Course: PE 821 CE RETROFITTING AND REHABILITATION OF STRUCTURES

PROFESSIONAL ELECTIVE – III (CBCS SEM VIII)

Bachelor of Engineering (B.E.), Year IV, Semester II

University College of Engineering, Osmania University

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UNIT III
Condition Assessment, Non-Destructive Testing and Evaluation

- Introduction to NDT
- Situations and contexts, where NDT is needed
- Classification of NDT procedures
- Visual inspection
- Half-cell electrical potential methods
- Schmidt Rebound Hammer Test
- Resistivity measurement
- Electromagnetic methods
- Radiographic testing
- Ultrasonic testing
- Infra-Red thermography
- Ground penetrating radar
- Radio isotope gauges
- Other methds.

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Introduction to Non-Destructive Testing of Concrete

Importance: It is often necessary to test concrete structures after the concrete has hardened to evaluate its performance for its designed use. Such testing should be done without damaging the concrete.

Types of Tests on Concrete:

1. Tests in its fresh state
2. Partially destructive tests (in hardened state)
3. Non-destructive tests (in hardened state)

Non-Destructive Tests (Scope)

To check the quality of:

- Workmanship
- Structural integrity and serviceability
- Material deterioration

Situations and Contexts where NDT are needed:

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

1. quality control of pre-cast units or construction in situ
2. removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance with specification
3. confirming or negating doubt concerning the workmanship involved in batching, mixing, placing, compacting or curing of concrete

1. monitoring of strength development in relation to formwork removal, cessation of curing, pre-stressing, load application or similar purpose
2. location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure
3. determining the concrete uniformity, possibly preliminary to core cutting, load testing or other more expensive or disruptive tests

Situations and Contexts where NDT are needed:

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

11. determining the position, quantity or condition of reinforcement
12. increasing the confidence level of a smaller number of destructive tests
13. determining the extent of concrete variability in order to help in the selection of sample
14. locations representative of the quality to be assessed
15. confirming or locating suspected deterioration of concrete resulting from such factors as
16. overloading, fatigue, external or internal chemical attack or change, fire, explosion,
17. environmental effects
18. assessing the potential durability of the concrete
19. monitoring long term changes in concrete properties
20. providing information for any proposed change of use of a structure for insurance

Situations and Contexts where NDT are needed:

Situations where NDT is an option to consider for investigation of *in situ* concrete

- to investigate the homogeneity of concrete mixing
- lack of grout in post tensioning ducts
- to determine the density and strength of concrete in a structure
- to determine the location of reinforcing bars and the cover over the bars
- to determine the number and size/diameter of reinforcing bars
- to determine the extent of defects such as corrosion
- to determine the location of in-built wiring, piping, ducting, etc.
- to determine whether internal defects such as voids, cracks, delaminations,
- honeycombing, lack of bonding with reinforcing bars, etc. exist in concrete
- to determine if there is a bond between epoxy bonded steel plates and concrete members.

Mechanical Properties

- **Compressive Strength**
  - -Core testing (1)
  - -Windsor probe (3)
  - -Rebound hammer (2)
- **Quality of Concrete**
  - Ultrasonic pulse velocity(4)
- **Tensile Strength**
  - -Pull off testing
  - -Splitting tensile strength (5)
- **Flexural Strength**
  - (6) (7)
- **Abrasion resistance**
  - (8)
- **Bond Strength**
  - -Pull off testing

Chemical Make-up

- **Electro-chemical Activity**
  - -Half cell potential (9)
  - -Electrical resistivity (10)
- **Carbonation Depth**
  - -Acid based indicators (Phenolphthalein Solution)
  - -Petrographic analysis (11)
  - -X-ray diffraction
  - -Infrared spectroscopy
- **Alkali-Aggregate Reactions**
  - -Petrographic analysis (11)
  - -Uranyl (Uranium) Acetate fluorescence method
- **Chloride Content**
  - (12) (13) (14)

Physical Condition

- **Uniformity**
  - -Petrographic analysis (11)
  - -Pulse velocity (4)
  - -Windsor probe (3)
  - -Rebound hammer (2)
  - -Core testing (1)
- **Air-Void System**
  - (15)
- **Delaminations/voids**
  - -Hammer sounding
  - -Chain drag
  - -Impact echo
  - -Pulse velocity (4)
  - -Exploratory removal
  - -Remote viewing (TV, Borescope)
  - -Infrared thermography
- **Location/Condition of Embedded Metals**
  - -Pachometer
  - -Radiography
  - -Ground penetrating radar
  - -Exploratory removal
- **Water permeability**
- **Air permeability**
- **Water absorption**
  - (19)

External Manifistation (behavior)

- **Cracks/spalls**
  - -Hammer sounding
  - -Infrared thermography
  - -Impact echo
  - -Pulse velocity (4)
  - -Remote viewing (TV, borescope)
  - -Exploratory removal
- **Deflections from Service Loads**
  - -Load testing (ACI 437R)
  - -Monitoring movements
- **Movements of Service/Exposure Conditions**
  - -Load testing (ACI 437R)
  - -Monitoring movements
- **Leakage**
  - -Visual observations
  - -Infrared thermgraphy
- **Temperature/moisture conditions**
  - -Thermocouple
  - -Thermometer
- **External Geometry**
  - -Visual observations

Non-Destructive Testing – Visual Inspection

VISUAL INSPECTION

- **The most important of all non-destructive tests.**
- **Provides valuable information to the well trained eye.**
- **Visual features related to workmanship, structural serviceability, and material deterioration.**
- **Extensive information gathered from visual inspection gives preliminary indication of the condition of the structure.**
- **Allows formulation of a subsequent testing programme.**

VISUAL INSPECTION

It is not confined only to the structure being investigated.

It also includes neighbouring structures, the surrounding environment and the climatic condition.

Even minor observations cannot be omitted.

"I see no more than you but I have trained myself to notice what I see."

VISUAL INSPECTION: Tools and Equipments Required

A complete set of relevant drawings showing plan views, elevations and typical structural details, must be carried and carefully studied.

In addition, some or all of the following are required:

- Measuring tapes or rulers,
- Markers,
- Thermometers,
- Anemometers,
- Binoculars, telescopes, borescopes
- Endoscopes or the more expensive fibre scopes
- Crack width microscope or a crack width gauge
- Magnifying glass or portable microscope
- Good camera with the necessary zoom and micro lenses and other accessories.

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VISUAL INSPECTION: General Procedure

1. **Familiarizing with the structure:** Careful study of the building drawings, plan and elevation
2. **Studying Past History:** Methods and dates of construction, materials used, construction records, details of past testing and inspections
3. **Estimate the Usage of the Structure:** Current and Past Usage
4. **Evaluate the Surrounding Environmental Conditions:** Condition of the adjacent structures, environmental and weather conditions
5. **Examination:** Careful observation and examination of building surface, like-structural elements, joints, expansion joints, bearings, drainage channels, and so on, for structural and non-structural defects.
6. **Taking Notes:** Noting down the observations supplemented by sketches and photographs.
7. **Assessment Report:** Assessing the observations and recommending the further course of action either of further non-destructive tests or partially destructive tests and repair works.

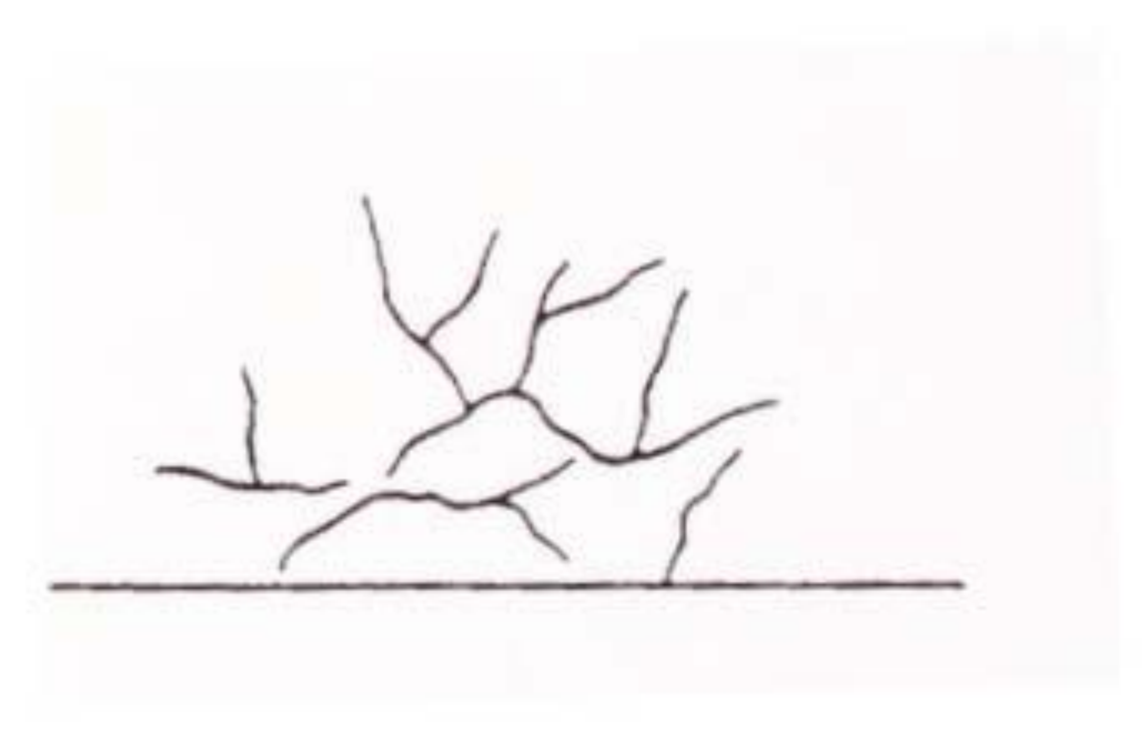
VISUAL INSPECTION: General Procedure

Defects that commonly need recording include:

- cracking which can vary widely in nature and style depending on the causative mechanism
- surface pitting and spalling
- surface staining
- differential movements or displacements
- variation in algal or vegetative growths
- surface voids
- Honeycombing
- bleed marks
- constructional and lift joints
- exudation of efflorescence.

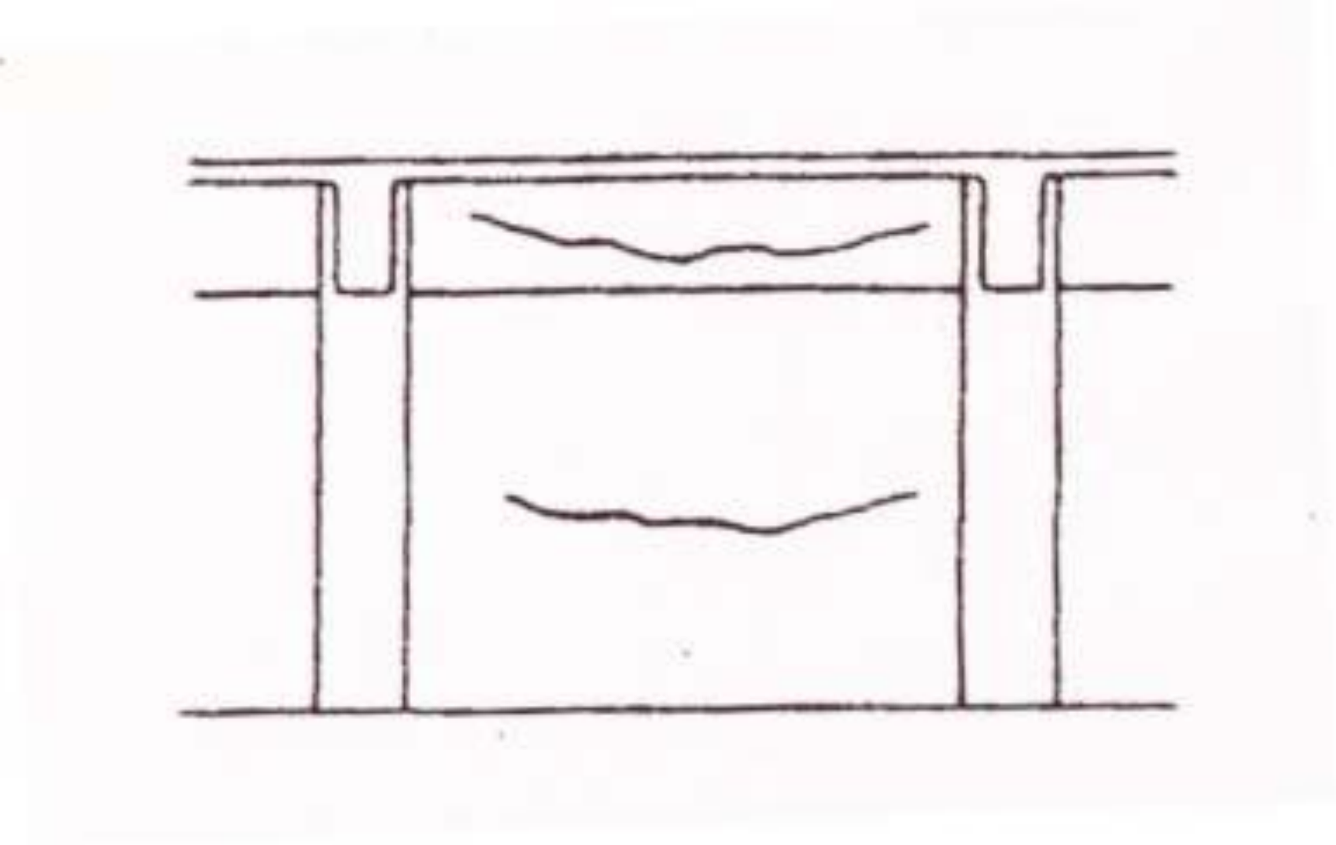
VISUAL INSPECTION: Some Common Sketches

Fig. 1. Sketch of surface appearance when concrete has been mixed for too long or the time of transport has been too long.



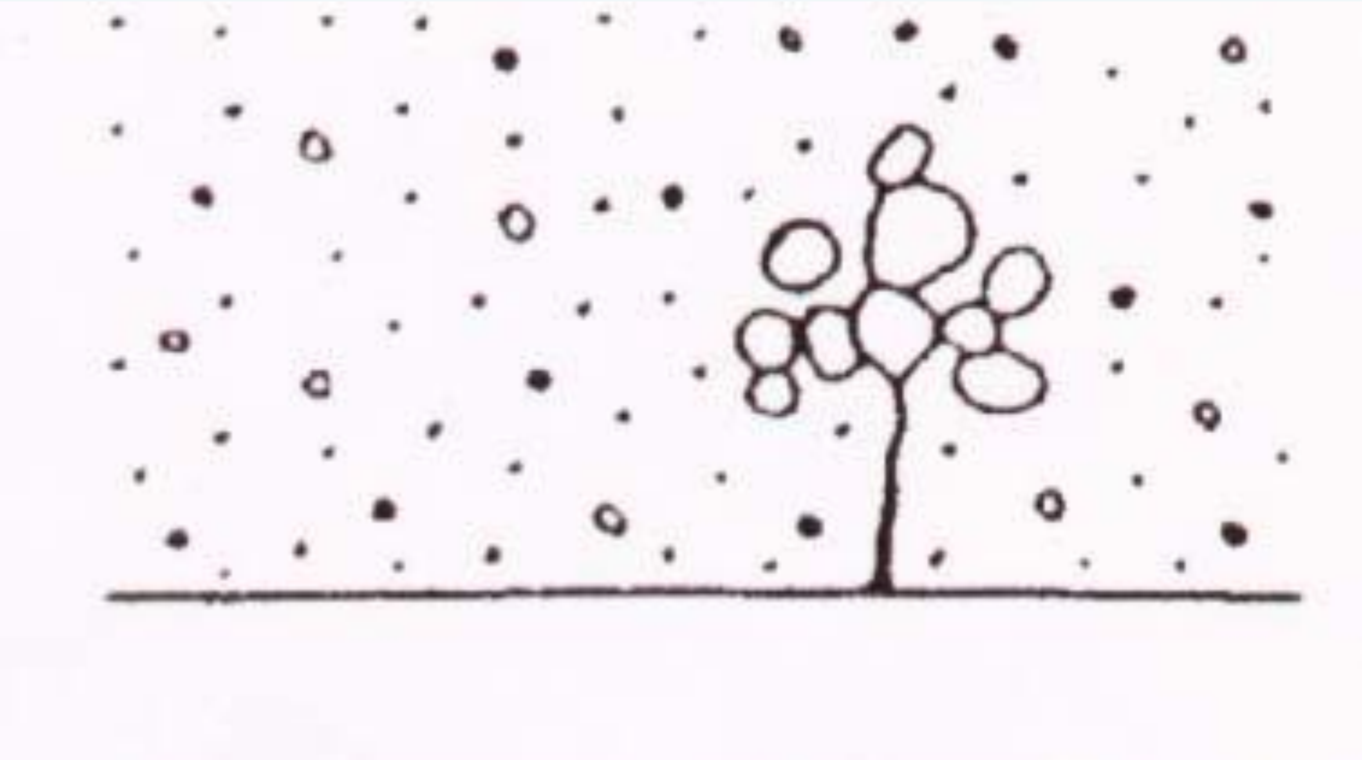
VISUAL INSPECTION: Some Common Sketches

Fig. 2. Sketch of crack due to concrete settling.



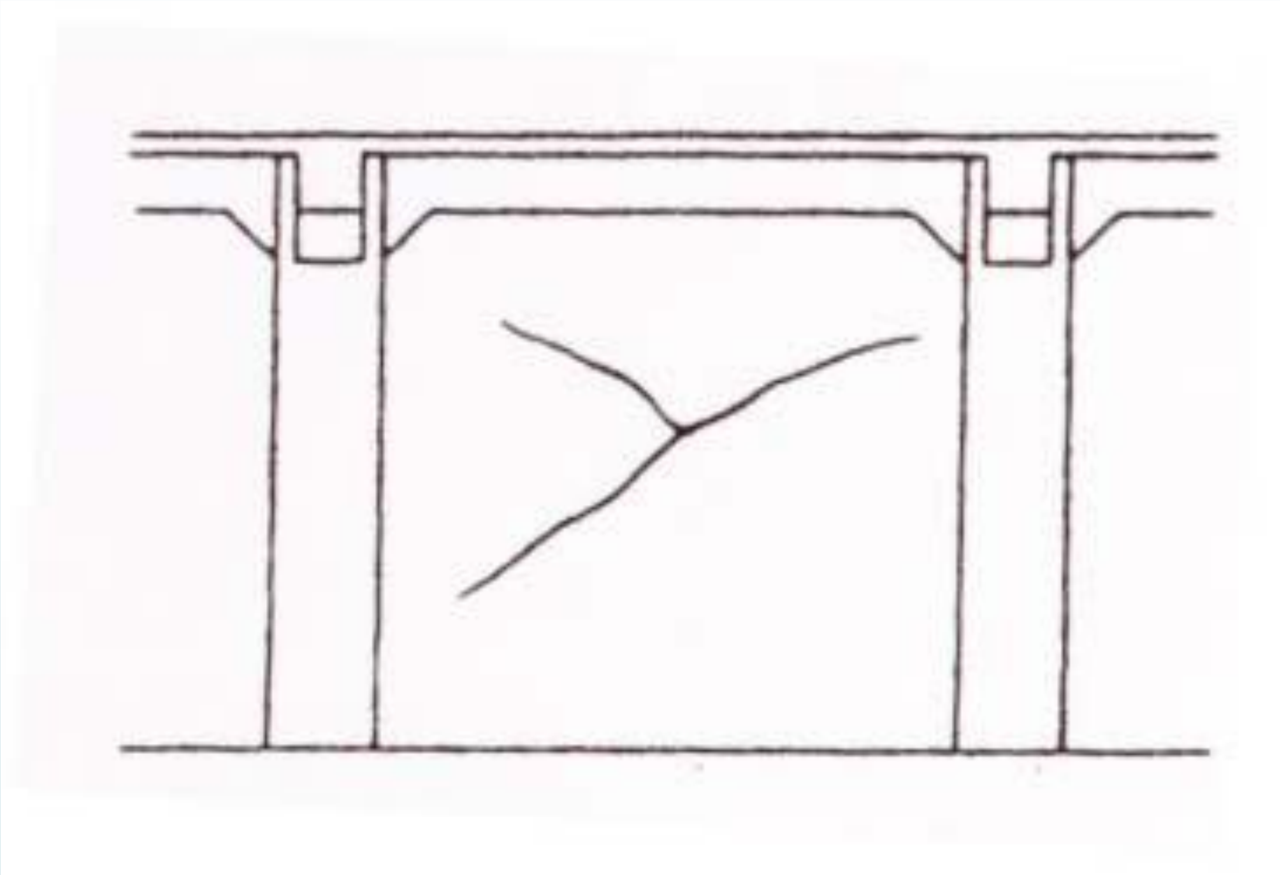
VISUAL INSPECTION: Some Common Sketches

Fig. 3. Sketch of exposed aggregate in concrete.



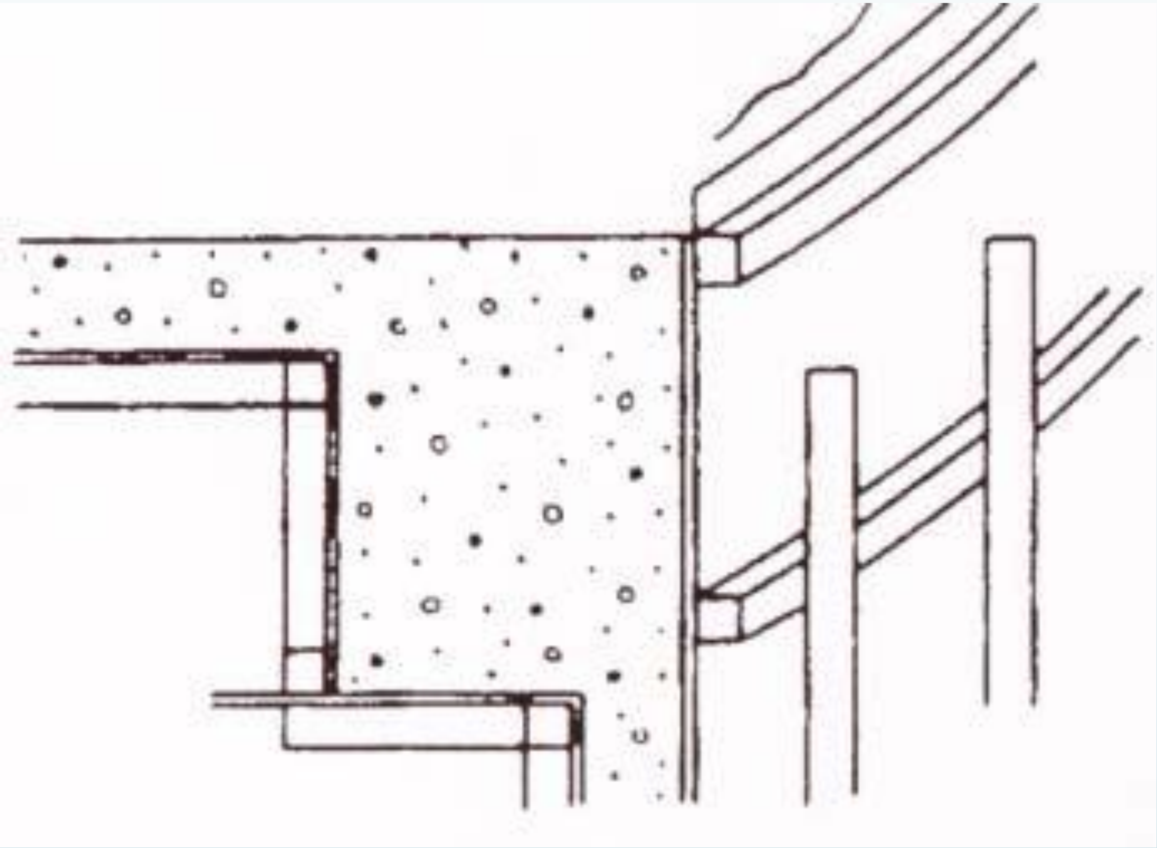
VISUAL INSPECTION: Some Common Sketches

Fig. 4. Unsuitable Processes at construction joints



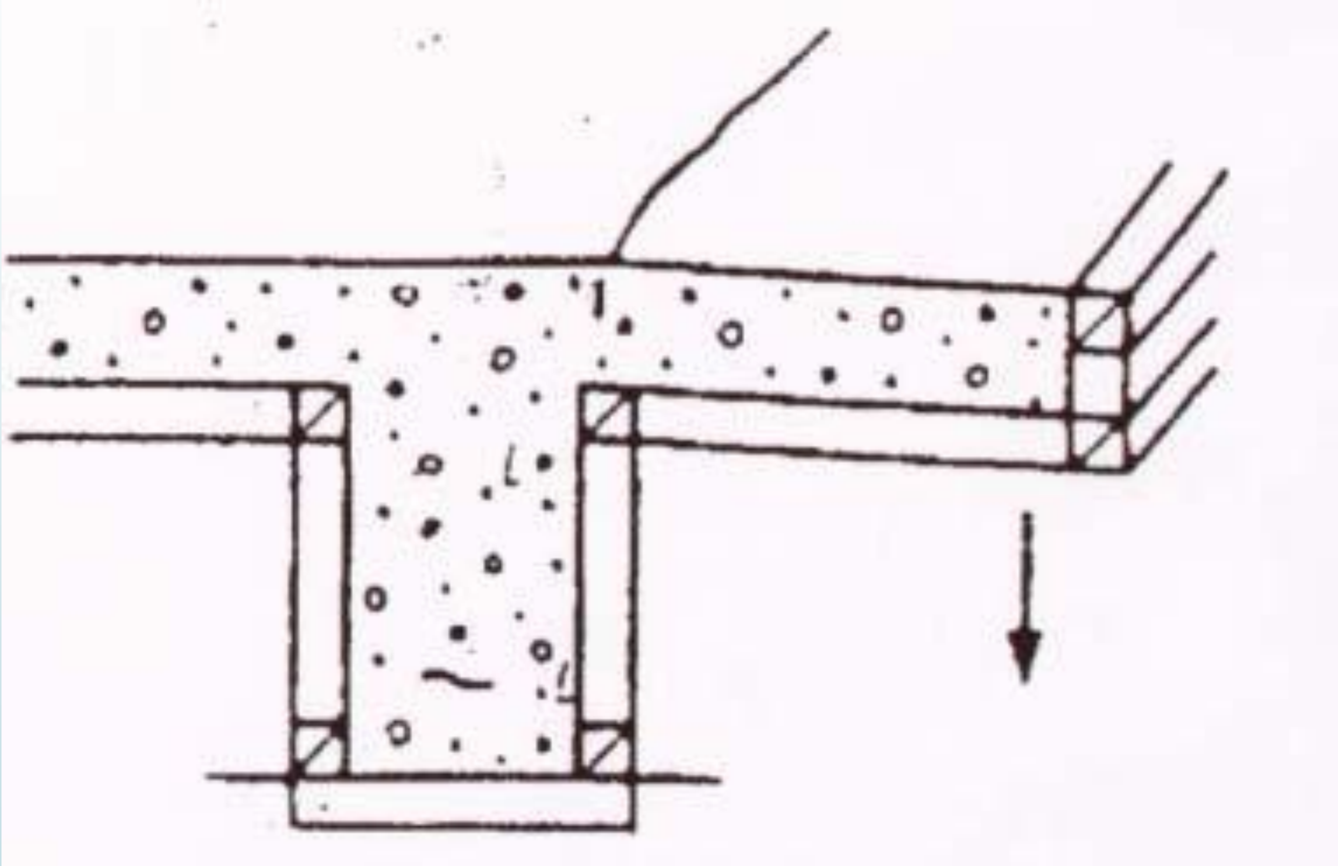
VISUAL INSPECTION: Some Common Sketches

Fig. 5. Sketch of cracking due to bowing of formwork



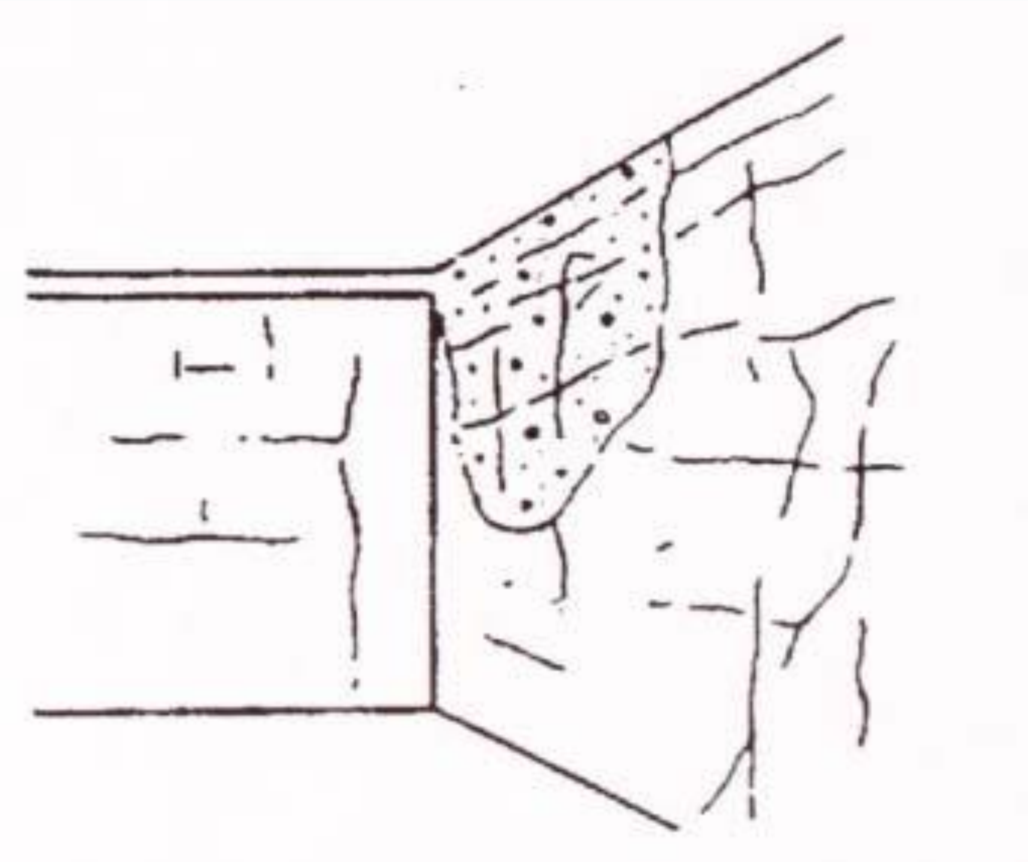
VISUAL INSPECTION: Some Common Sketches

Fig. 6. Sketch of cracking due to sinking of timber



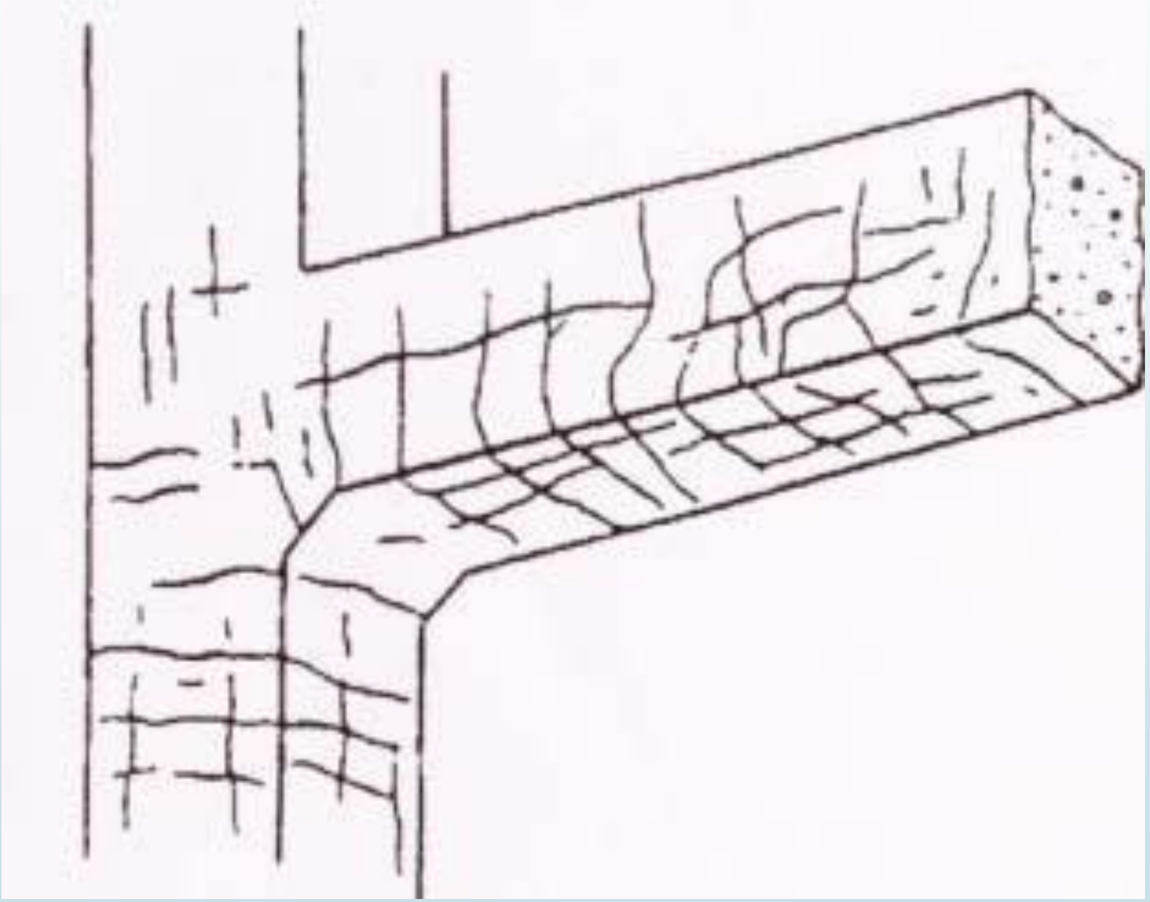
VISUAL INSPECTION: Some Common Sketches

Fig. 7. Sketch of severe rusting of reinforcement bars due to chemical action



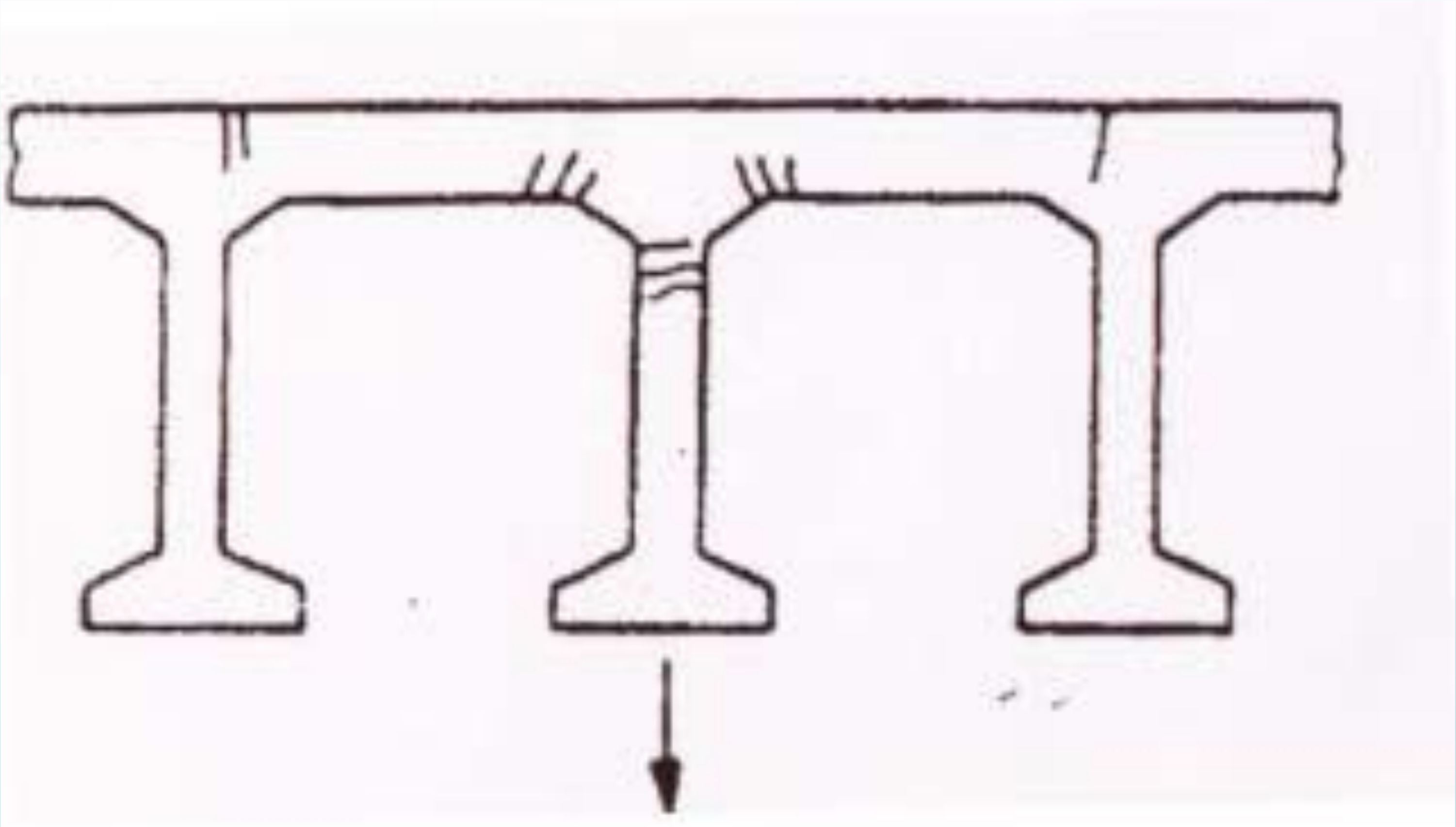
VISUAL INSPECTION: Some Common Sketches

Fig. 8. Sketch of effect of fire on concrete



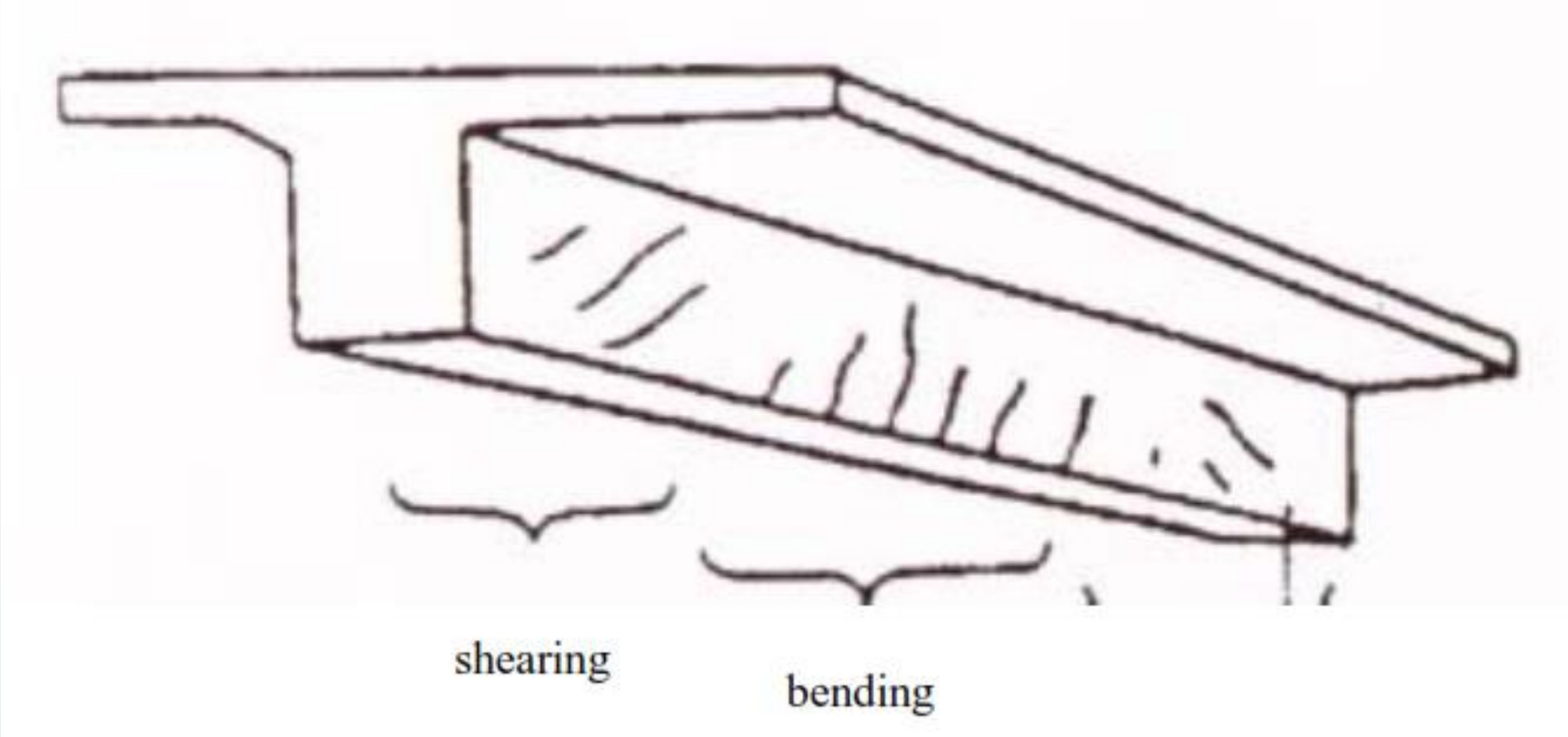
VISUAL INSPECTION: Some Common Sketches

Fig. 9. Cracks due to differential settlement of the central column



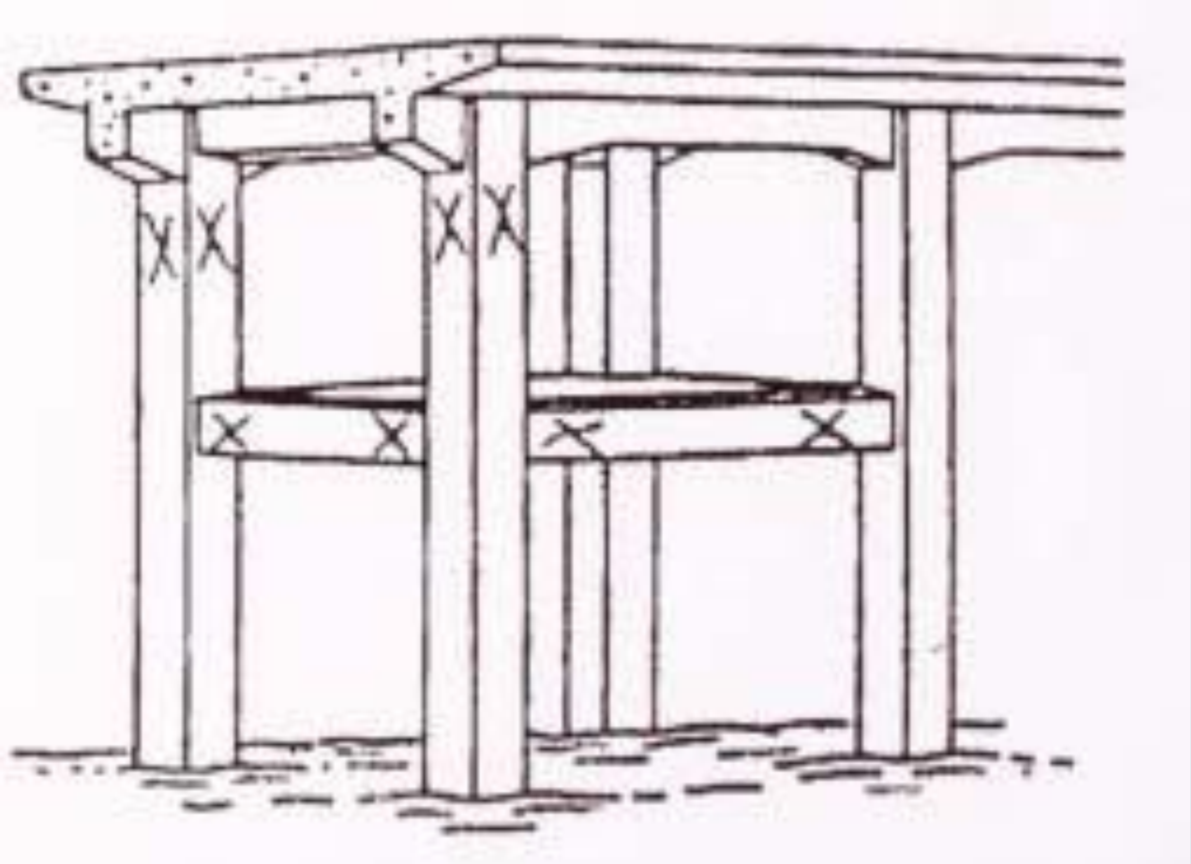
VISUAL INSPECTION: Some Common Sketches

Fig. 10. Cracks due to bending and shearing stresses



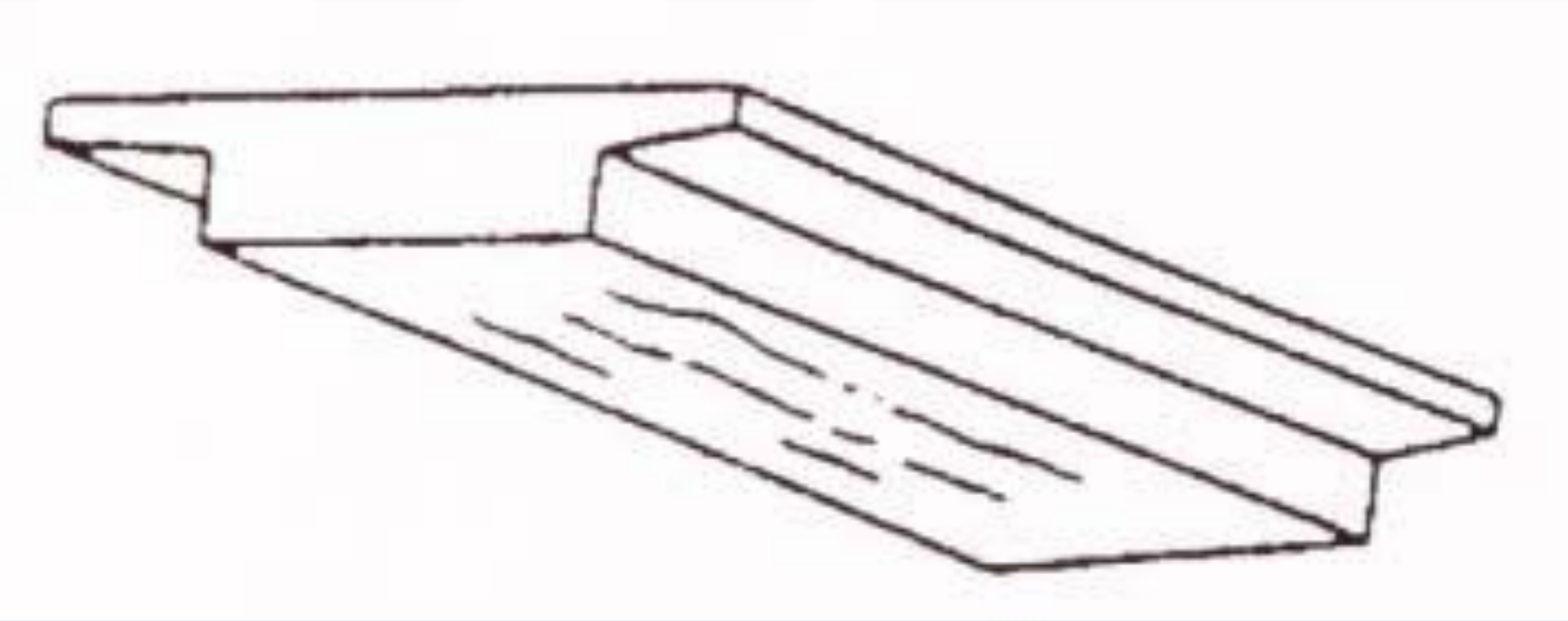
VISUAL INSPECTION: Some Common Sketches

Fig. 11. Cracking in beams and columns due to earthquake



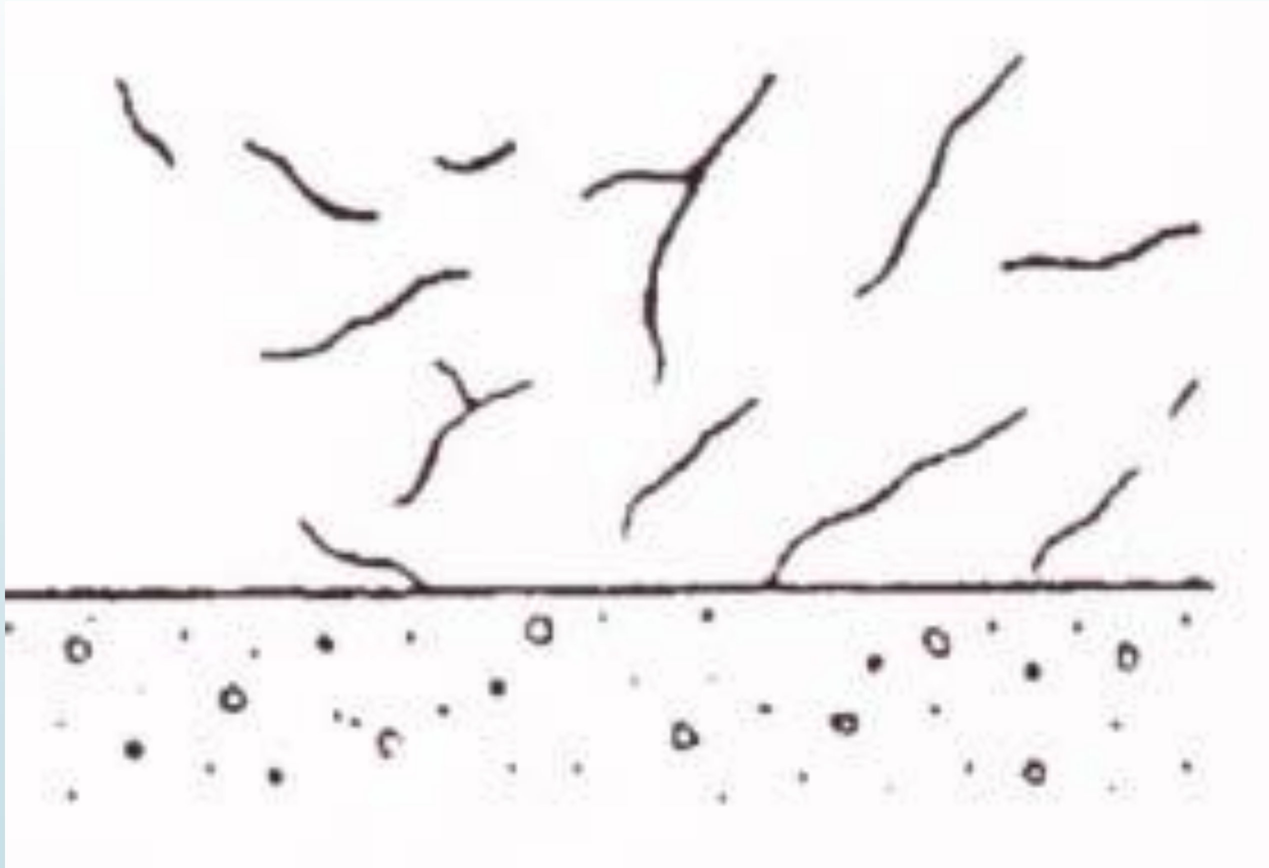
VISUAL INSPECTION: Some Common Sketches

Fig. 12. Cracks due to insufficient reinforcement bars



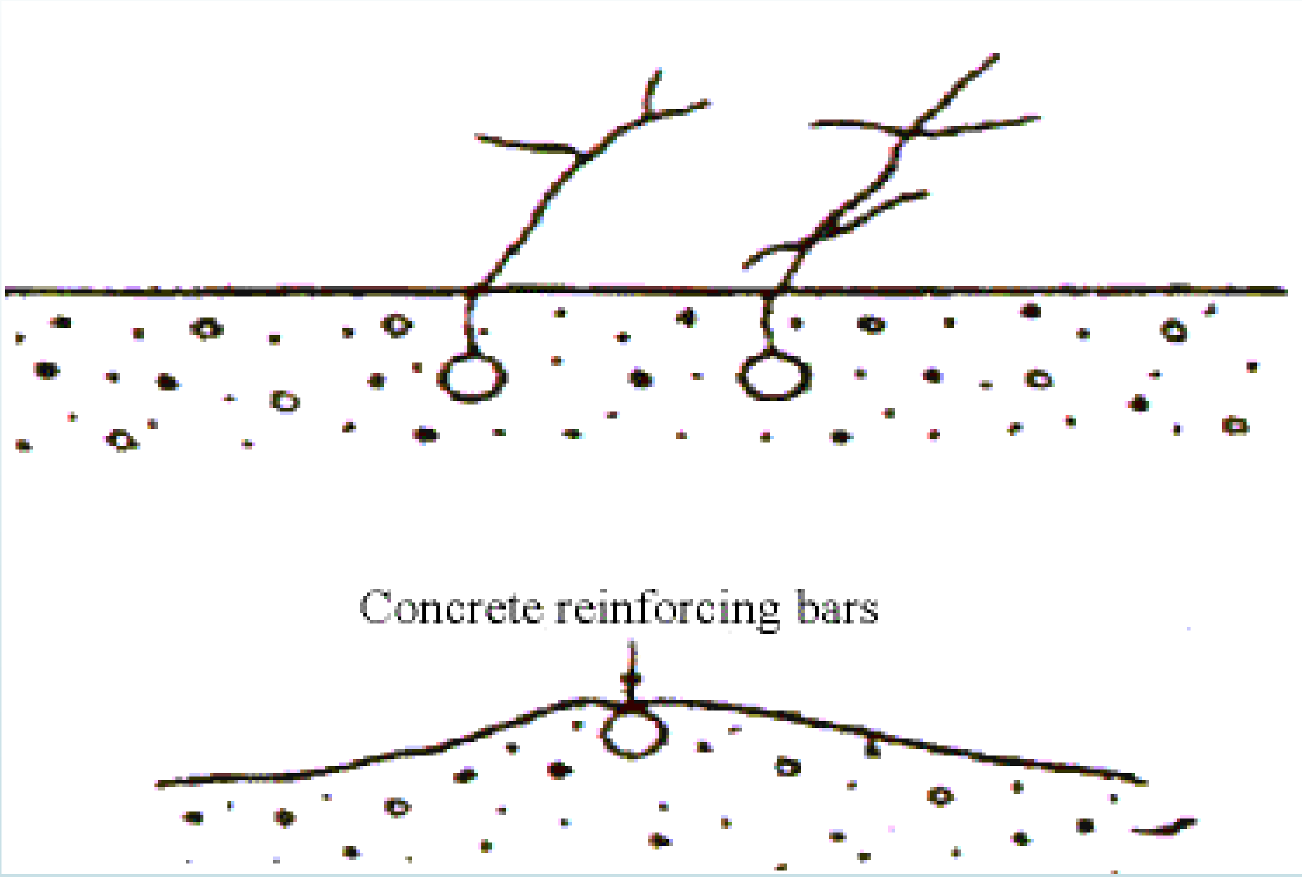
VISUAL INSPECTION: Some Common Sketches

Fig. 13. Cracks due to abnormal set of cement



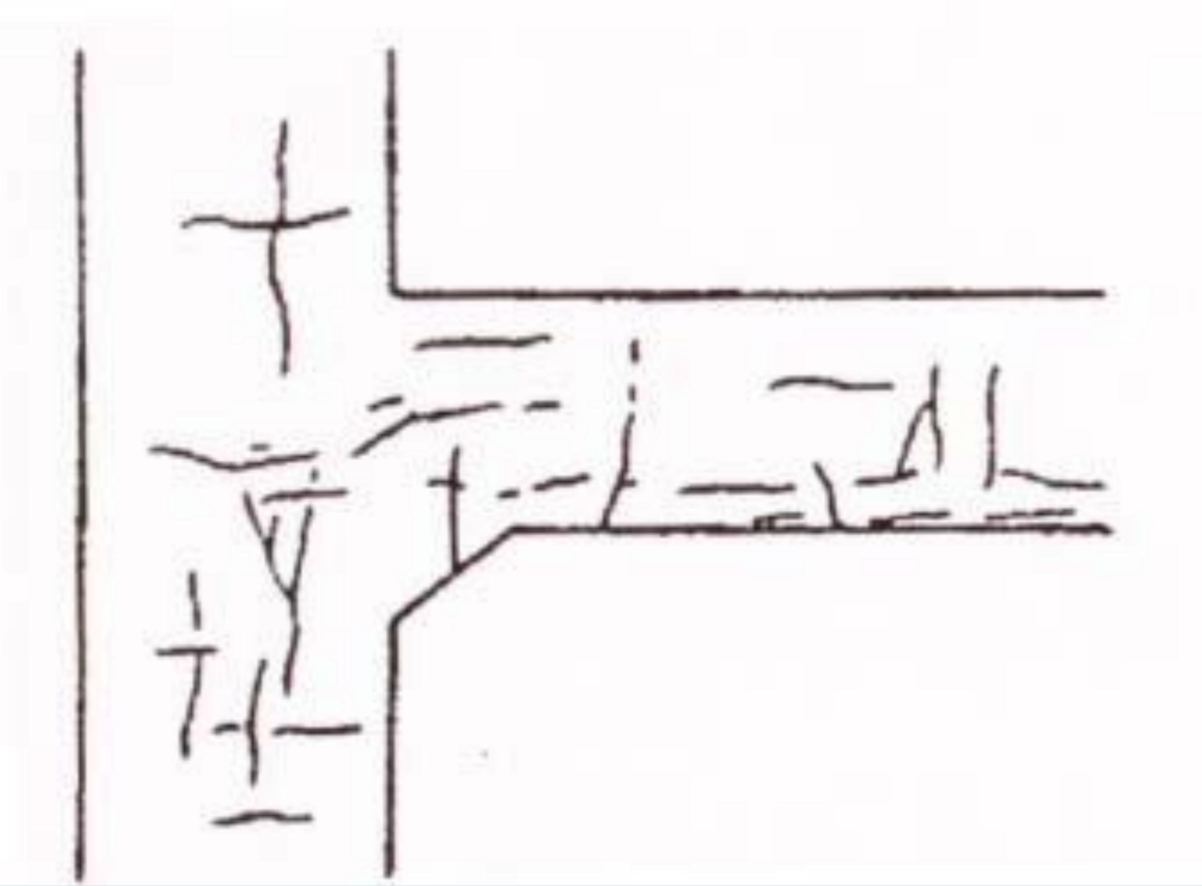
VISUAL INSPECTION: Some Common Sketches

Fig. 14. Sinking of concrete



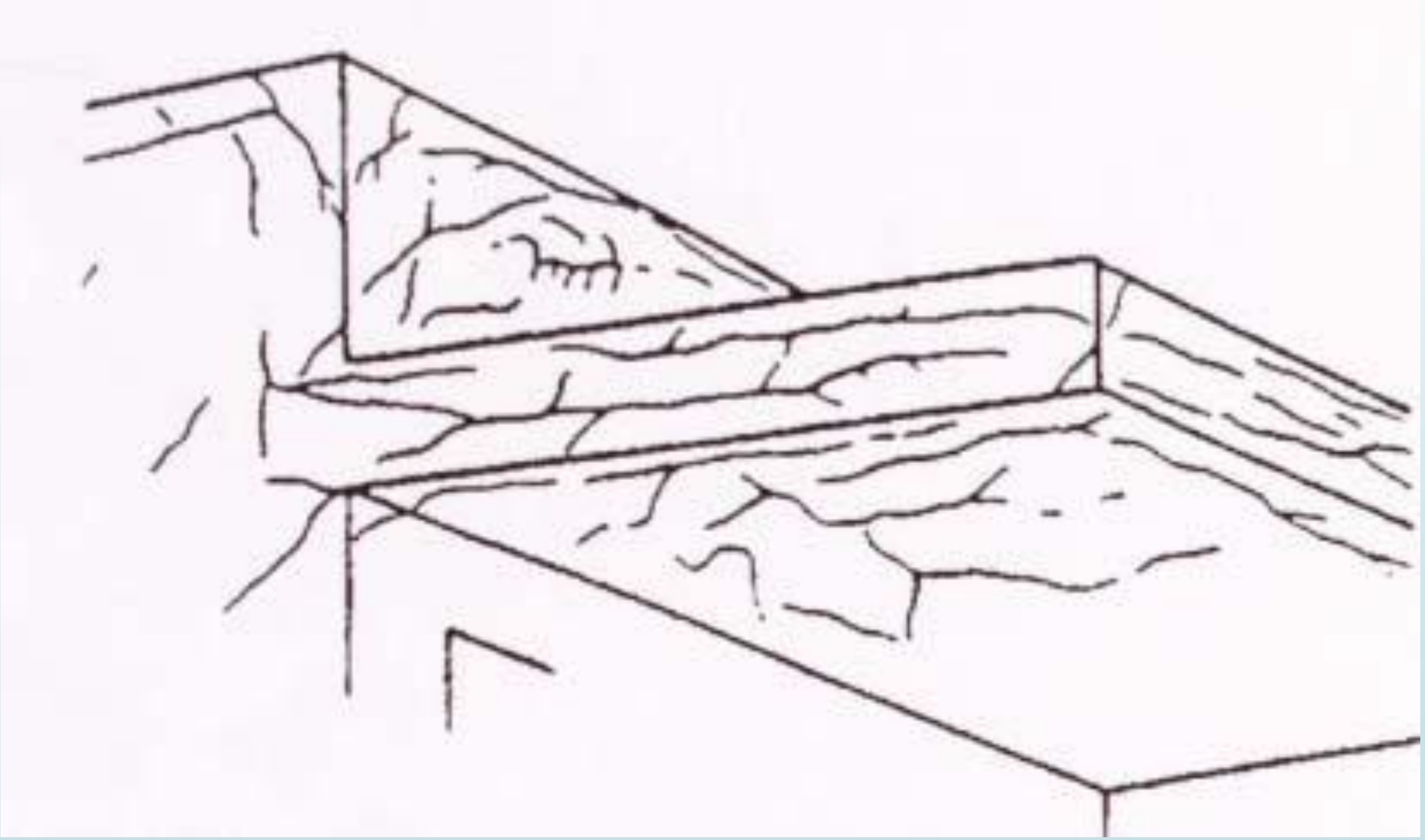
VISUAL INSPECTION: Some Common Sketches

Fig. 15. Rusting of Reinforcement Bars



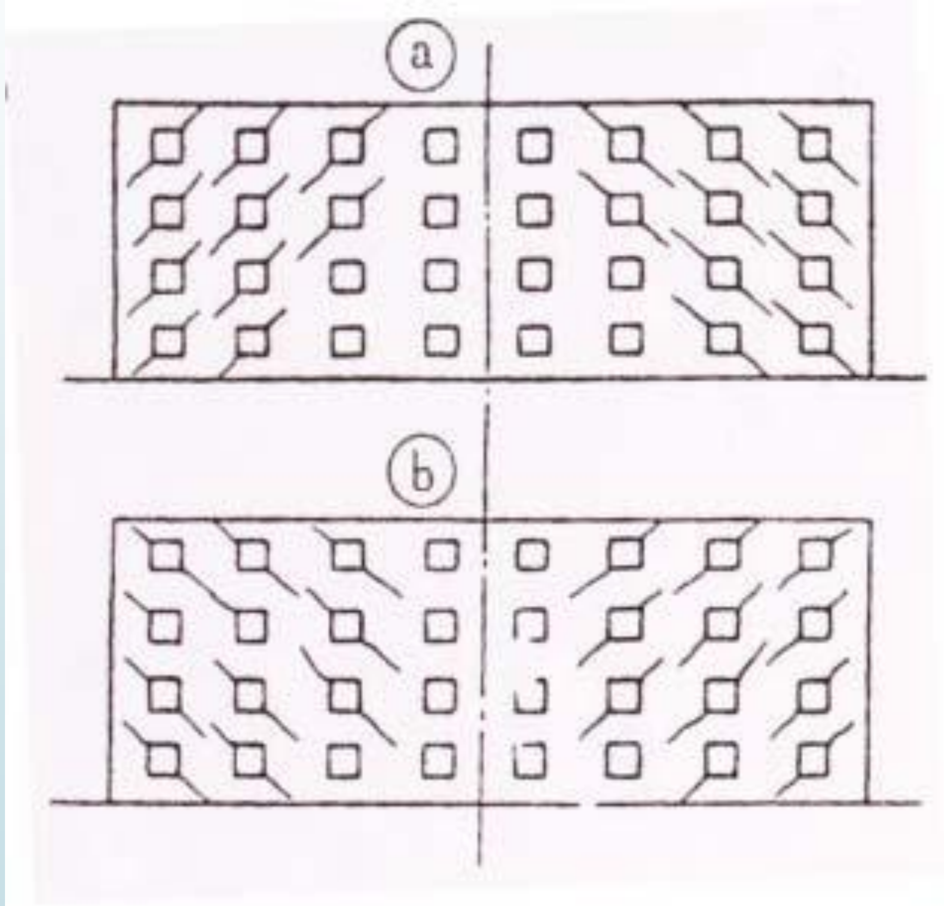
VISUAL INSPECTION: Some Common Sketches

Fig. 16. Effect of heating and freezing cycles



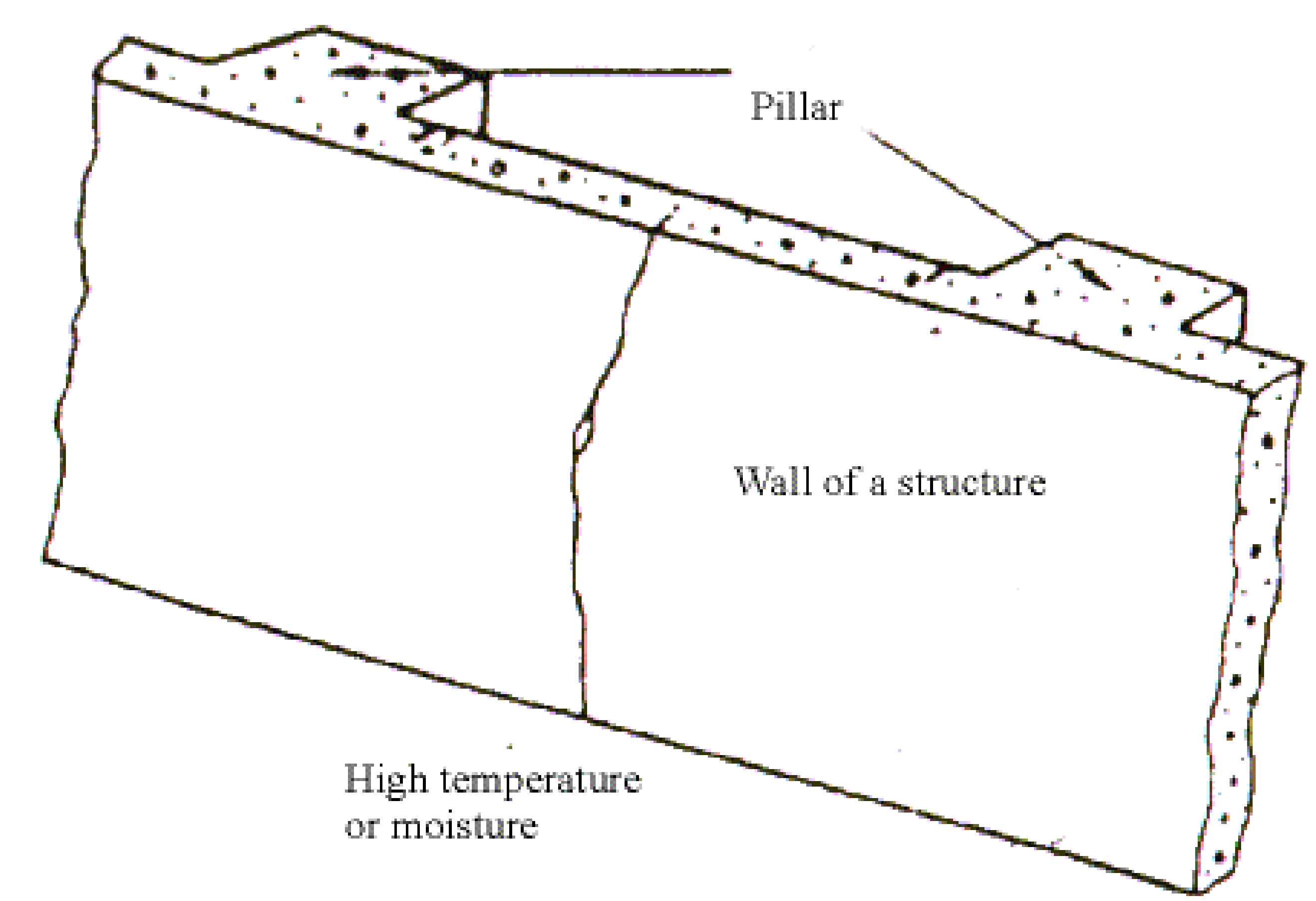
VISUAL INSPECTION: Some Common Sketches

Fig. 17. Effect of changing ground conditions (a) low temperature (b) dryness



VISUAL INSPECTION: Some Common Sketches

Fig. 18. Effect of atmospheric conditions



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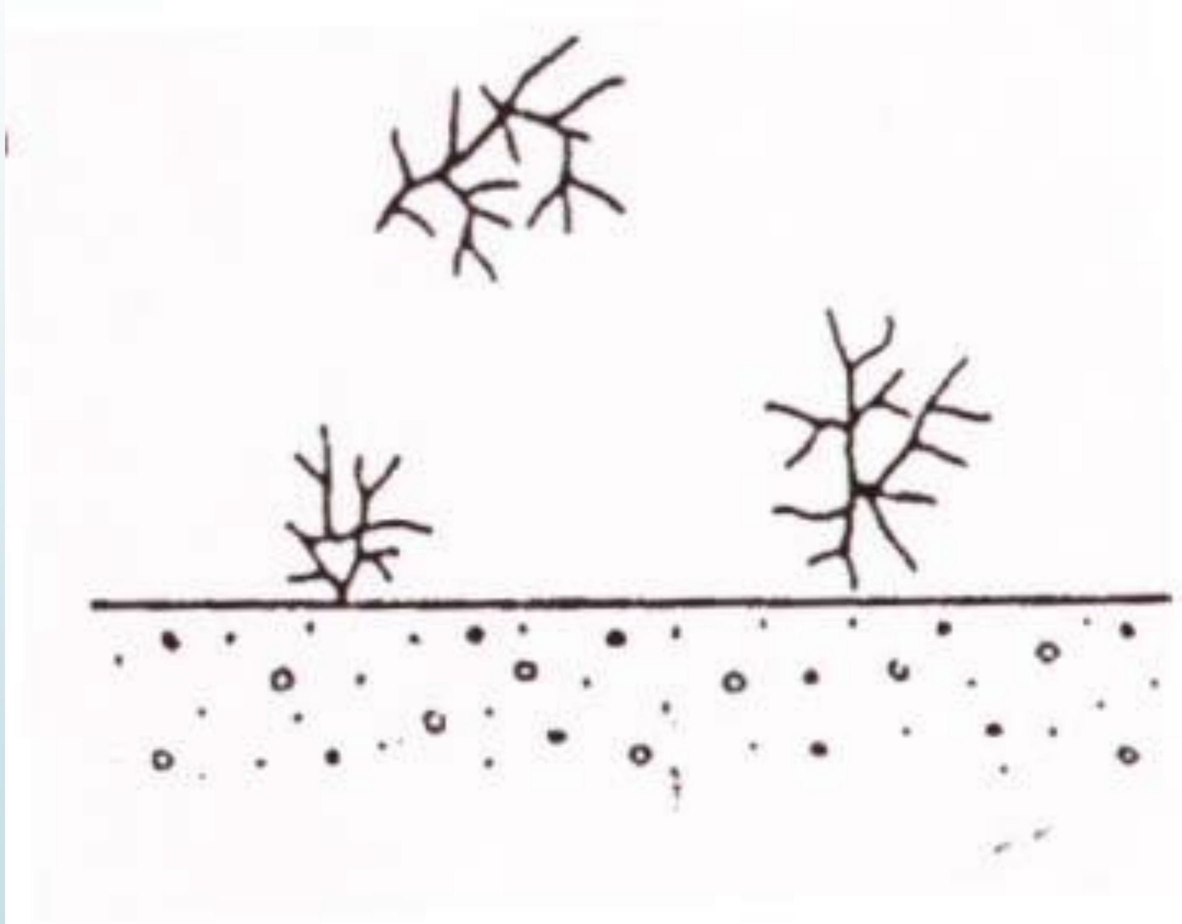
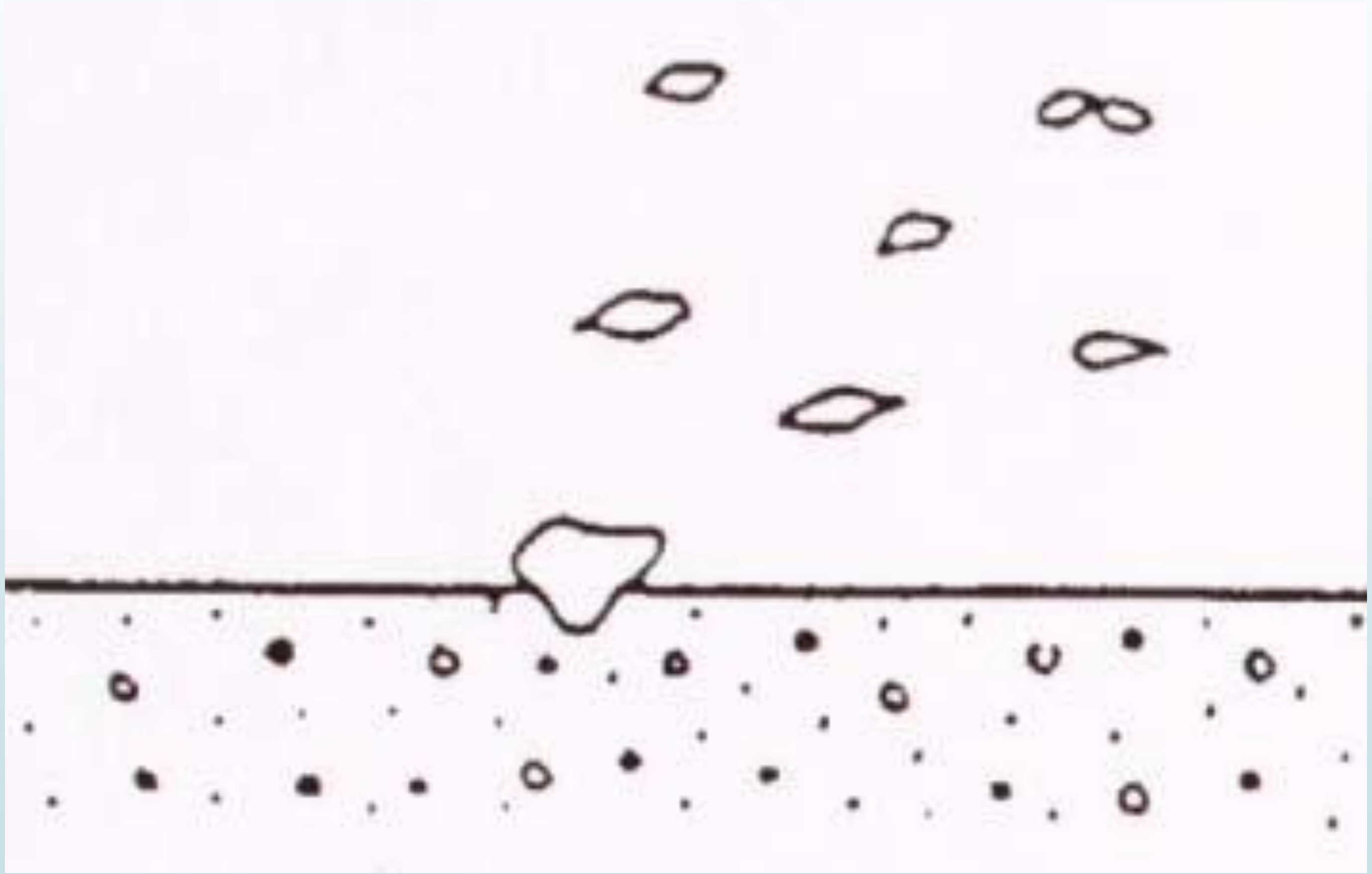
VISUAL INSPECTION: Some Common Sketches

Fig. 19. Non-uniformity of the admixture



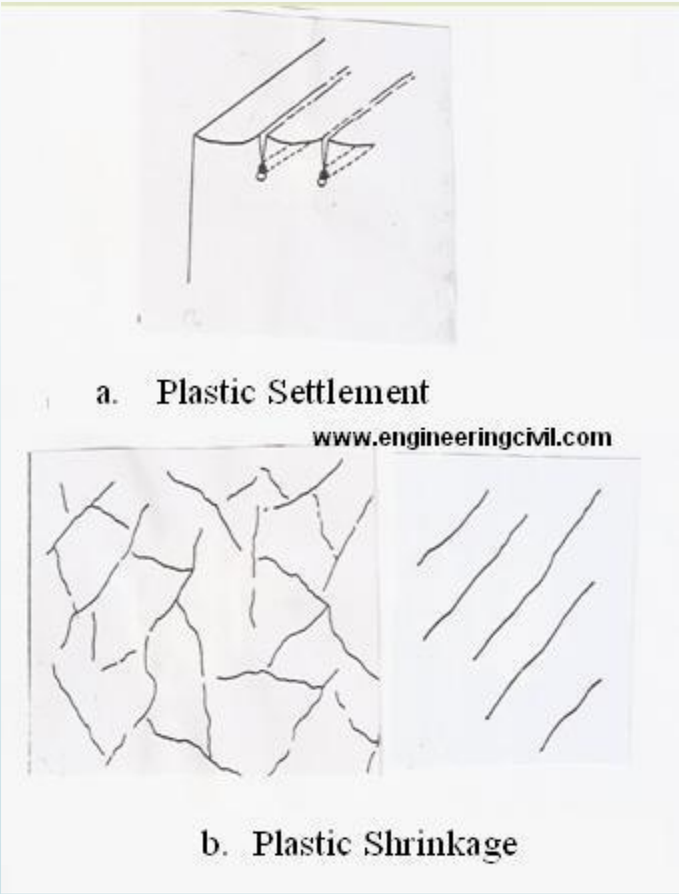
VISUAL INSPECTION: Some Common Sketches

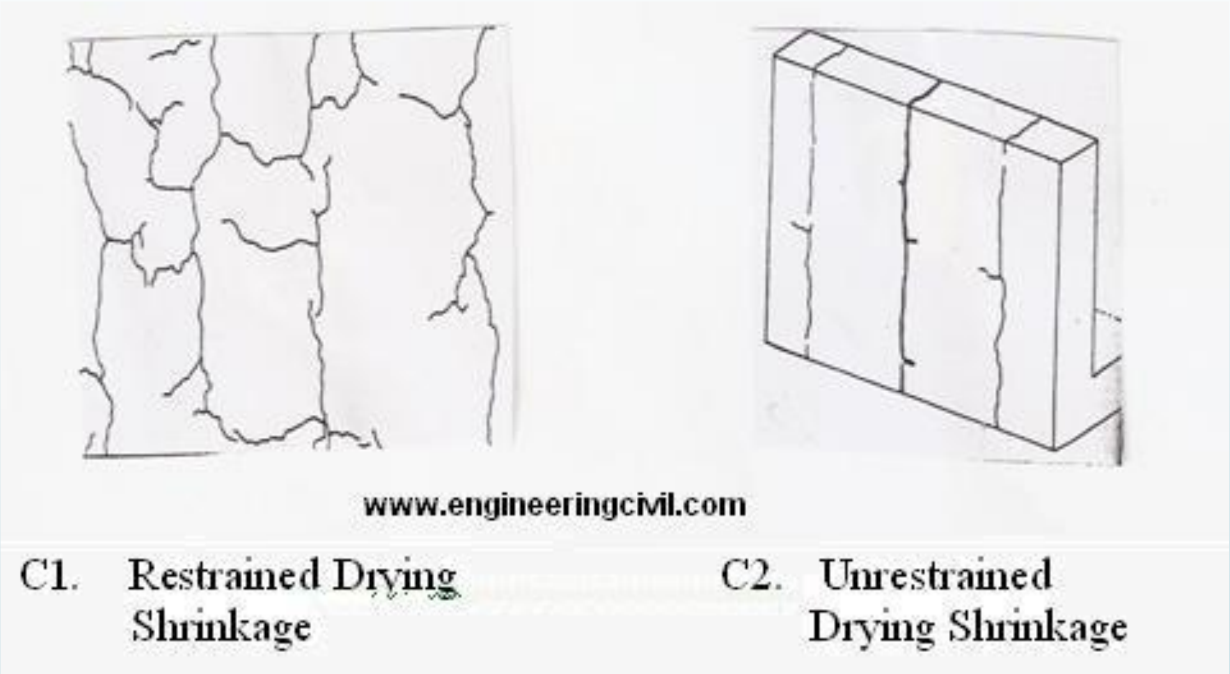
Fig. 20. Pop-out due to reactive aggregate and high humidity



VISUAL INSPECTION: Some Common Sketches

Fig. 21. Types of Cracks

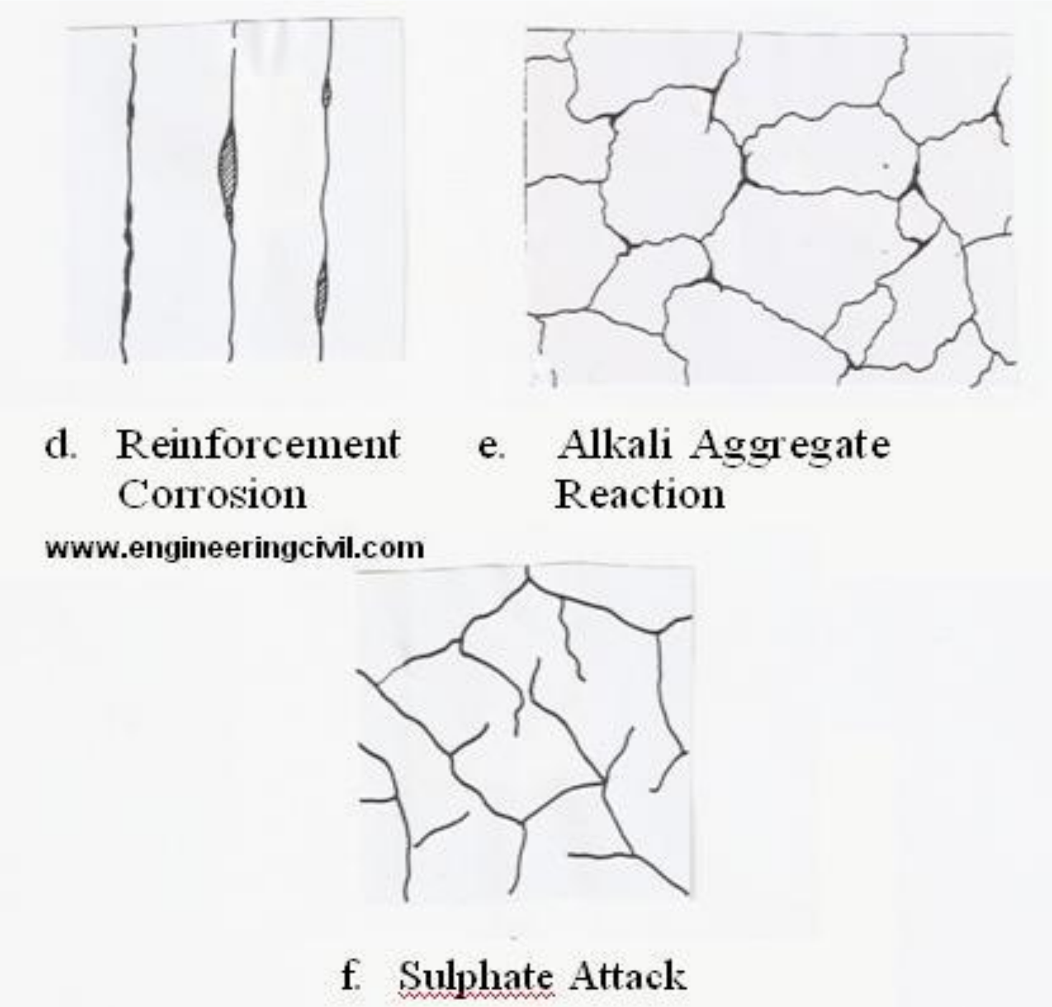




Reference:
http://www.engineeringcivil.com/visual-inspection-of-concrete-structure.html

VISUAL INSPECTION: Some Common Sketches

Fig. 21. Types of Cracks



Reference: http://www.engineeringcivil.com/visual-inspection-of-concrete-structure.html

VISUAL INSPECTION: Typical Images

Cold joints are created when concrete is poured against concrete that has already hardened to some degree. This condition results in a weakened bond between the existing and the newly poured concrete

Fig. 22. Cold Joint in Concrete

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Honeycombing is the term used to describe areas of the surface that are coarse and stony. It may be caused by insufficient fine material in the mix, perhaps due to incorrect aggregate grading or poor mixing. This can be corrected by increasing the sand and cement content of the mix and by proper mixing, placing and compaction.

Fig. 23. Honey-combing due to improper consolidation

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Plastic settlement can be caused by subsidence around rebar. As soon as concrete is placed, it begins to consolidate, and as bleed water rises to the surface, cement particles consolidate and the concrete settles. The settling process is restrained by reinforcement steel and, under certain circumstances, cracks will develop directly above the steel.

Fig. 23. Plastic Settlement Cracking

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Scaling is the shedding of flakes of hardened concrete at the surface. It can be caused by a number of conditions.

Fig. 24. Scaling of Concrete

Reference: https://www.nachi.org/visual-inspection-concrete.htm

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VISUAL INSPECTION: Typical Images

Typically occurs due to freeze-thaw cycles, application of de-icing salts and early finishing of the concrete even before bleeding is completed.

Fig. 25. Scaling and dusting of Concrete

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Crazing: Pattern cracking, also called map cracking and craze cracking, appears as a network of random cracking on the concrete's surface. The cracking is usually shallow (less than 1/8-inch deep) and not a structural issue. It's seldom a durability problem but more of a cosmetic one.

Fig. 25. Crazing Cracks

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Drying shrinkage is shrinkage that takes place after the concrete has hardened and some degree of bonding has developed between the cement paste and the aggregate. As concrete continues to dry, it will continue to shrink. Drying shrinkage includes both shrinkage that takes place while losing moisture to the air and autogenous shrinking, as noted previously.

Fig. 26. Drying Shrinkage Cracks

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Drying shrinkage cracks need not be continuous

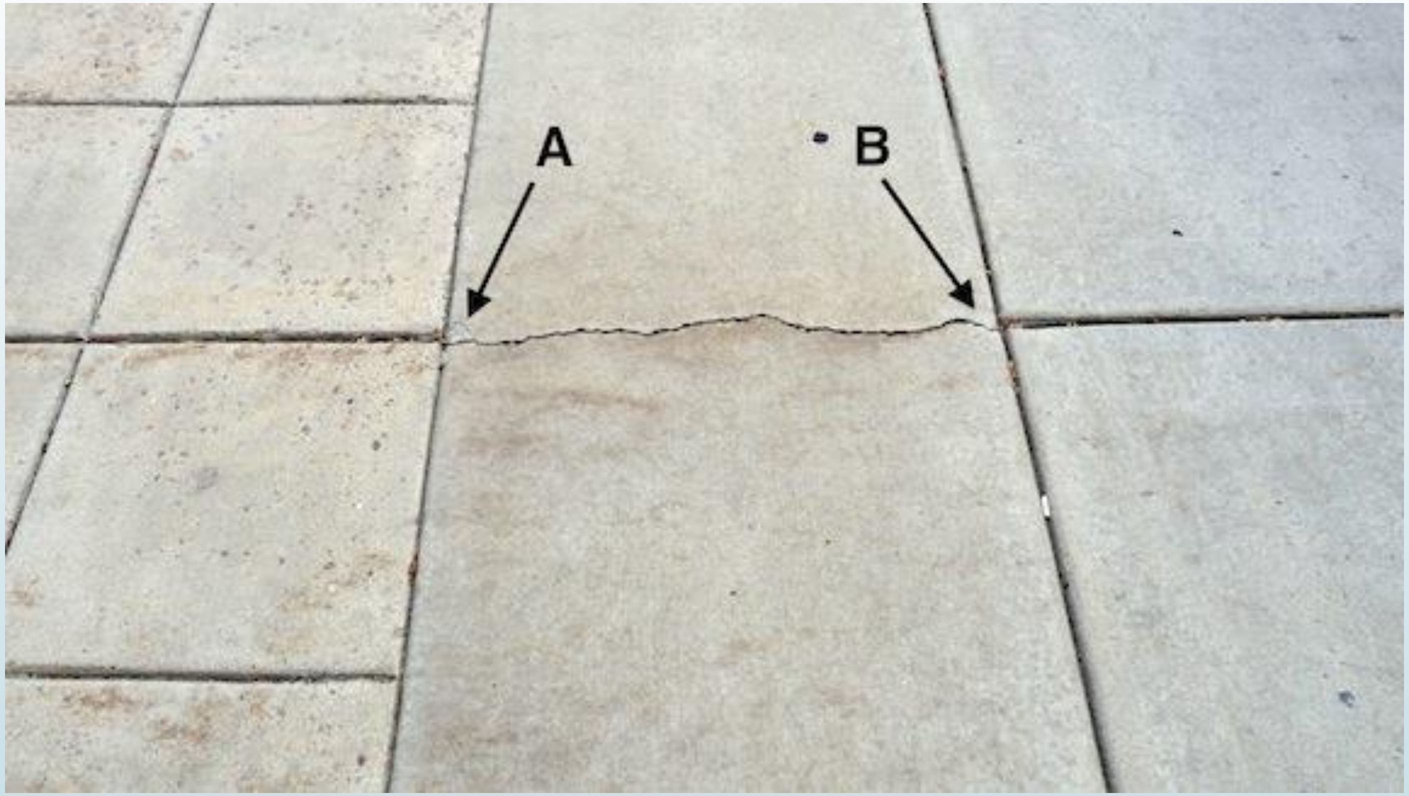
Fig. 27. Drying Shrinkage Cracks (Discontinuous)

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

In the photo above, areas A and B were the points at which the highest stress developed due to adjacent cracking in the control joints, so that is where the walkway panel split first, following the path of greatest stress. As the slab continued to shrink, the two cracks connected with each other to form a single transverse crack.

Fig. 28. Traverse Shrinkage Cracks extended between cracks located in control joints



Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

A re-entrant corner is where any inside corner forms an angle of less than 180 degrees into the body of the slab. As the concrete dries and shrinks, the wedge shape of the re-entrant corner encourages concrete to crack off the point of the angle into the slab.

Fig. 29. Re-entrant corner cracks

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

A re-entrant corner is where any inside corner forms an angle of less than 180 degrees into the body of the slab. As the concrete dries and shrinks, the wedge shape of the re-entrant corner encourages concrete to crack off the point of the angle into the slab.

Fig. 30. Re-entrant corner cracks

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Deformation and cracking under load sustained over a long period of time.

Fig. 31. Creep with cracks

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Due to improper compaction or preparation of the subgrade, possibility of differential settlement of sub-grade exists. Due to this, the overlaying concrete pavement or slab develops cracks.

Fig. 32. Differential Settlement Cracks

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Soil with poor load-bearing capacity allows settling.

Fig. 33. Masonry cracks due to Differential Settlement

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

To confirm AAR, further laboratory investigations will be required.

Fig. 34. Cracks Pattern due to chemical action – Possibly Alkali Aggregate Reaction (AAR)

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Physical sulphate attack is often evidenced by bloom (presence of sodium sulphate salts) at exposed concrete surface. It is not only a cosmetic problem but the visible display of possible chemical and micro-structural degradation within the concrete.

Fig. 35. Damage Pattern due to chemical action – Sulphate Attack

VISUAL INSPECTION: Typical Images

The concrete floor in question was under severe sulphate attack. Due to the underlying soil conditions, the ingress of moisture started the reaction.

Fig. 36. Cracks Pattern due to chemical action – Sulphate Attack

Reference: https://www.nachi.org/visual-inspection-concrete.htm

VISUAL INSPECTION: Typical Images

Severe Sulphate Attack due to exposure of the pillar to sea water.

Fig. 37. Deterioration due to chemical action – Sulphate Attack

Reference: https://www.nachi.org/visual-inspection-concrete.htm

Fig. 38. Spalling due to Reinforcement Corrosion

VISUAL INSPECTION: Typical Images

Corrosion of reinforcing steel causes spalling of the cover concrete

VISUAL INSPECTION: Typical Images

Another example

Fig. 39. Spalling due to Reinforcement Corrosion

VISUAL INSPECTION: Typical Images

Another example

Fig. 40. Crack due to excessive loading

Reference: https://www.nachi.org/visual-inspection-concrete.htm

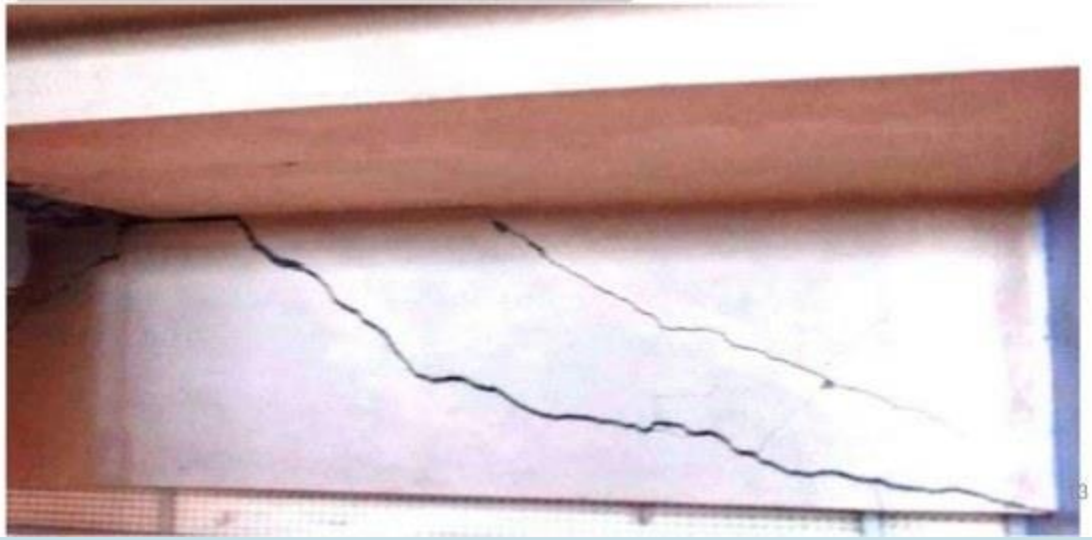
VISUAL INSPECTION: Typical Images

Another example

Fig. 41. Crack due to excessive loading

Flexure-Shear Failure

A flexure-shear failure, is the result of a crack which begins as a flexural crack, but as shear increases, the crack begins to "turn over" and incline towards the loading point. Failure finally occurs when the concrete separates and the two planes of concrete slide past one another. *This mode of failure is common in beams which do not contain web reinforcement*.



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2. https://www.nachi.org/visual-inspection-concrete.htm
3. https://www.cforcivil.com/steel-reinforcement-corrosion-control-methods/
4. https://www.quora.com/What-is-flexural-shear-failure

THANK YOU