stressed strands.

Different types of hardware are available, providing various load configura-tions and corrosion protection. High strength thread bar is commonly used for straight lengths, and strand is generally used where drape is required.

External post-tensioning provides for immediate and active participation in both dead and live load distribution. Prior to the pre-stressing, any flexural cracks should be pressure- grouted with epoxy for uniform compression distribution.

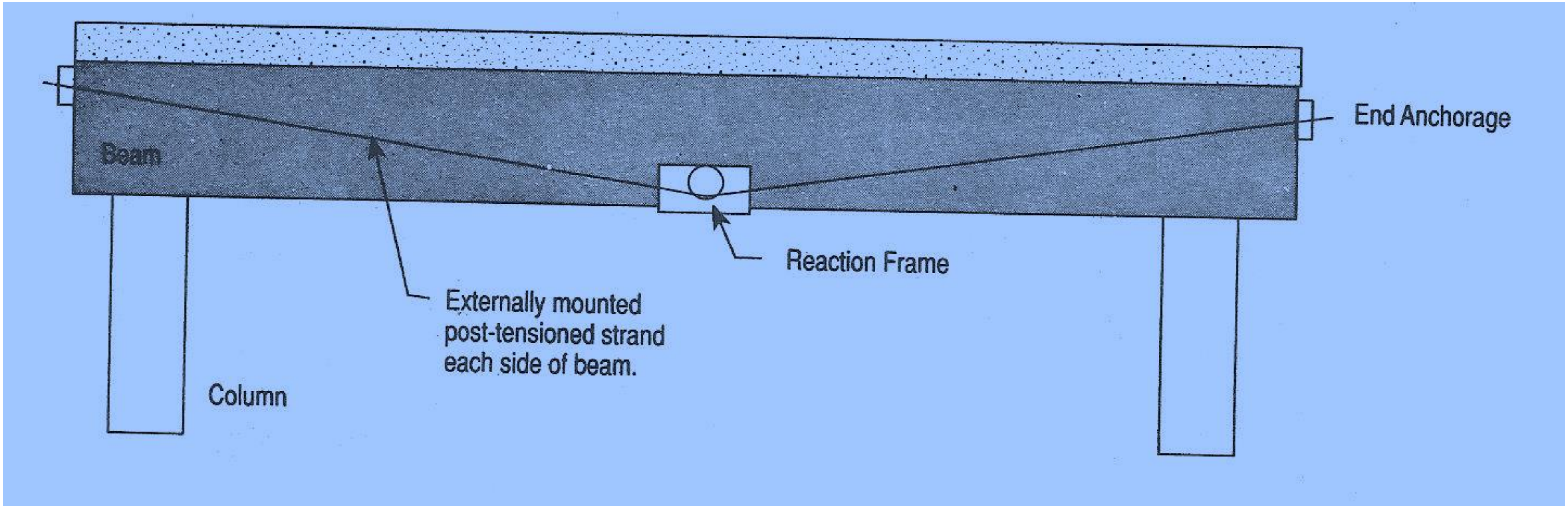
V. Flexural Strengthening

External Post-Tensioned Reinforcement



V. Flexural Strengthening

(1) External Post-Tensioned Reinforcement



V. Flexural Strengthening

(2) Span Shortening Techniques

Span length shortening, adding additional flexural capacity or stiffness, can be very cost effective. Span shortening for slabs and beams is accomplished by various methods, including enlarging the column capitals, adding steel or concrete diagonal braces, or placing sub-framing within the span.

V. Flexural Strengthening

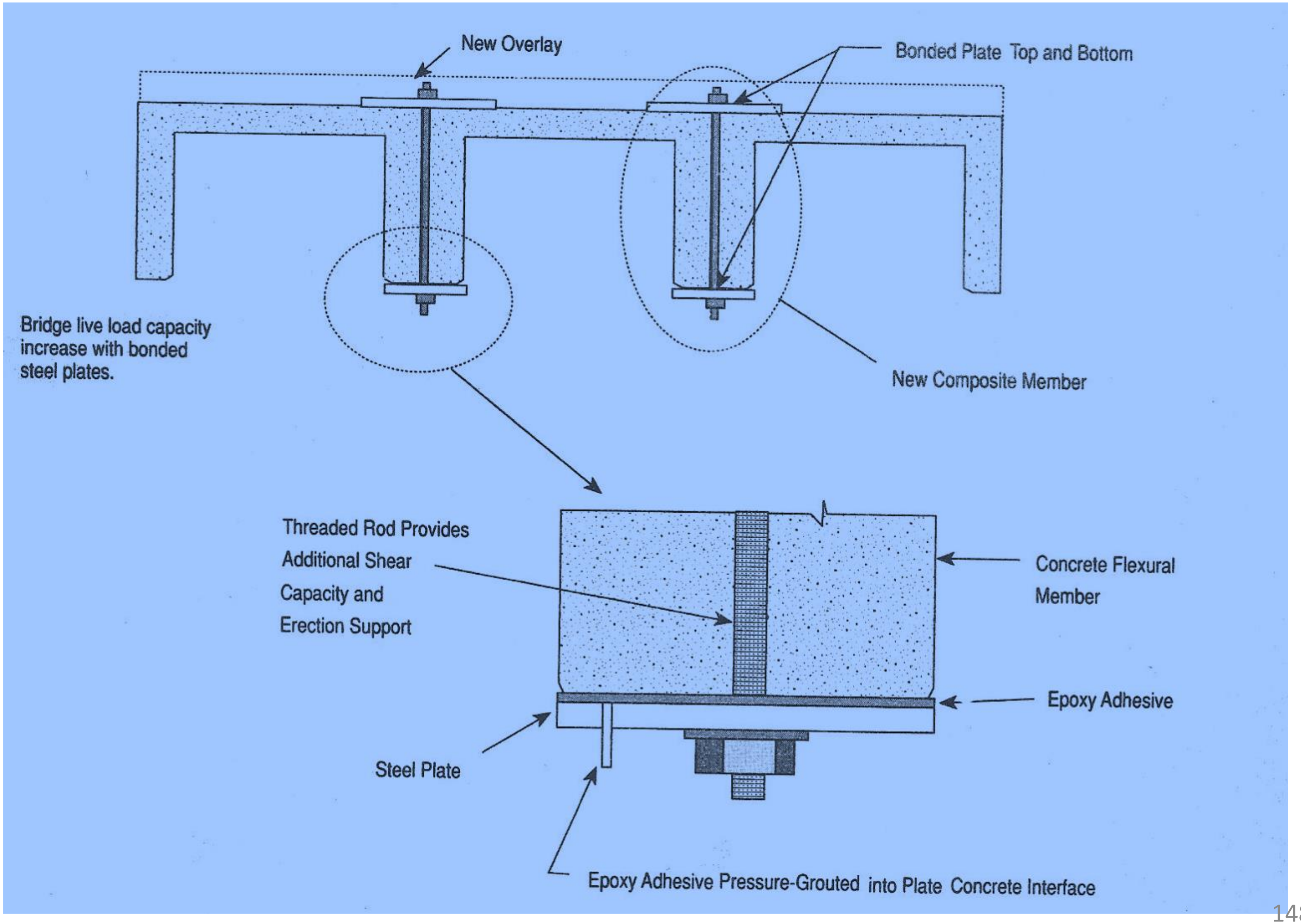
(3) Bonded Steel Plate Reinforcement

Externally bonded reinforcement is an effective method of increasing live load capacity or removing unwanted deflection. In most cases, steel plates are bonded, using epoxy, to the soffit or sides of flexural members. An advantage of this technique is that repair results in only a small increase in dimensions, which may be important for vertical traffic clearance or aesthetics.

The reinforcement can only be stressed by the application of live loads, or if the flexural member is jacked, prior to installation of the bonded reinforcement. When using steel plates, removal of mill scale and any bond-inhibiting materials is required. Shot blasting or heavy abrasive blasting produces a rough surface on the steel, which improves the adhesive bond and shear transfer. Mating concrete surfaces, heavy abrasive blasting is required. Effective bonding has been achieved using either pressure-injected flowable epoxy resin or epoxy gel applied to the mating surfaces prior to final erection of the steel plates. In some applications, expansion anchors are used in combination with the epoxy adhesive to develop adequate shear transfer between the concrete and steel.

V. Flexural Strengthening

(3) Bonded Steel Plate Reinforcement



V. Flexural Strengthening

(4) Correction of Deflected Member with Bonded Steel Plate

Procedure for Correcting Deflected Slab

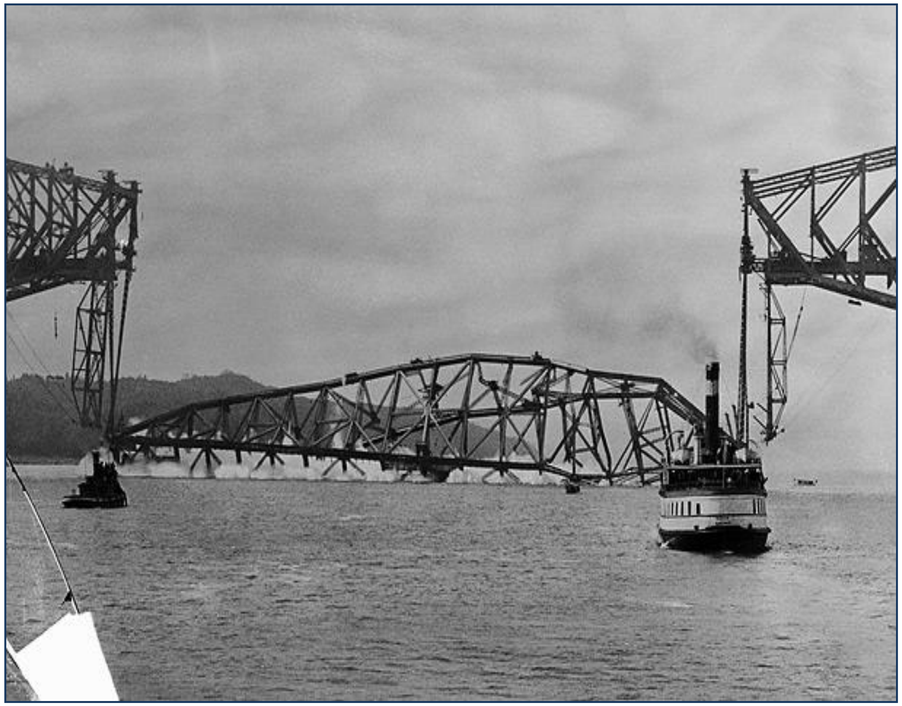
1. Lift slab to design position, or slightly above.
2. Install new bonded reinforcement to slab soffit.
3. Release temporary shoring.
4. Loads are transferred to new bonded reinforcement, and deflection is controlled.

UNIT- V
STRUCTURAL
HEALTH MONITORING

SYNOPSIS

- Major Unexpected Catastrophes
- Need for Continuous Monitoring of Structures
  - Real-time on-line monitoring concept
- Definition: Structural Health Monitoring
- Levels of System Identification by SHM
- Components of a SHM system
- Types of Sensors
  - Passive Sensing, Active Sensing
- Building Instrumentation

Structural Health Monitoring



1916: Quebec Bridge, Canada

2007: Minnessota Bridge, USA

Structural Health Monitoring

2009: 13 storey building, Shanghai

2008: Firdous Bldg, Surat

Neglect of incipient damages can be disastrous.
Need for automated real-time structural health monitoring.


LANSING


Jollibee
AVON


(AP PHOTO)

Consequences of Structural Failures

- **Loss of invaluable human lives**
- **Heavy loss of property**
- **Engineering embarrassment/ loss of trust**
- **Potential revenue earning activities halted**
- **Effects economy on local or global scale (depends on the utility of the building)**

NEED FOR STRUCTURAL HEALTH MONITORING

Analysis and Design Phases

Imperfections in Analysis and Design

Assumptions of ideal construction conditions

Construction Phases

Compromises in implementing the design

Poor quality of materials and workmanship

Degradation

Deterioration of material properties with time

Damages due to excessive loading and unforeseen impacts

Environmental effects on material properties

Natural Calamities

Earth Quakes

Storms and Cylones

Floods and Tsunamis effect on structures built over water bodies

Chemical Attacks

Need for Continuous Monitoring

- **Periodic Visual Inspections and Localized NDTs will not help in detecting suddenly manifesting changes in the structure**
- **These techniques require expertise in analysis and assessment of structural integrity**
- **Being localized techniques they cannot give a global evaluation of the structure**
- **The deteriorating portions of the structure may be inaccessible for NDE.**
- **Most of the times for NDE, the portion of the structure being inspected is rendered unusable throughout the length of the tests**

Need for Continuous Monitoring

Efforts are being invested by many capable researchers around the world in recent times towards the development of an efficient structural health monitoring system, which is capable of ***real-time on-line automated health monitoring***.

Need for Continuous Monitoring

Real-time on-line automated health monitoring:

Real-time implies that the monitoring is continuous even during the service period of the structure and the level of responsiveness of such a system is quick enough to enable appropriate remedial action or evacuation.

On-line implies that the alerting system must use user friendly on-screen imaging and audible alarms.

Automated implies that the diagnosis and alerting system does not need human interference for its operation.

Need for Continuous Monitoring

***Motivation for such a Structural Health Monitoring System*:**

I. Structural View

- predicts optimal use of the structure
- minimizes downtime of the structure
- avoids catastrophic failures

II. Constructor View

- gives the constructor a scope for improvement in his products
- gives him a chance for repair before an embarrassing collapse of the structure

Need for Continuous Monitoring

***Motivation for such a Structural Health Monitoring System*:**

III. Maintenance Services View

- drastically changes the work organization of maintenance services
- replaces scheduled and periodic maintenance inspection with performance-based (condition-based) maintenance
- reduces the present maintenance labor, in particular by avoiding dismounting parts where there is no hidden defect;
- by drastically minimizing the human involvement, and consequently reducing labor, downtime and human errors, and thus improving safety and reliability.

Need for Continuous Monitoring

***Motivation for such a Structural Health Monitoring System*:**

IV. Improving Safety (Most important reason)
- To overcome failures due to unsatisfactory maintenance
- To detect the deterioration and aging of the structure before it becomes critical

V. Reducing Accidents and Losses

VI. Economic savings primarily for end users.

Structural Health Monitoring is a process of real-time, on-line and automated evaluation of a structure's integrity and performance, prediction of the remaining serviceable life of structure and timely warning to the end-user of it deterioration.

Structural Health Monitoring

Typically, a critical structure in service is monitored for
(a) the strength of the constituent materials,
(b) the stresses due to loads to be with permissible limits,
(c) deflections and strains for appropriate serviceability conditions
(d) the integrity of the structural assembly at its joints,
(e) occurrences of damages etc.

This is done so as to take a suitable rehabilitation and retrofitting work to prevent a catastrophic failure.

LEVELS OF SYSTEM IDENTIFICATION WITH SHM

Levels of System Identification

SHM is classified into two categories, namely the Diagnosis and Prognosis.

Through diagnosis, one can determine the presence of a flaws, their location, and their extent along with the possibility of looking at the delaying the propagation of flaws in the structure.

The prognosis part uses the information of the diagnosis part and determines the remaining life of the structure.

Levels of System Identification

The SHM can be broadly divided into following levels.

Level 1: Confirming the presence of damage
Level 2: Determination of location and orientation of the damage
Level 3: Evaluation of the severity of the damage
Level 4: Possibility of controlling or delaying the growth of damage
Level 5: Determining the remaining life in the structure (prognosis)

Components of a SHM System

- Sensing Technology
- Diagnostic Signal Generation
- Signal Processing
- Damage Identification Analysis
- System Integration

Components of SHM system

➢ Sensing Technology

It consists of an array of distributed sensors, either wired or wireless to interrogate the structure at periodic intervals or continuously.

➢ Diagnostic Signal Generation

This involves generation of suitable signals from the sensors, which must reflect the desired parameters in the health assessment of the structure, with the properties of controllability, repeatability, reliability and sensitivity to damages.

➢ Signal Processing

This involves the necessary electronic components to efficiently transmit the diagnostic signal, while filtering out unwanted noise so that the signal analysis gives realistic picture of the state of the structure.

➢ Damage Identification Analysis

This is considered as the brain of the SHM system as it relates the sensor measurements to the physical changes in the structures. It involves expertize in identification and characterization of damages using the knowledge of static and dynamic structural mechanics, material properties and the physics of the specific sensing technology being used.

System Integration

This involves software development, with the support of suitable hardware components, to control the above mentioned components with a user friendly interface and must be capable of giving needed indications and warnings to the maintenance department or the user.

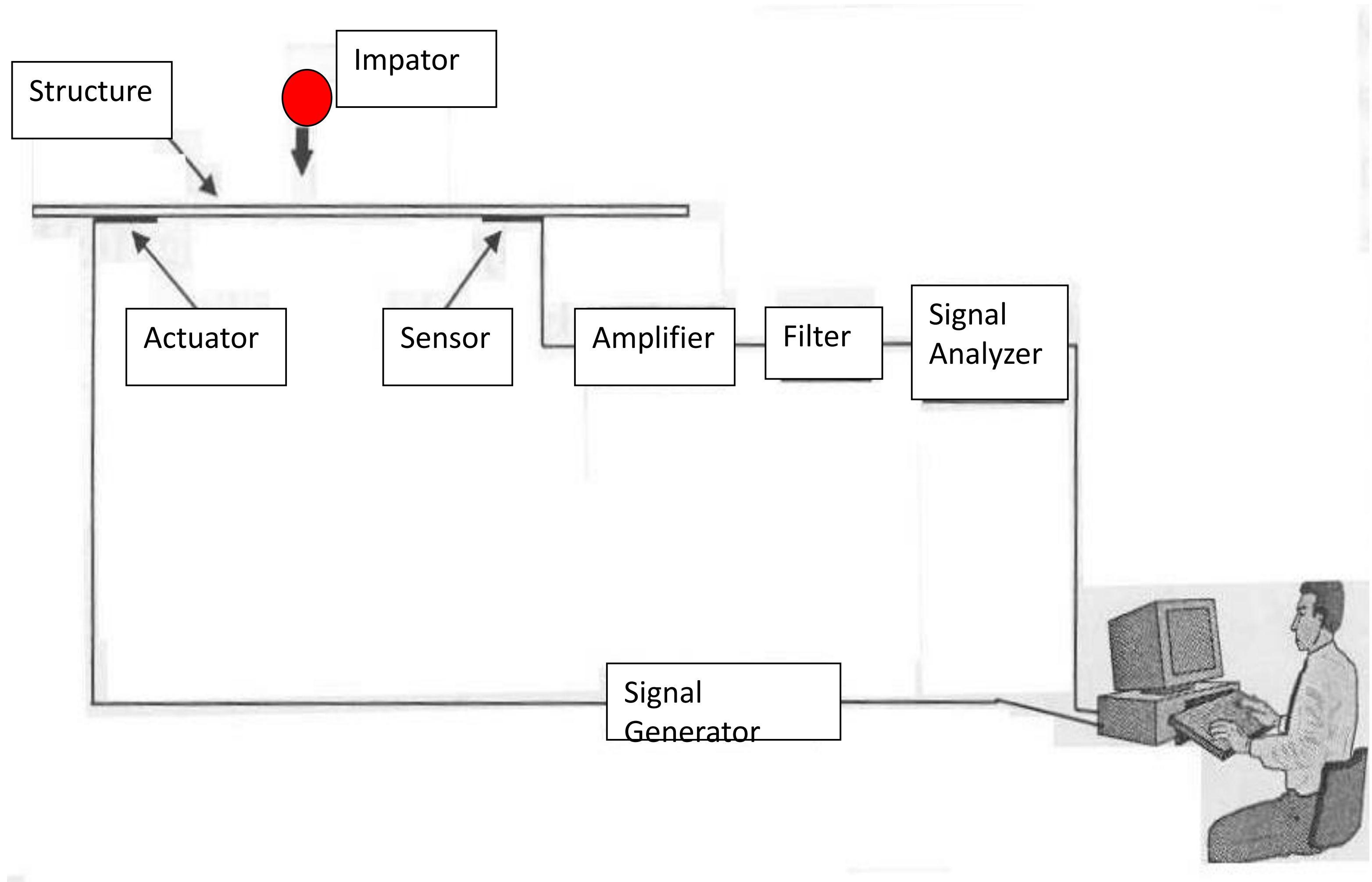


Figure illustrating the components and operation of typical SHM system

What is an Actuator?

An actuator typically is a mechanical device that takes energy — usually energy that is created by air, electricity or liquid — and converts it into some kind of motion.

Actuator is used to generate force or induce displacement or vibrations.

What is a Sensor?

A **sensor** (also called **detector**) is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an (today mostly electronic) instrument.

What is Passive SHM technique?

If the monitoring process is based only on the diagnostic signal from the sensors, which is generated only upon occurrence of damage/deflections in the structure, such a technique is called "***passive monitoring***."

Examples:
(A) Monitoring with acoustic emission sensors
(B) SHM using static displacement/strain guages
(C) SHM using velocity meters and accelerometers

What is active SHM technique?

If the monitoring process is consisting of both actuators and sensors and some perturbations/vibrations are generated by the actuators and the structural response is captured by the sensors, which is then analysed for identifying damages, then such a technique is called "***active monitoring***."

In active monitoring technique the diagnostic signal is generated at will and not dependent on the situation where damage induced changes produce the diagnostic signal.

Examples:
(A) Ultrasonic Tests (Example: Impact-Echo method)
(B) Piezoeletric actuators and sensors based methods
(C) Vibration response based methods.

TYPES OF SENSORS

- Displacement Sensors
- Strain Sensors
- Vibration Sensors
- Acoustic Sensors
- Optical Sensors
- Thermal Sensors

SENSORS for SHM based on Structural Response

Static Response

Displacement Sensors
(Eg: Displacement gauges,LVDTs)

Strain Sensors
(Eg: Resistive Strain gauges)

Vibration/Dynamic Response

Vibration Sensors
(Eg. Accelerometers)

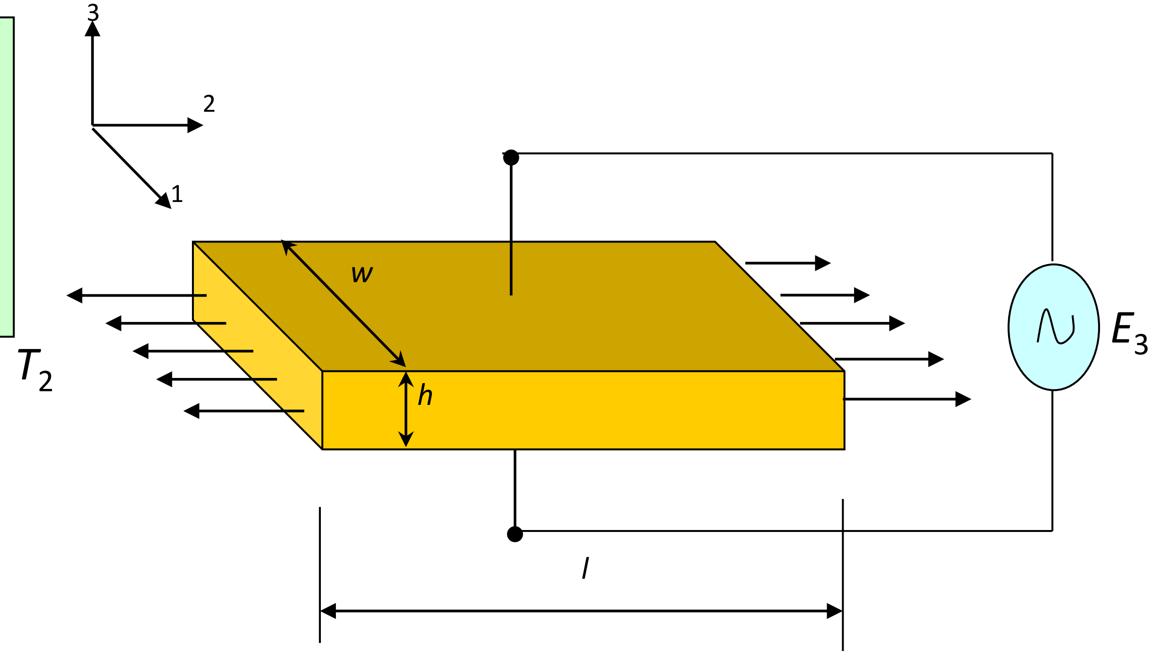
Acoustic Sensors
(Velocity receiver,
ultrasonic thickness gauges)

SMART MATERIALS SENSORS AND ACTUATORS

- PIEZOELECTRIC MATERIALS
- ELECTROSTRICTIVE MATERIALS
- MAGNETOSTRICTIVE MATERIALS

- ELECTRORHEOLOGICAL FLUIDS
- SHAPE MEMORY ALLOYS
- FIBRE OPTIC SENSORS

PIEZO-ELECTRIC MATERIALS



(a) Direct Effect (Sensor)

Mechanical stress → Electric field

$$D_3 = \overline{\varepsilon_{33}^{T}} E_3 + d_{32} T_2$$

(b) Converse Effect (Actuator)

Electrical field → Mechanical Strain

$$S_2 = \overline{s_{22}^{E}} T_2 + d_{32} E_3$$

Actuation is possible at very high frequencies – in the order of MHz

THANK YOU