BUILDING REPAIRS AND MAINTENANCE

PART-I

Dr. S. THIRUGNANASAMBANDAM

ASSOCIATE PROFESSOR

DEPT. OF CIVIL & STRUCTURAL ENGINEERING

ANNAMALAI U NIVERSITY

ANNAMALAINAGAR-608 002

Structures are designed to withstand safely a particular predetermined load during their life period. Generally reinforced concrete (RC) structures can suffer varying degrees of damage due to several reasons including material deterioration, construction technique adopted, poor workmanship, overloading, aggressive environments, fatigue and corrosion of steel reinforcement embedded in concrete.

BUILDING MATERIALS

Building materials can be generally categorized into two sources:

- Natural and Synthetic Materials

- Natural building materials are those that are unprocessed or minimally processed by industry, such as clay, sand, wood, rocks and glass.

- Synthetic materials are made in industrial settings after much human manipulations, such as plastics and petroleum based products.

Concrete is a composite building material made from the combination of aggregates and a binder such as cement.

IS CONCRETE SO POPULAR?

Concrete is used more than any other man-made material in the world.

- **Can be fabricated practically anywhere**
- **Can be moulded and cast into a wide range of shapes and geometries**
- **Is relatively cheap**
- **Stronger and more durable**

Age of Cement nearly 150 Years

- 33 Grade Ordinary Portland Cement
- 43 Grade Ordinary Portland Cement
- 53 Grade Ordinary Portland Cement
- Rapid Hardening Portland Cement
- Portland Pozzolana Cement (fly ash based)
- Portland Pozzolana Cement (calcined clay based)
- Low Heat Portland Cement
- Sulphate Resisting Cement

Ordinary Concrete

M10, M15, M20

Standard Concrete

M25, M30, M35, M40, M45, M50, M55

High Strength Concrete

M60, M65, M70, M75, M80

Minimum Grade of Concrete: R.C.C - M20

P.C.C - M15

P.S.C - Pre tensioned M40

Post tensioned M30

Plain and Reinforced Concrete Code of Practice: IS 456 - 2000

- **Strength Concept**
- **Durability Concept**

Durability of Concrete: **A Durable Concrete is One that Performs Satisfactorily in the Working Environment During its Anticipated Exposure Conditions During Service.**

Environmental Condition: **Mild, Moderate, Severe, Very Severe and Extreme.**

Nominal Cover to Reinforcement : **Slab:20mm, Beam:25mm, Column:40mm and Foundation: 50mm**

Quality of Concrete

- water cement ratio
- sand/stone ratio
- cover depth
- chloride content in constituents
- moisture content
- oxygen
- pH value
- temperature
- permeability of concrete
- method and time of curing
- electrical resistivity of concrete
- crack width
- type and size of reinforcement bars.

DAMAGE

Quay Wall Collapse

Damages in RC Structures:

- Cracking
- Leakage
- Settlement
- Over Deflection
- Wearing
- Spalling
- Disintegration
- Delamination
- Over loading
- Aggressive Environments
- Materials used for construction
- Fatigue and Corrosion

- A strip of notched tape works similarly :

  Movement is indicated by tearing of the tape
- The device using a typical vernier caliper is the most satisfactory of all.

  Both extension and compression are indicated
- If more accurate readings are desired, extensometers can be used
- Where extreme accuracy is required resistance strain gauges can be glued across the crack

Design and construction stages - durability of structures:

- Right choice of material
- Proper construction methods
- Adequate specifications for construction and installation work.
- Effective supervision throughout the construction period and rectification of defects prior to final handover of the buildings.
- Provision of adequate space for landscaping with proper design

♦ Damage Assessment of Structures

- To identify the suitable repair procedure, it is necessary to have a planned approach to investigate the condition of concrete and reinforcement

- ♦ **Repair and Rehabilitation**

  Repair and rehabilitation mean restoring the damaged structures to make them fit for serviceability condition.

- ♦ **Selection of repair materials**
  - **Dimensional stability**
  - **Modulus of elasticity**
  - **Permeability**
  - **Chemical resistance**
  - **Adhesion with parent concrete**
  - **Coefficient of thermal expansion**
  - **Easy to use**

CRACKS

CAUSES OF CONCRETE CRACKING

- Physical damage
- Structural damage
- Chemical and electrochemical damage
- Construction damage

I. Physical damage

- a. Plastic shrinkage
- b. Plastic Settlement
- c. Drying Shrinkage
- d. Thermal effects
- e. Freeze and thaw
- f. Abrasion
- g. Erosion and cavitation
- h. Fire

II. Structural damage

- a. Design errors
- b. Overloading
- c. Settlement
- d. Creep
- e. Deflection
- f. Fatigue

III. Chemical and electrochemical damage

- a. Corrosion of reinforcement
- b. Alkali-aggregate reaction
- c. Sulphate attack
- d. Acid attack
- e. Carbonation

IV. Construction damage

- a. Movements of the ground and formwork
- b. Construction movement
- c. Vibration

TYPES OF CRACKS

- 1. Plastic Shrinkage Cracks
- 2. Plastic Settlement Cracks
- 3. Drying Shrinkage Cracks
- 4. Thermal Cracks
- 5. Map Cracks due to alkali aggregate reaction
- 6. Longitudinal Cracks due to Corrosion
- 7. Transverse Cracks due to loading
- 8. Shear Cracks due to loading

Plastic Shrinkage Cracks

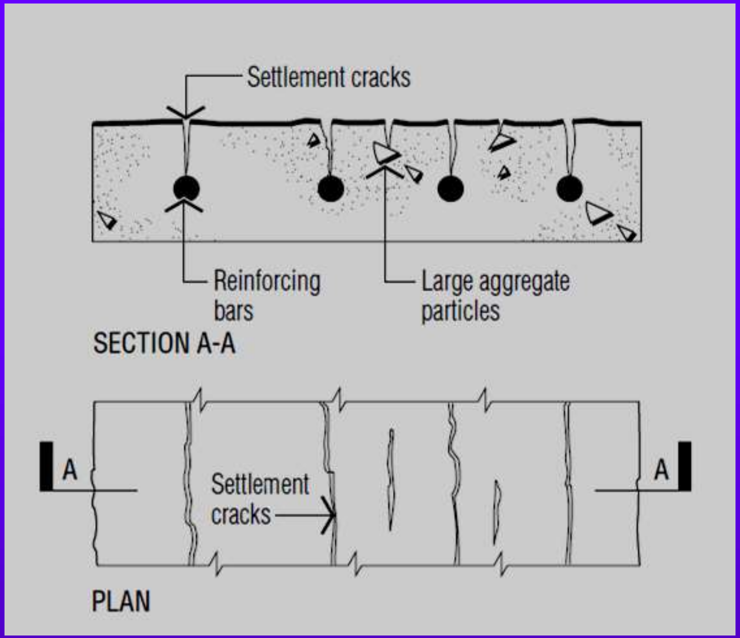
Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade is believed to be the **main reasons** of plastic shrinkage. The loss of water results in the reduction of volume.

The **factors affecting** the plastic shrinkage are (i) Ambient temperature (ii) Relative humidity (iii) Wind velocity (iv)Temperature of concrete.

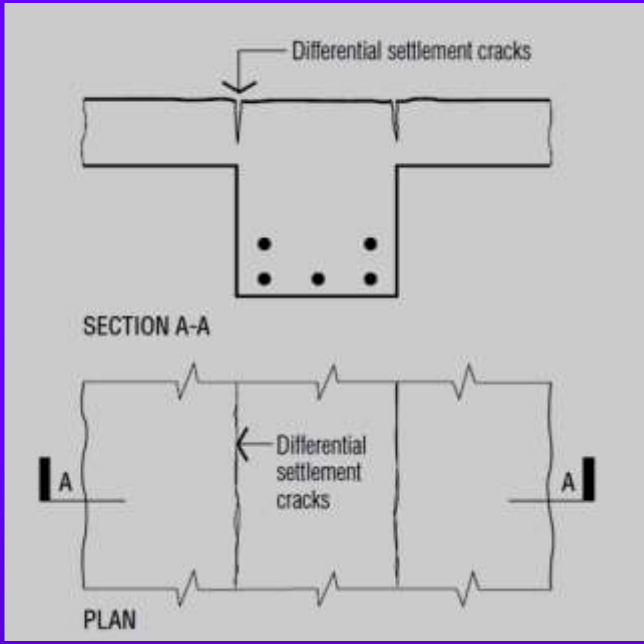
The **preventive measures** for plastic shrinkage are listed below:

1. Dampening of subgrade and forms
2. Controlling the wind velocity by erection of windbreaks
3. Minimizing placing and finishing time
4. Using membrane curing, begin curing as soon as possible after finishing
5. Using monomolecular films (evaporation retarders) or fog spray immediately after the screeding to maintain the water/cement ratio at the surface
6. Using surface dry aggregates

Plastic Settlement Cracks



These cracks form during construction in concrete due to settlement of concrete and bleeding of excess water from the concrete.



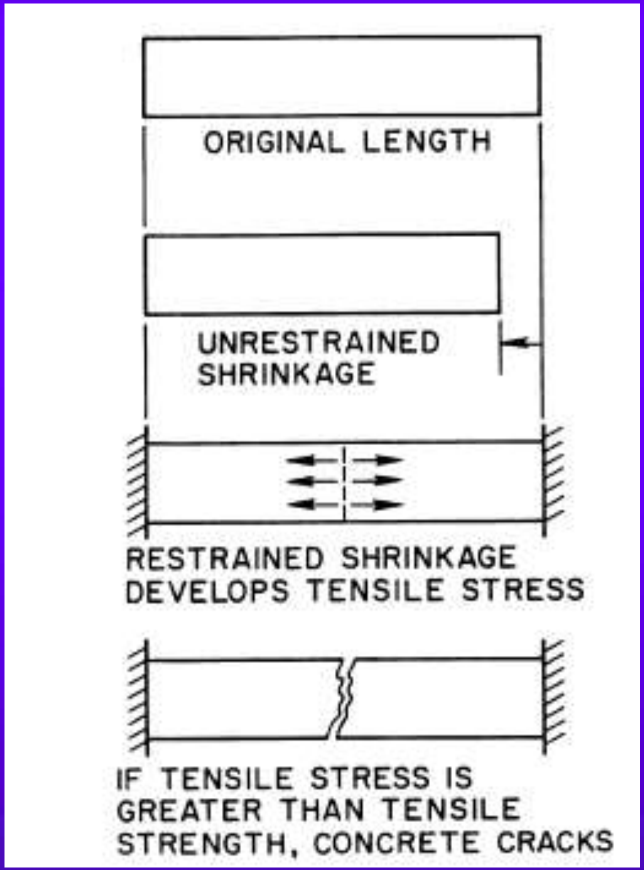
Differential Settlement Cracks

At changes of section such as the section at a beam/slab junction, the different amount of settlement can lead to cracks forming at the surface as shown in Figure

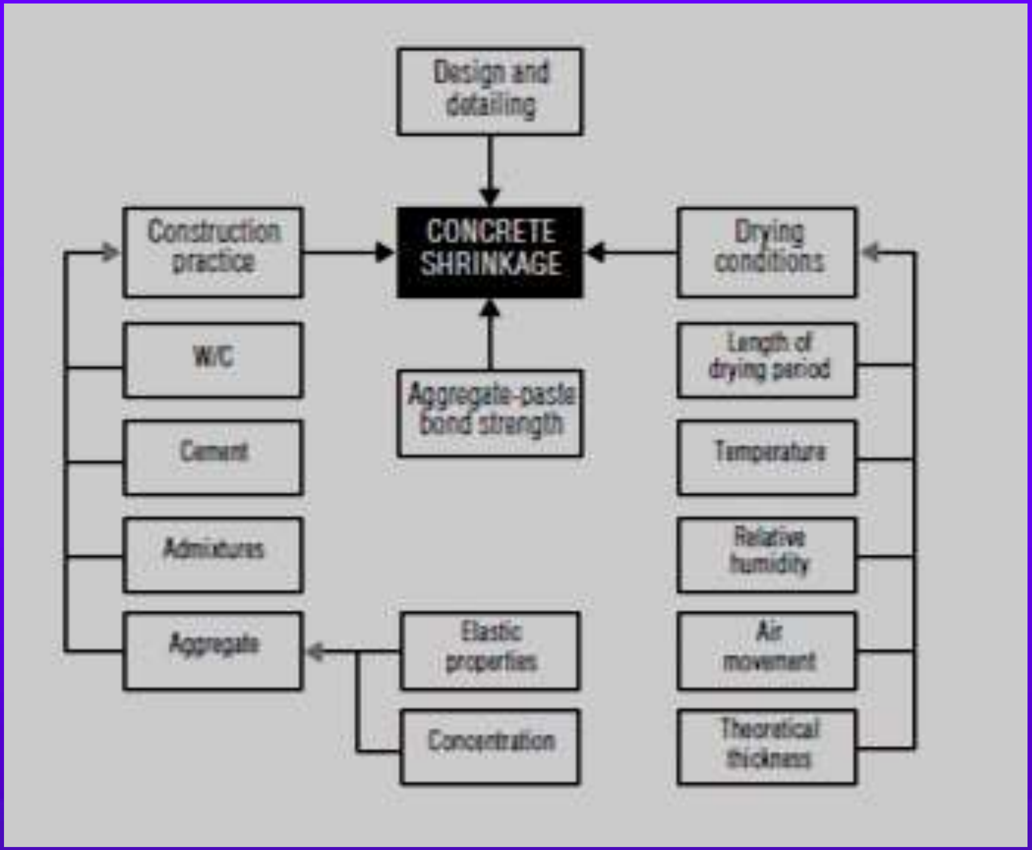
Drying Shrinkage Cracks

Floor

Above the doors



Cracking of concrete due to drying shrinkage



Factors affecting the drying shrinkage

Factors affecting the drying shrinkage

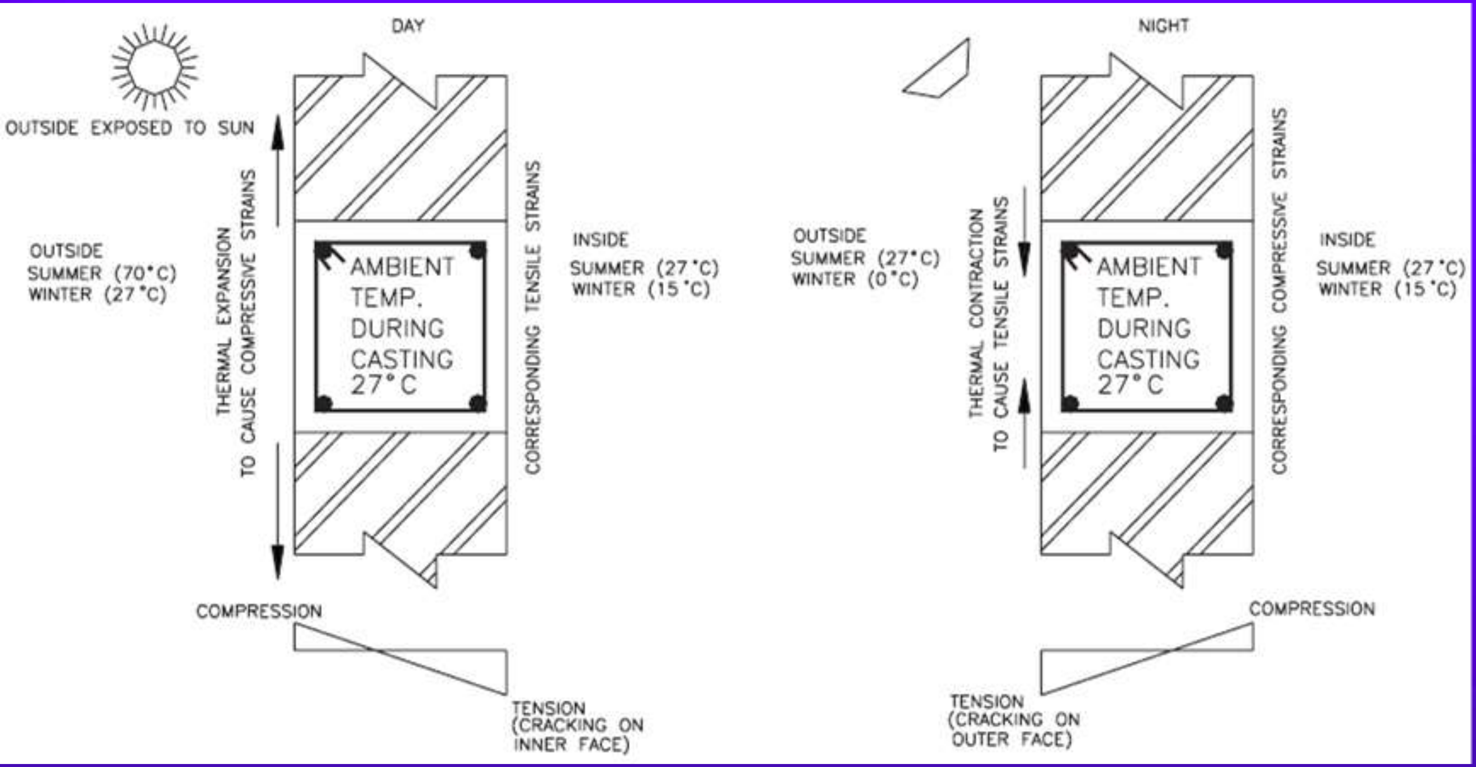
Factor	Reduced Shrinkage	Increased Shrinkage
Cement type	Low grade	High grade
Cement content	325 kg/m^2	450 kg/m^2
Aggregate Size	40mm	20mm
Aggregate type	granite	Sand stone
Slump	50 - 75mm	125mm – 150mm
Curing	7 days	3 days
Placement temperature	15-20°C	30°C
Aggregate state	washed	dirty

Thermal Cracks

The factors affecting the thermal cracks are as follows:

1. Initial temperature of materials
2. Ambient temperature
3. Large dimensions
4. Curing conditions
5. Early removal of formwork
6. More cement
7. Cement grade
8. Admixtures like flyash, etc.

Differential Thermal Exposure:



Map Cracks due to alkali aggregate reaction

The reaction of siliceous minerals (silica) in aggregate with alkalies (sodium oxide and potassium oxide) present in cement causes the swelling of concrete which results a pattern of cracking of concrete surface.

Longitudinal Cracks due to Corrosion

Transverse Cracks due to loading

These cracks form in the concrete after it has hardened due to shrinkage, thermal contraction or structural loading.

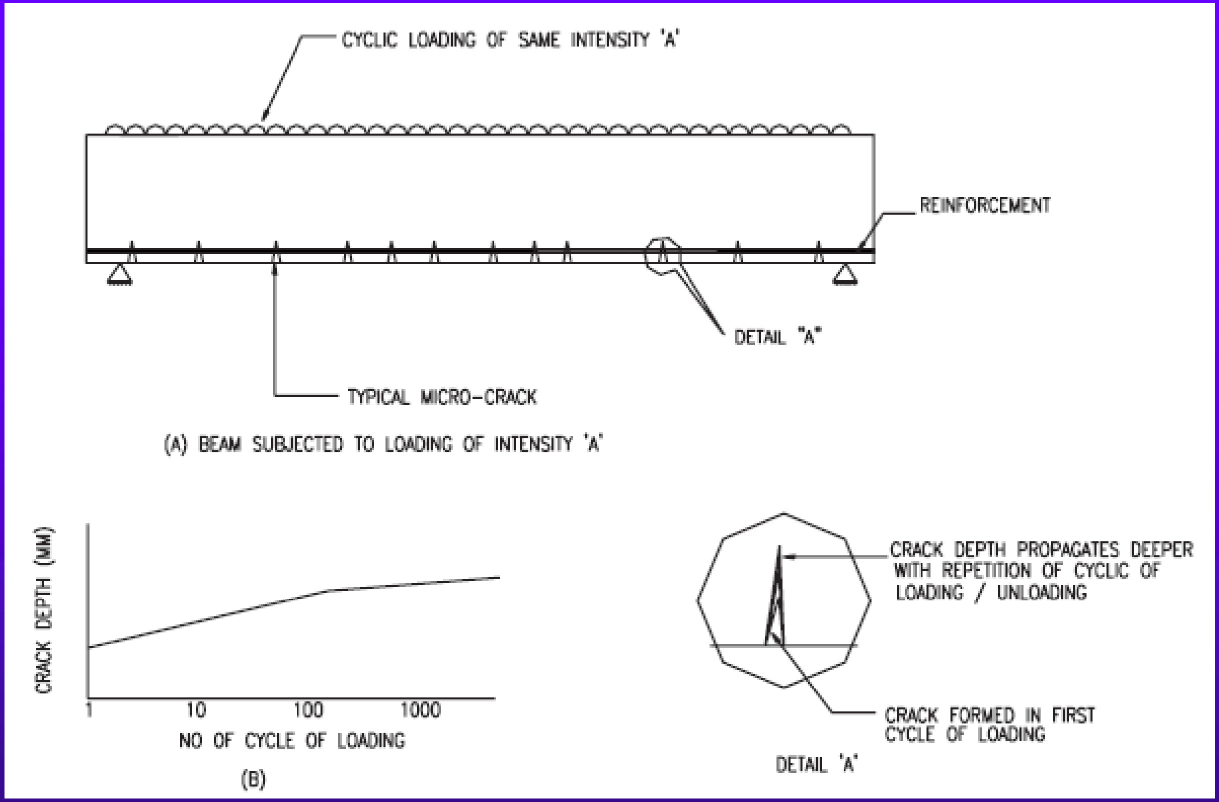
Shear Cracks due to loading

Beam

Column base

Columns of bridge.

MICRO CRACKS



MACRO CRACKS

0.1 mm to 3 mm

1. Improper placement of concrete
2. Settlement cracks of fresh concrete
3. Cracking due to
   - Intrinsic sulphate attack
   - Alkali aggregate reaction
   - Heat of hydration
   - Increased volume of corroded reinforcement exerting bursting pressure on concrete
4. Excessive loading

Corrosion damage

Corrosion of the reinforcing steel in a concrete structure


Poor maintenance blamed for Montreal collapse

2006

SALT CORROSION of steel reinforcement in the deck of a road bridge in Montreal is the likely cause of a collapse which killed five people on Saturday, engineers said this week

Heavy road salting, required during Canadian winters, was thought to have created a corrosive cocktail that easily penetrated the movement joint where the road deck slab met the cantilever supports – an acknowledged weak spot (*see diagram*).

Motorists contacted emergency services at around 11am last Saturday, as chunks of concrete fell onto the highway from the overpass.

A spokesperson for highway authority Transport Quebec, confirmed that a highway patroller arrived at the scene before midday, made a visual inspection, but did not conduct a full survey of the structure.

The patroller assumed that the falling concrete was not a structural threat and declared that the bridge did not need to close.

But debris continued to fall

The "flawed" half joint deck structure is no longer used in the UK or Canada

What is "Concrete Cancer"?

Corrosion of steel reinforcement in concrete structures is well known to be "Concrete Cancer", which is a significant worldwide problem and causes multi-billion dollars losses to the infrastructure and building owners each year.

India loses around Rs.25,000 Crores every year on account of corrosion.

The detection, diagnosing and appropriate treatment of this complicated problem requires very special expertise in this field.

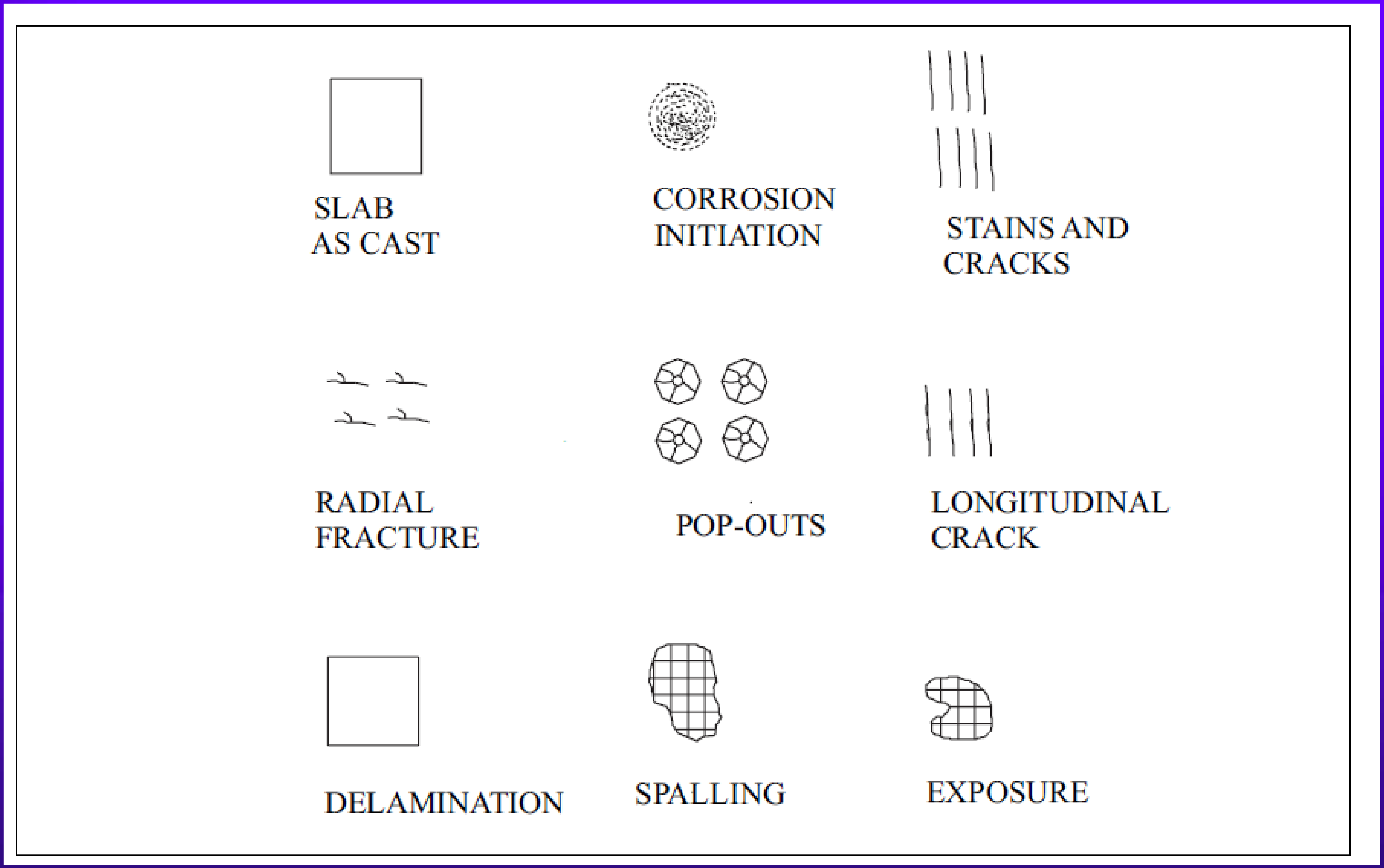
Stage 1: Initially, the concrete appears to be sound with relatively little macroscopic cracking and no reddish discoloration from corrosion product formation.

Stage 2: Macroscopic cracks have appeared and the concrete surface is stained by reddish corrosion products.

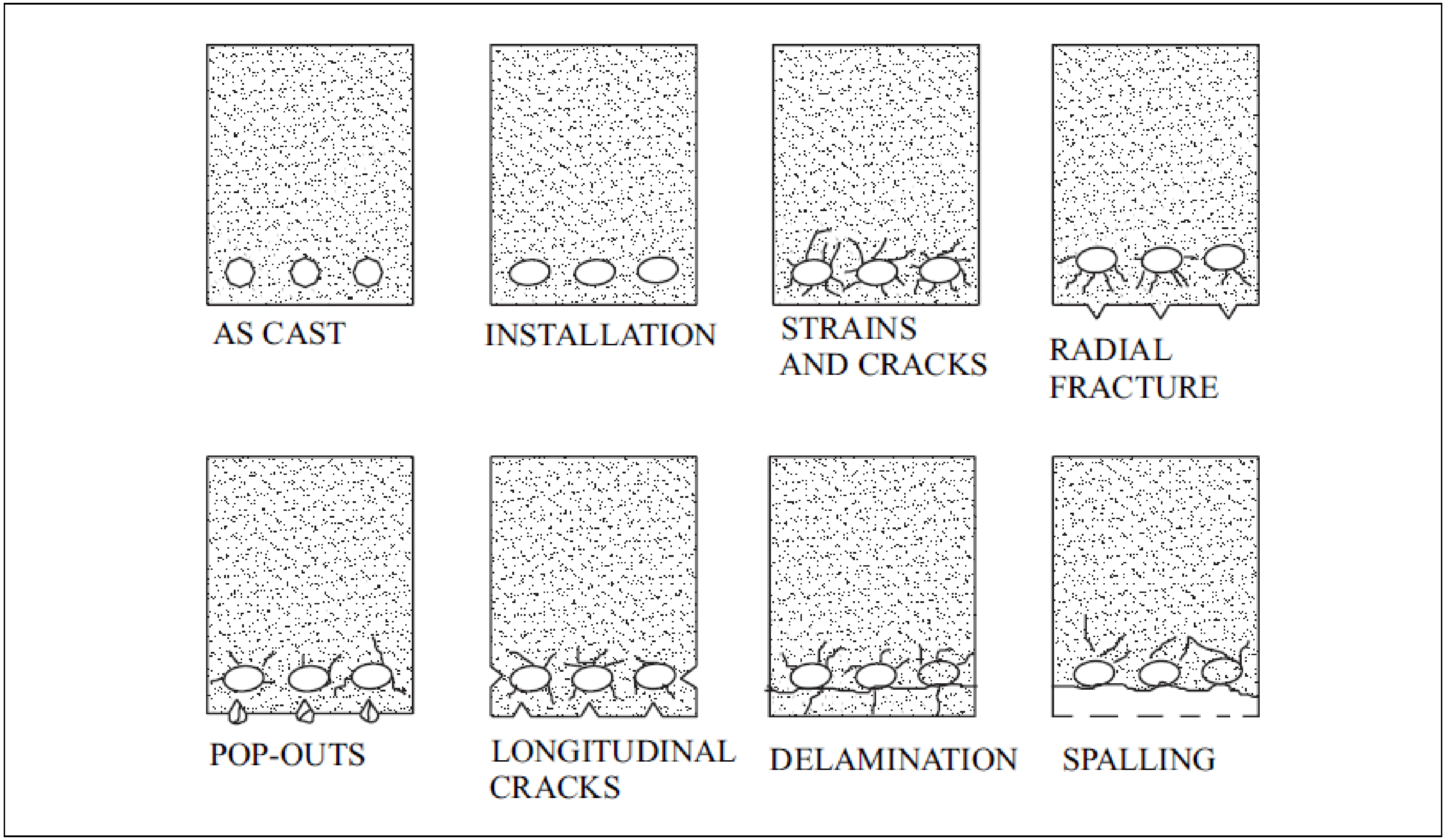
Stage 3: Spalling of the concrete cover over the reinforcing steel is clearly visible, due to the formation of voluminous corrosion products.

Stage 4: Severe spalling of the concrete cover over the reinforcing steel is evident, leaving the reinforcing steel bars directly exposed to the atmosphere.

Overall view of the advanced concrete degradation in the barrier wall. Spalling and the remains of uncovered reinforcing steel can be seen.

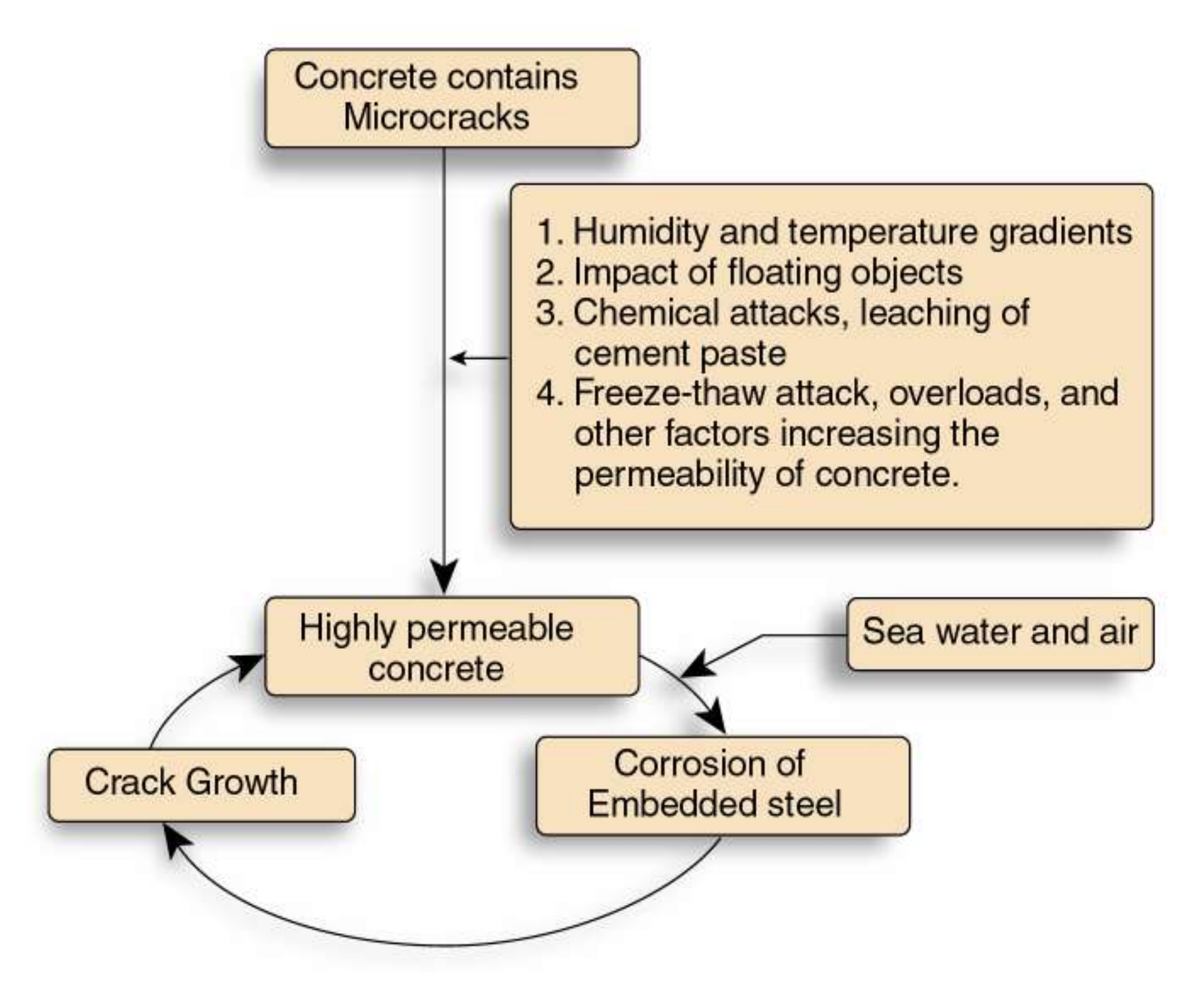


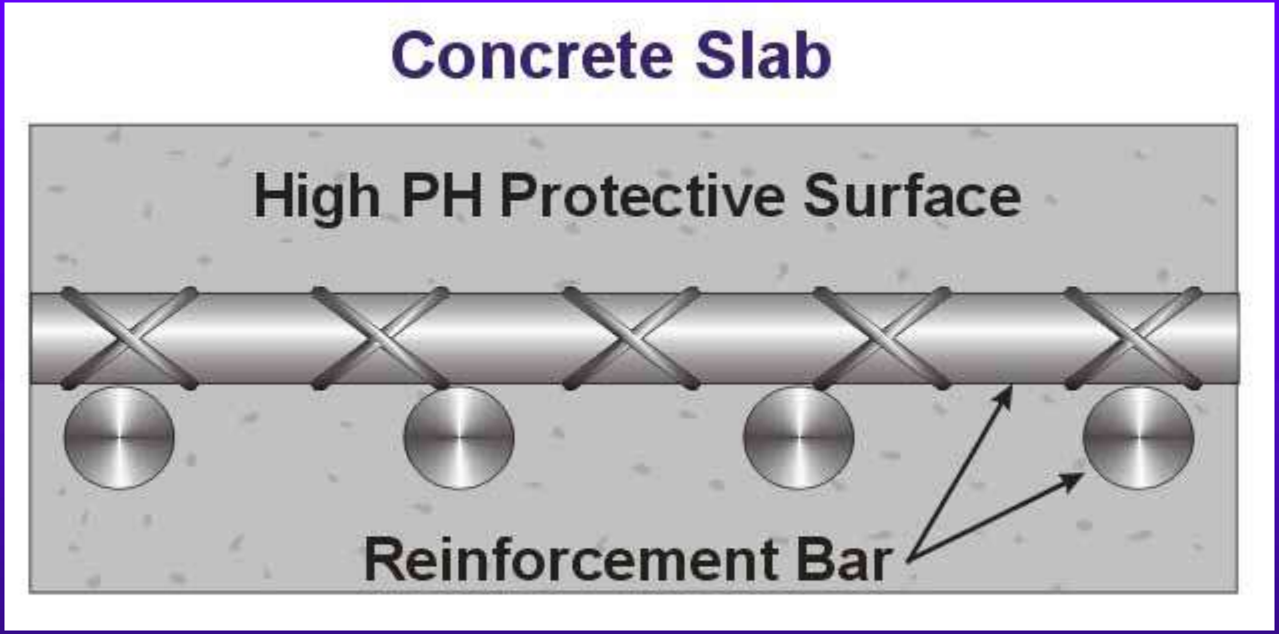
Symptoms of corrosion in a reinforced concrete slab

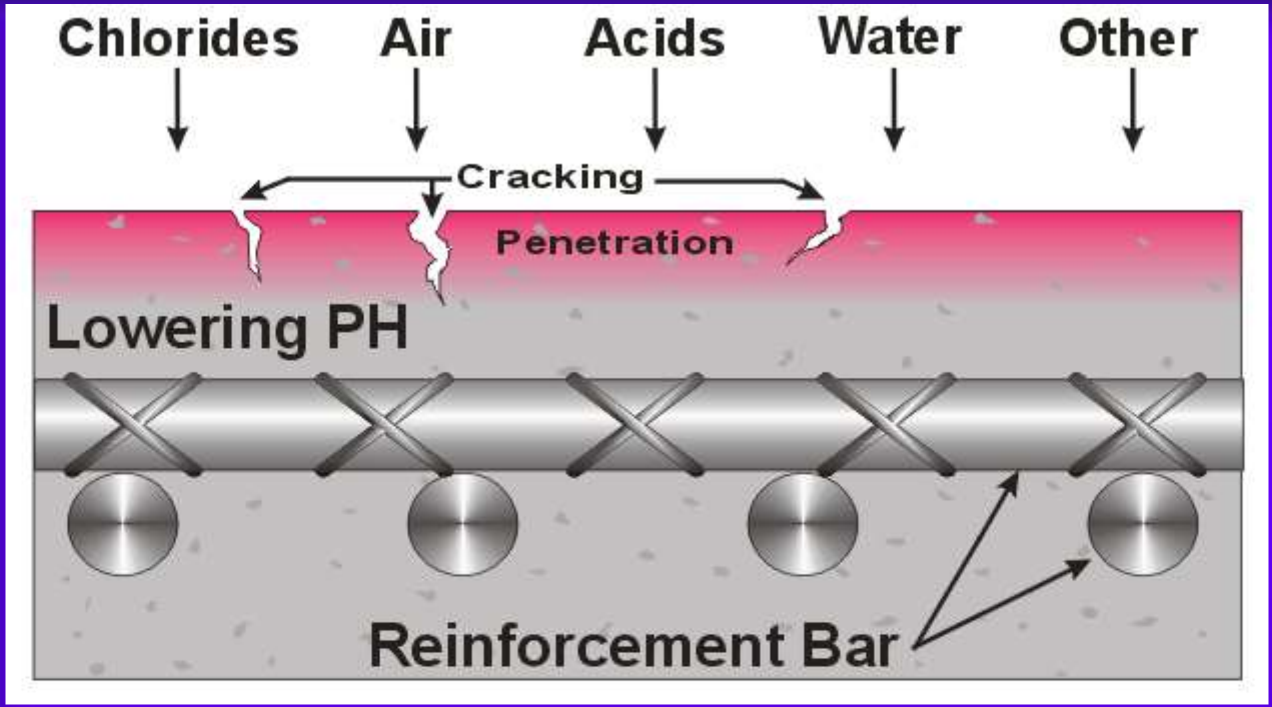


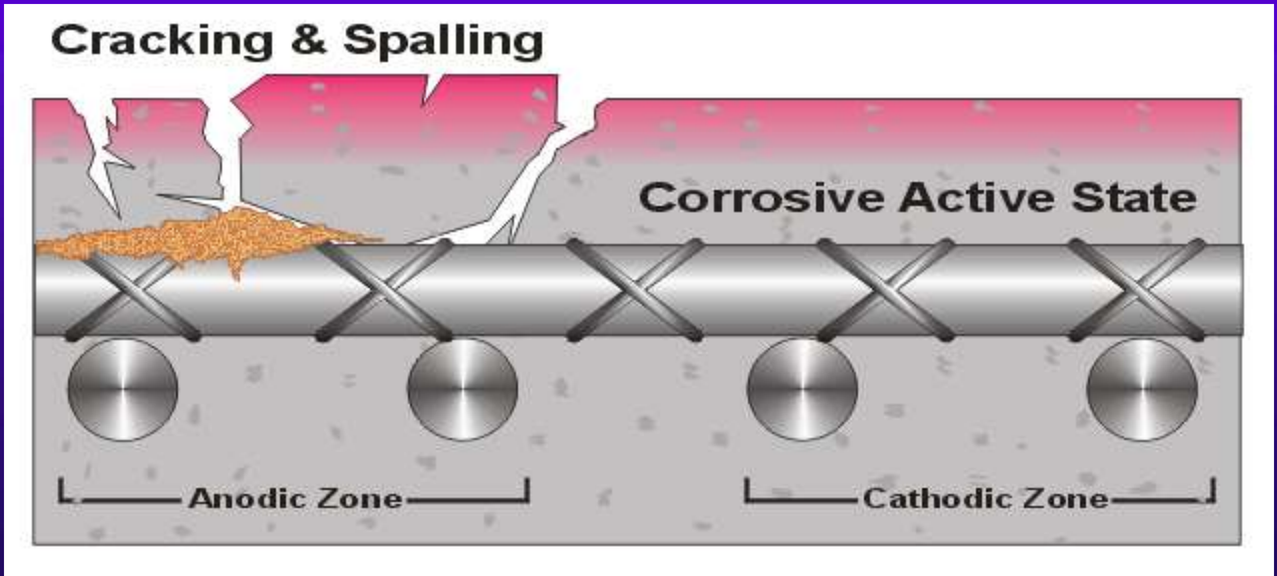
Symptoms of corrosion in a reinforced concrete beam

Diagrammatic representation of cracking – corrosion – cracking cycles




Concrete Slab
High PH Protective Surface
Reinforcement Bar


Chlorides
Air
Acids
Water
Other
Cracking
Penetration
Lowering PH
Reinforcement Bar


Cracking & Spalling
Corrosive Active State
Anodic Zone
Cathodic Zone

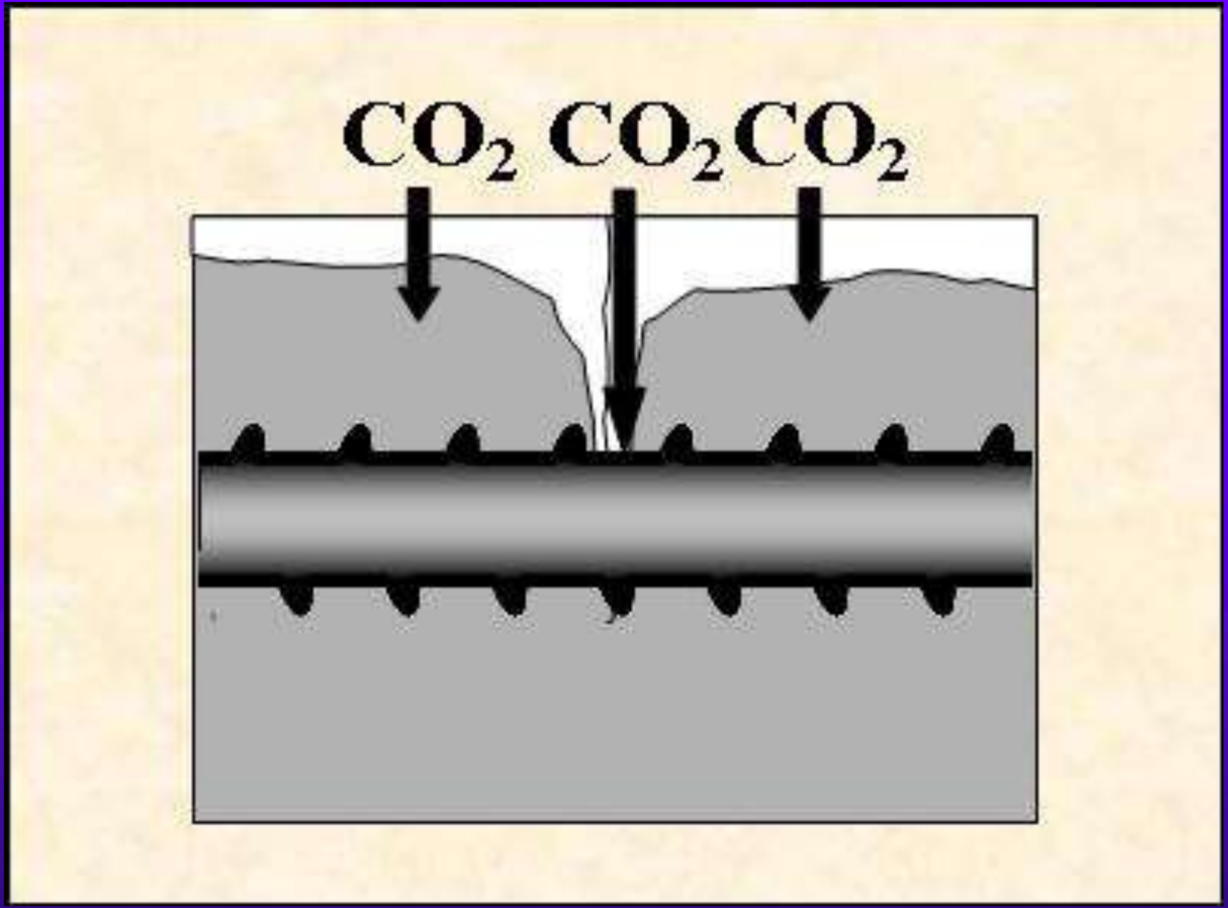
Corrosion initiation depends

- Concrete mix proportions
- Cement type
- Tri-calcium aluminate content of the cement
- W/C ratio
- Temperature
- Relative humidity
- Source of chloride penetration

Influence of Construction Defects on the Corrosion of Steel in Concrete

Adding too much water..

Carbonation

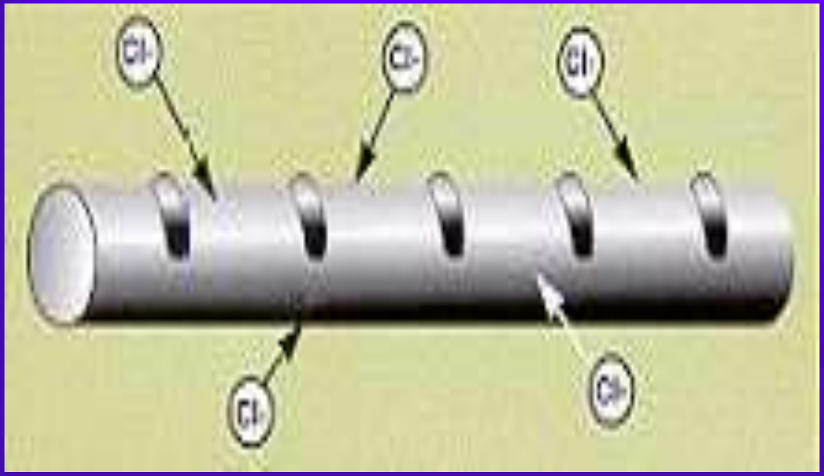


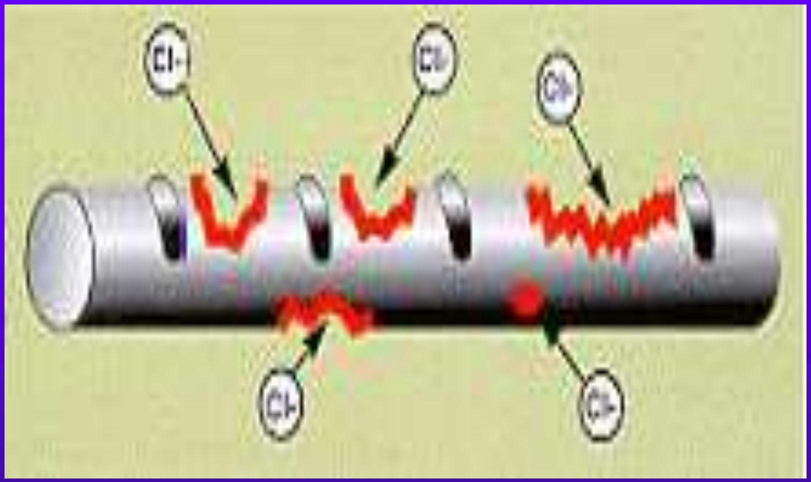
$Ca(OH)2+ CO2 \rightarrow CaCO3+H2O$

Hydration reaction of the cement Calcium carbonate

Carbonation

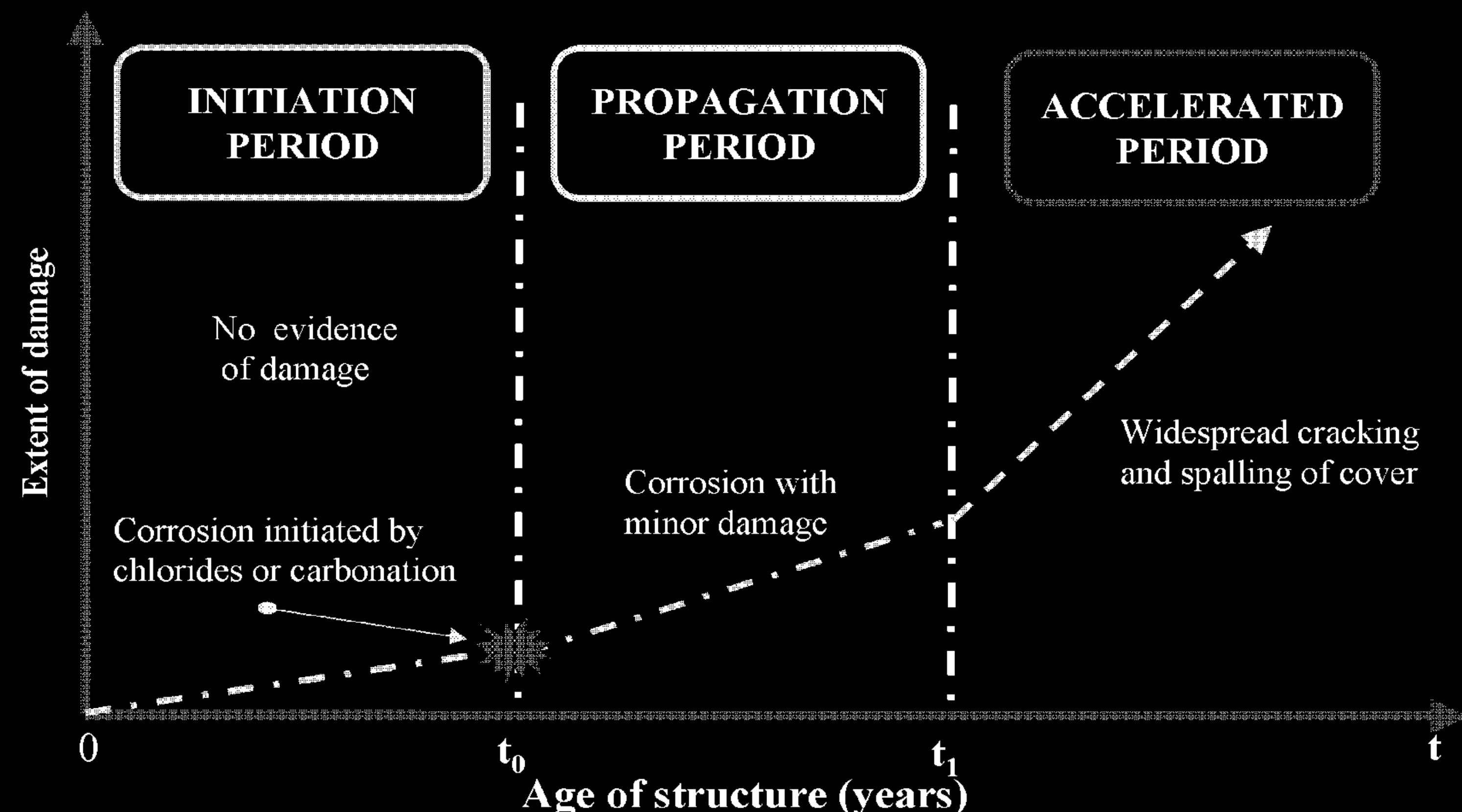
Chloride Attack



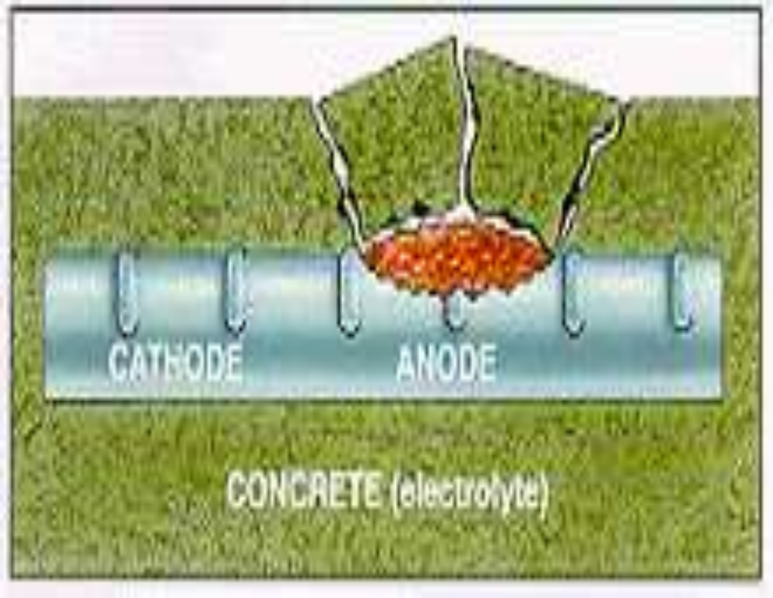


Passive film protecting the steel is directly destroyed due to Chloride attack

Chloride Attack



The three-stage model of corrosion damage



Localized corrosion

Uniform corrosion

Can corrosion be avoided in reinforced concrete?

Yes if:

(a) Concrete is always dry, then there is no H_2O to form rust. Also aggressive agents cannot easily diffuse into dry concrete.

(b) Concrete is always wet, then there is no oxygen to form rust.

(c) Cathodic protection is used to convert all the reinforcement into a cathode using a battery.

(d) A polymeric coating is applied to the concrete member to keep out aggressive agents. These are expensive and not easy to apply and maintain.

(e) A polymeric coating is applied to the reinforcing bars to protect them from moisture and aggressive agents. This is expensive and there is some debate as to its long- term effectiveness.

(f) Stainless steel is used in lieu of conventional black bars. This is much more expensive than black bars.

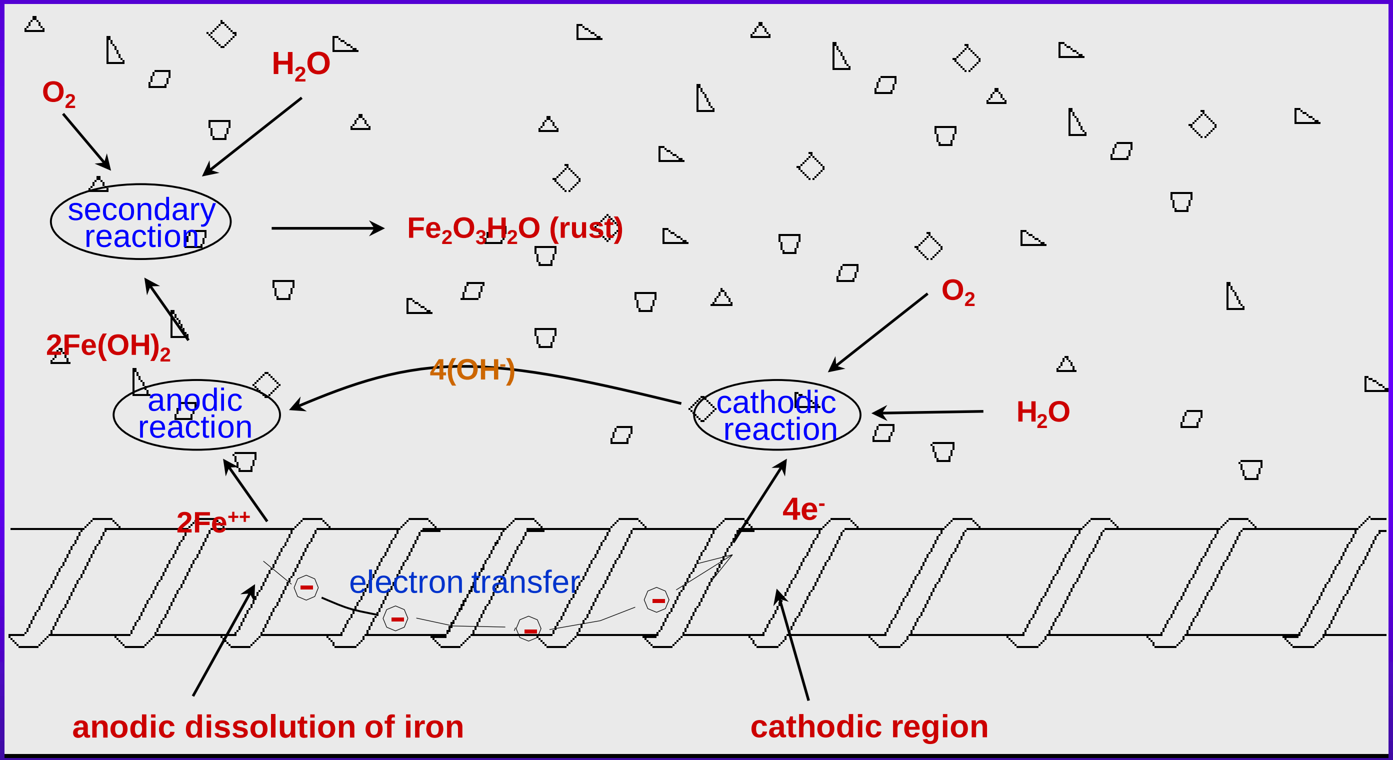
(g) Use FRP rebars.

Can we avoid corrosion?

No, not entirely:

Concrete is not usually under water or continuously dry. Aggressive agents such as carbon dioxide, de-icing agents and/or sea water can diffuse into the best of moist concrete, and corrosion will eventually result.

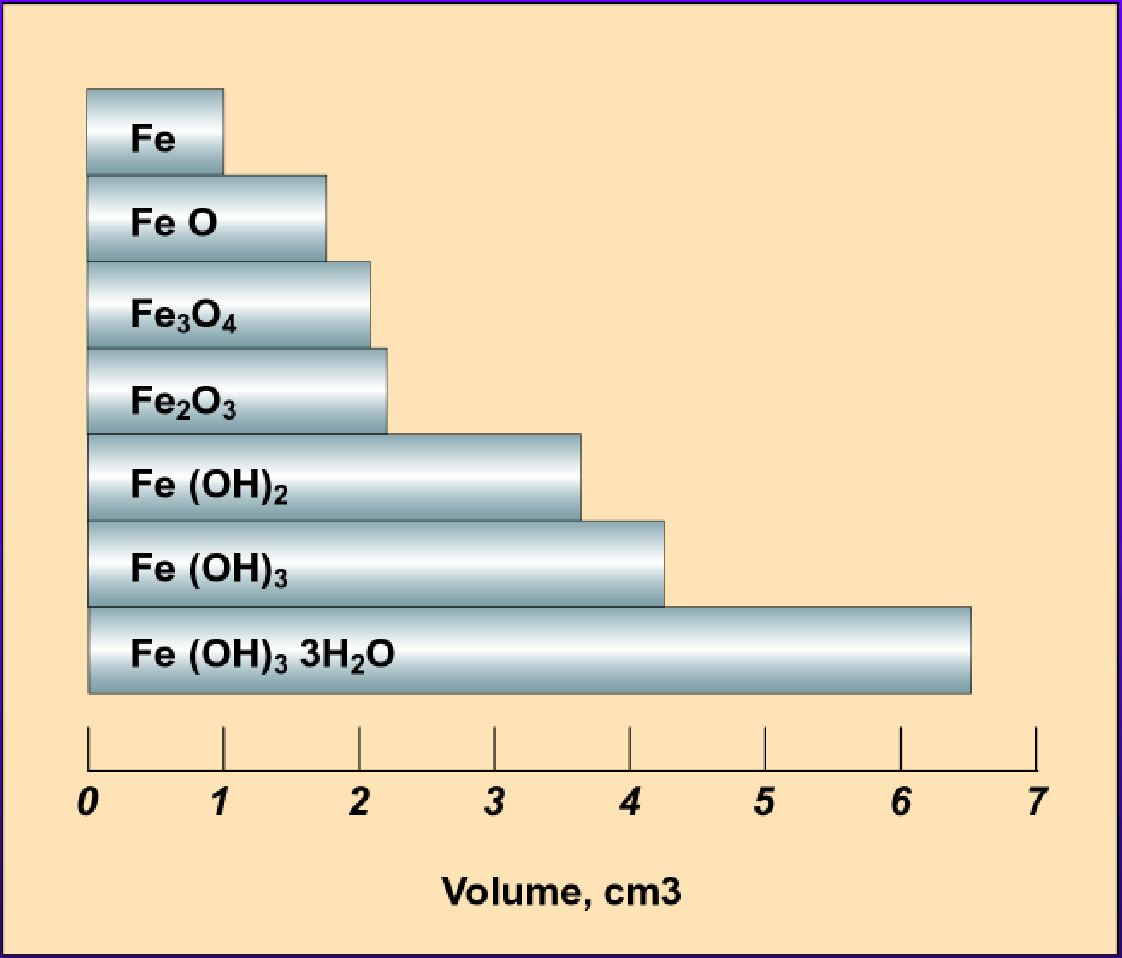
Corrosion in Reinforced Concrete



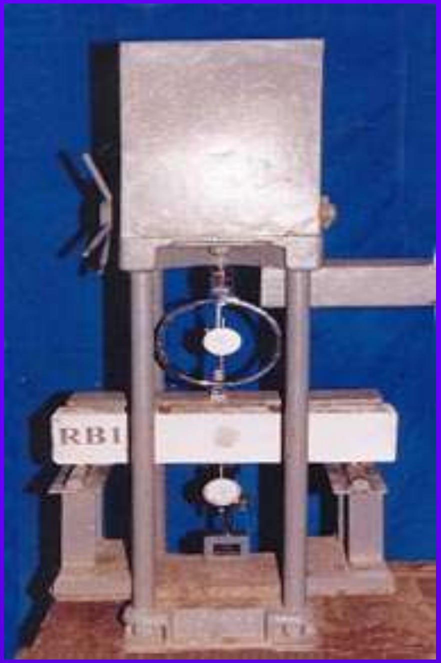
CORROSION REACTIONS

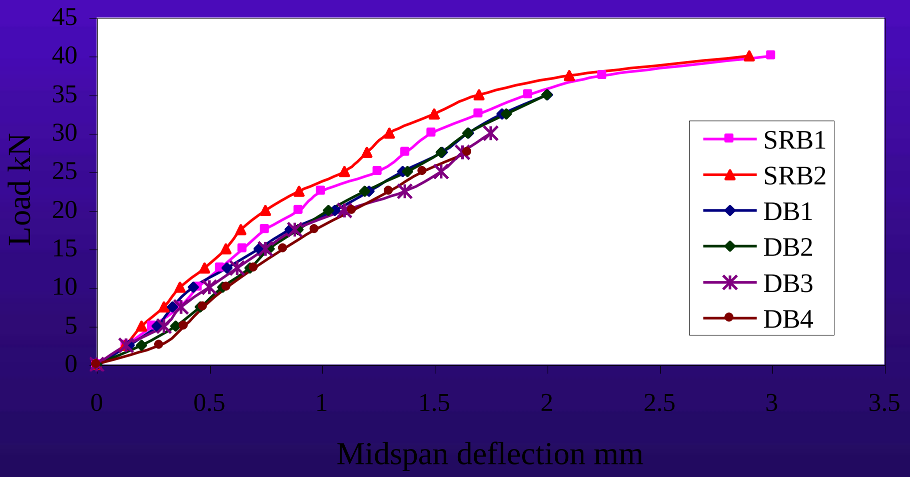
- Anode: $Fe \longrightarrow Fe^{++} + 2e^-$ (1.1)
- Cathode: $O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$ (1.2)
- $Fe^{++} + 2OH^- \longrightarrow Fe(OH)_2$ (1.3)
- $Fe(OH)_2 + O_2 \longrightarrow Fe_2O_3.H_2O + 2H_2O$
  (Red-brown rust) (1.4)
- $6Fe(OH)_2 + O_2 \longrightarrow 2Fe_3O_4.H_2O + 4\,H_2O$
  (1.5)
- $Fe_3O_4.H_2O \longrightarrow Fe_3O_4 + H_2O$ (1.6)
  (Black magnetite)

Volumetric change




DB1
DB2
DB3
DB4

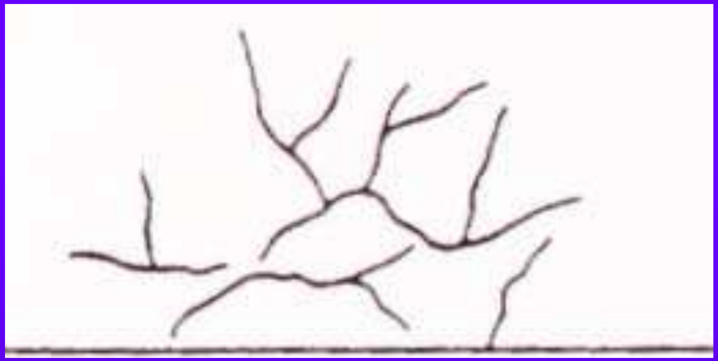

RB1


Load kN
Midspan deflection mm
0
5
10
15
20
25
30
35
40
45
0
0.5
1
1.5
2
2.5
3
3.5
SRB1
SRB2
DB1
DB2
DB3
DB4

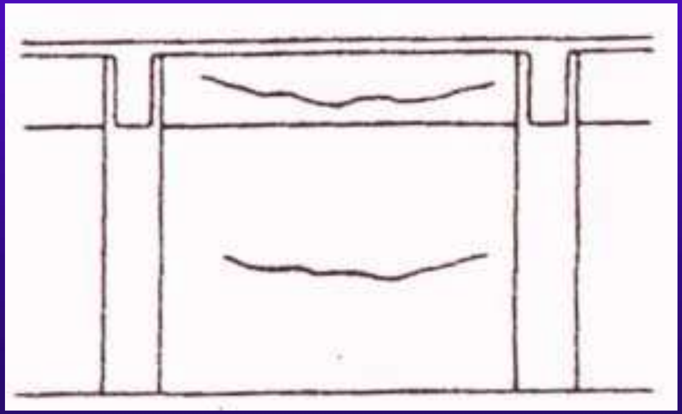
Comparison of damaged beams with reference beam

Serial number	Beam designation	With reference to reference beams		
		% Weight loss	% Reduction in flexural strength	% Reduction in deflection
1	DB1	5.0	10.36	32.60
2	DB2	5.0	11.84	33.70
3	DB3	7.5	19.20	35.24
4	DB4	15.0	36.29	48.80

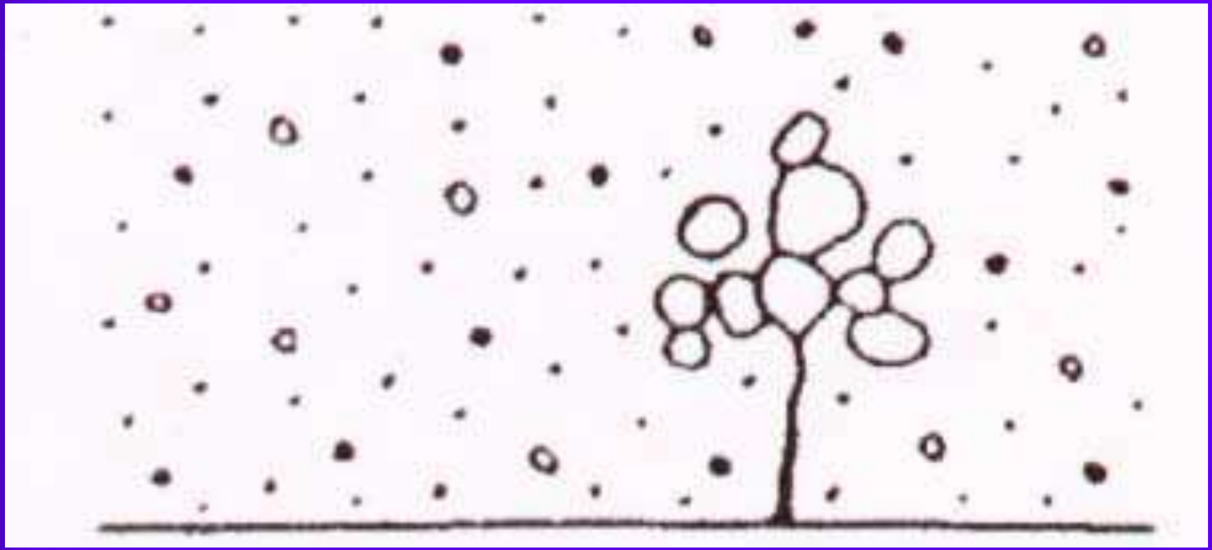
VISUAL OBSERVATION



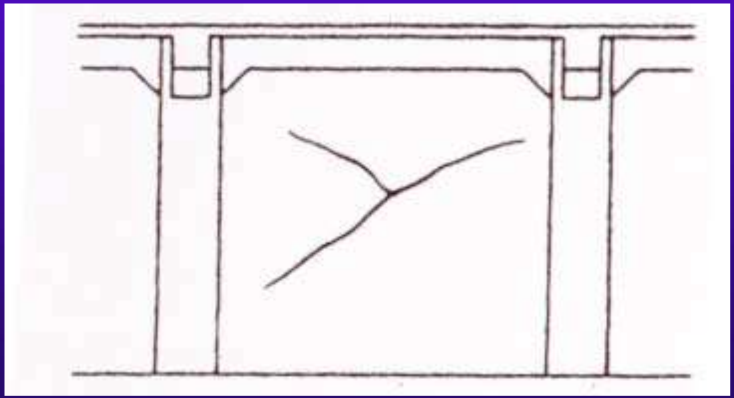
Sketch of surface appearance when concrete has been mixed for too long or the time of transport has been too long



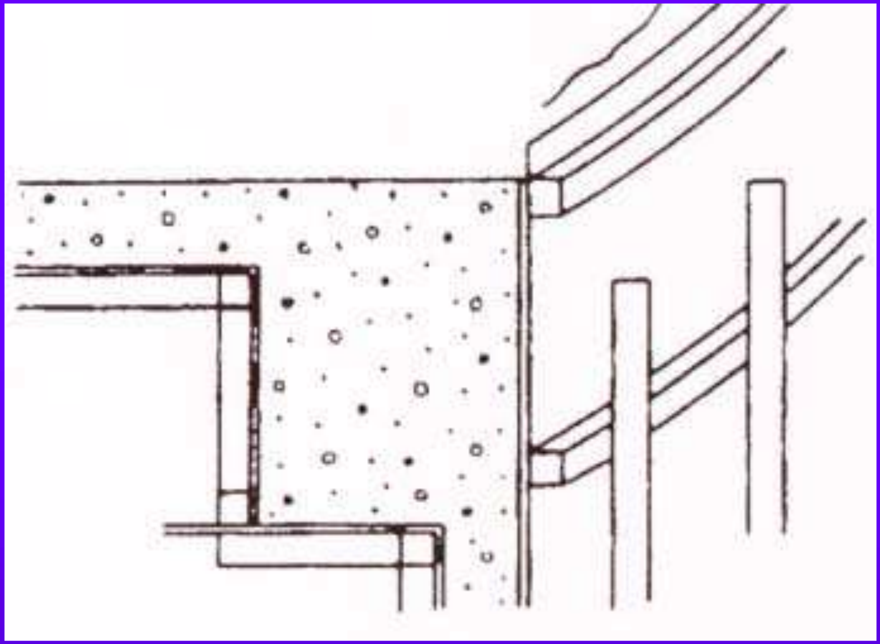
Sketch of crack due to concrete settling



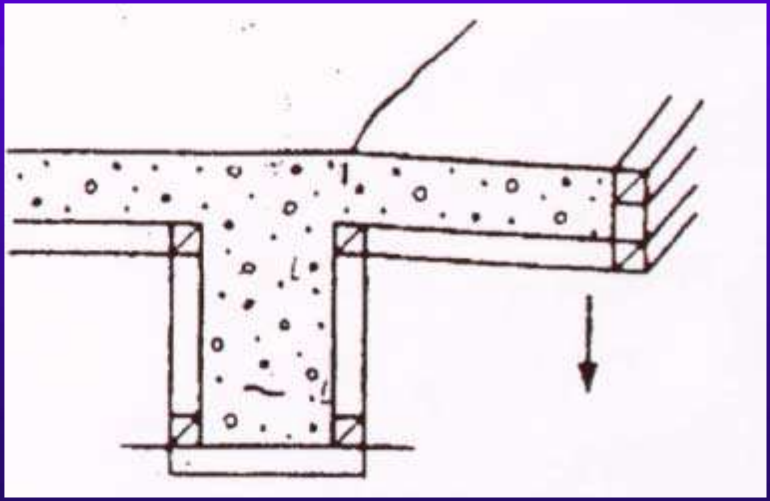
Sketch of exposed aggregate



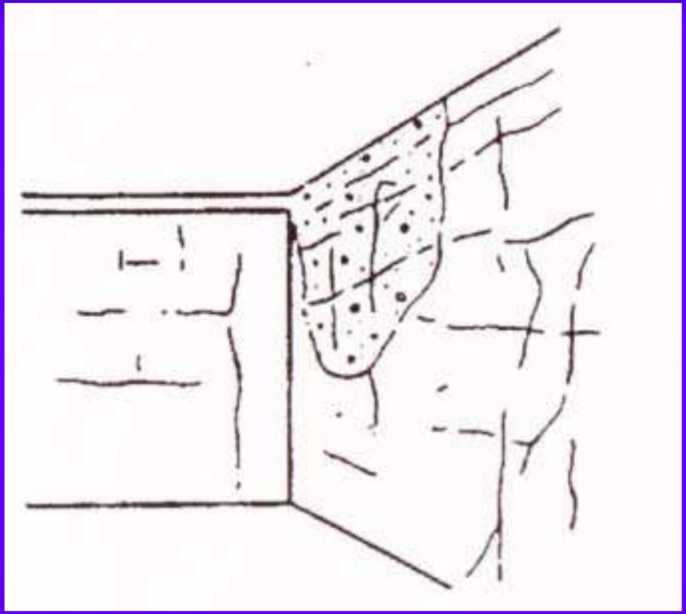
Unsuitable process at construction joint



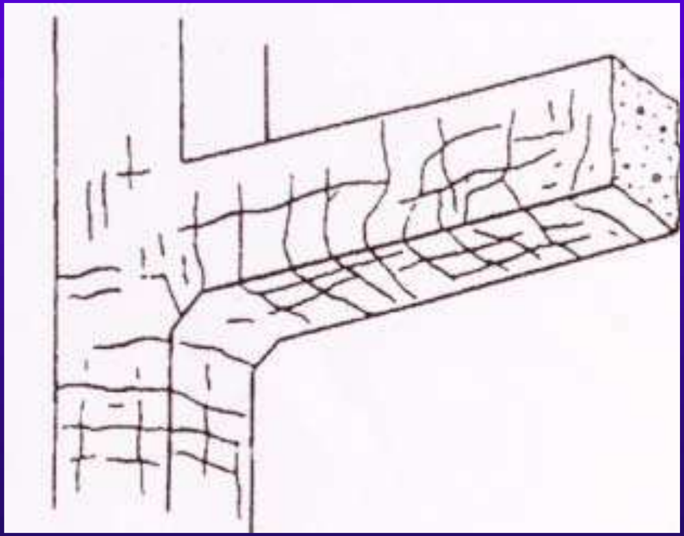
Sketch of cracking due to bowing of formwork



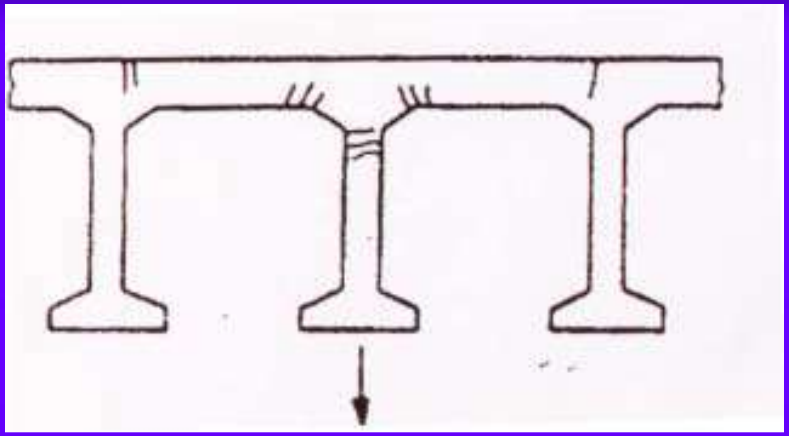
Sketch of cracking due to sinking of timbering



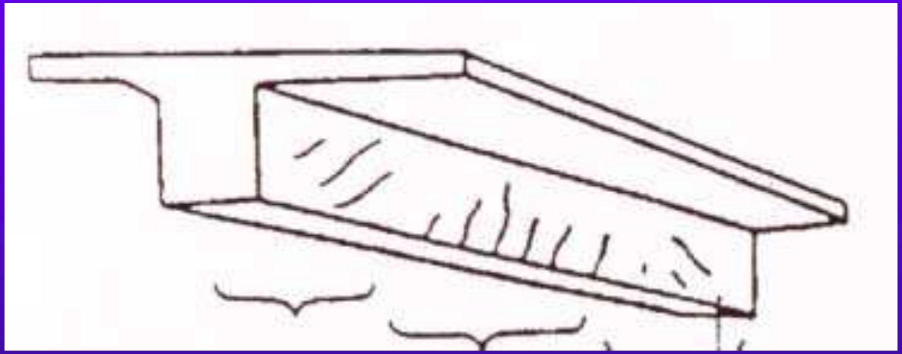
Sketch of severe rusting of reinforcing bars due to chemical action



Sketch of effect of fire on concrete

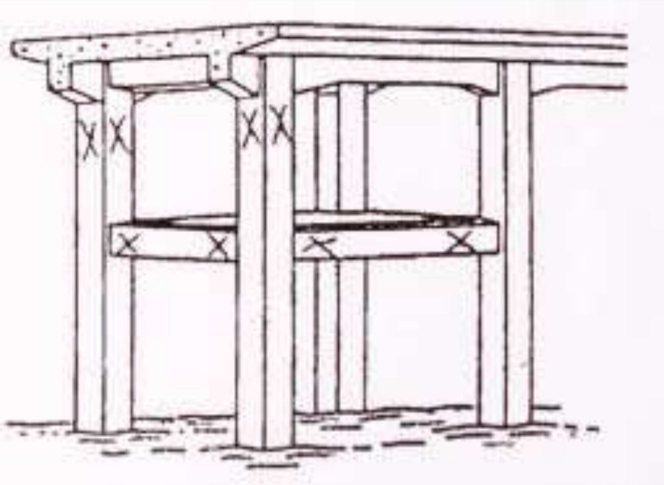


Cracks due to differential settlement of central column

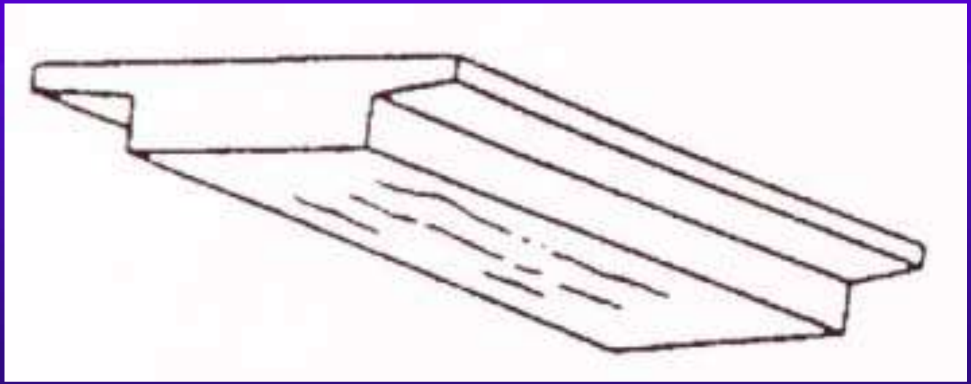


shearing bending

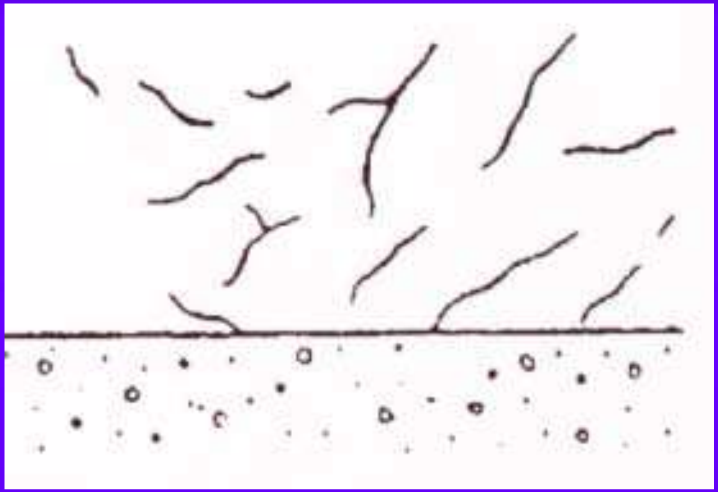
Cracks due to bending and shear stresses



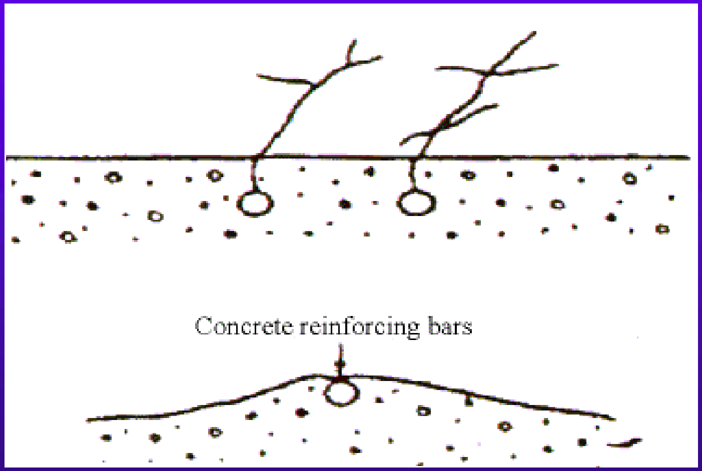
Cracking in columns and beams due to an earthquake



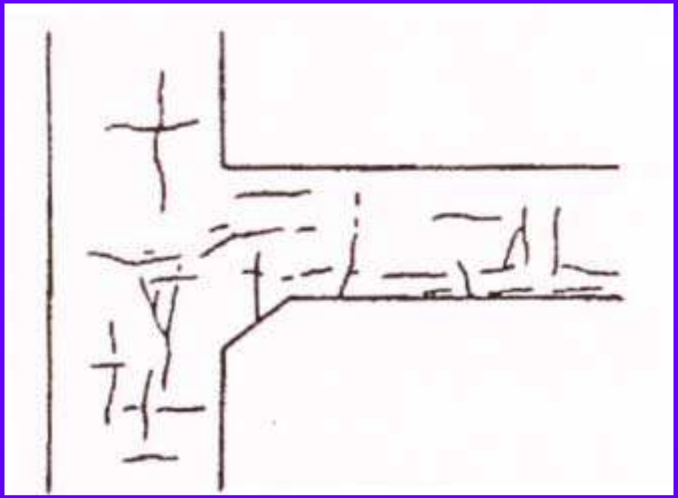
Cracks due to insufficient reinforcing bars



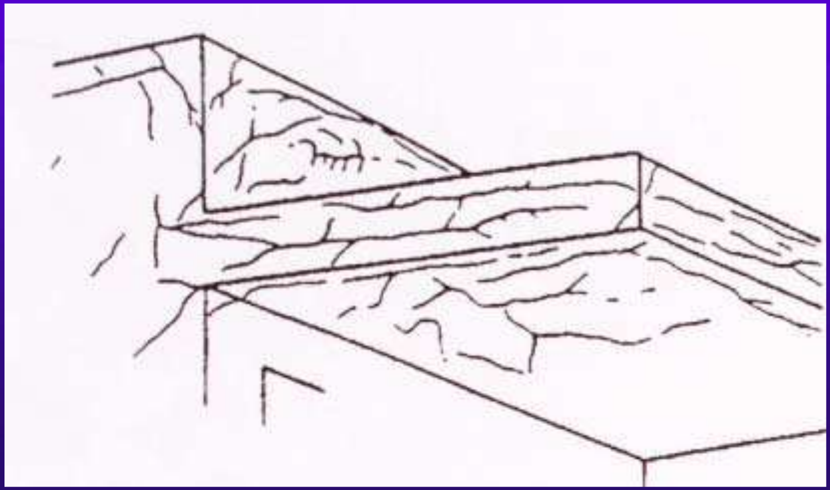
Cracks due to abnormal set of cement



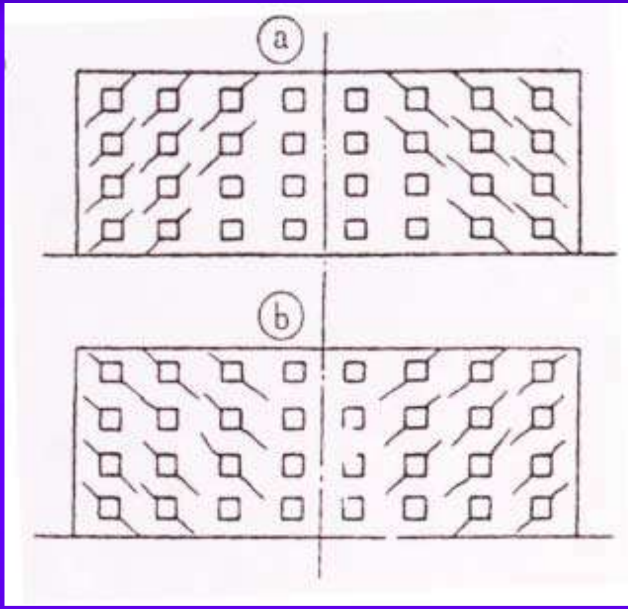
Sinking of concrete



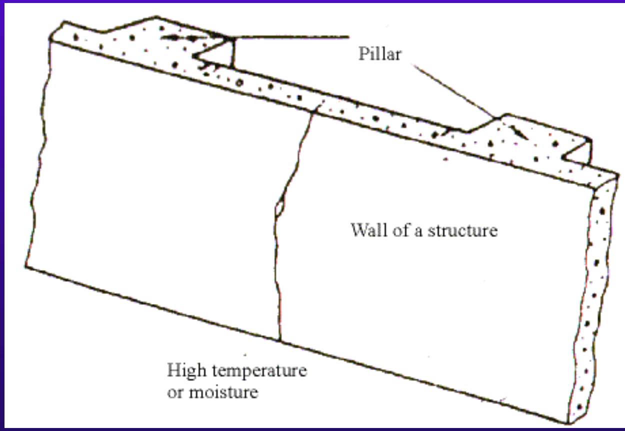
Rusting of reinforcing bars



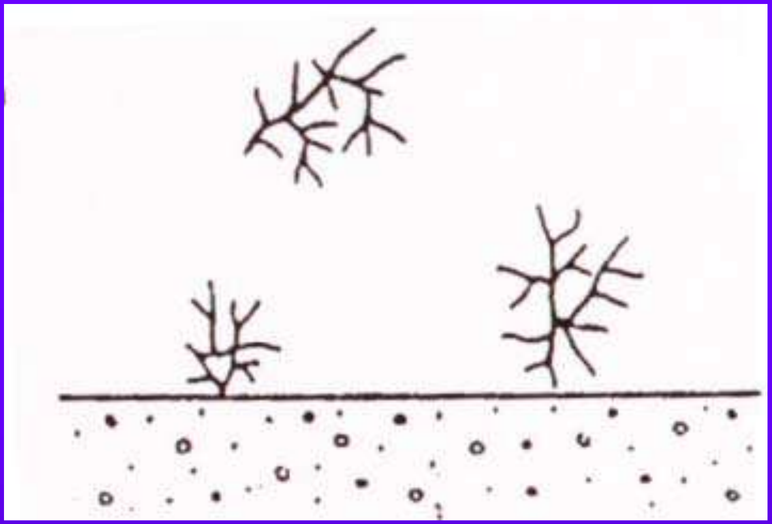
Effect of heating and freezing cycles



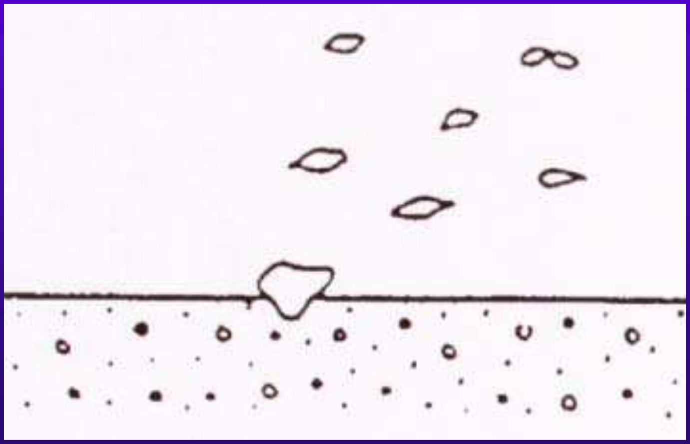
**Effect of changing ground conditions:
a)low temperature or b) dryness**



Effect of atmospheric conditions



Non-uniformity of admixture



Pop-out due to reactive aggregate and high humidity

NDT OF CONCRETE

Test Methods :

- Nondestructive
- Semi-destructive
- Destructive

Methods for Estimation of Concrete Strength

S.No.	Test	Equipment Type
1	Core test	Mechanical
2	Surface hardness method	Mechanical
3	Ultrasonic pulse velocity	Electrical
4	Break-off and Pull-off	Mechanical
5	Penetration Test (Windsor Prob)	Mechanical
6	Pull-out Test	Mechanical
7	Lok Test & capo Test	Mechanical

Strength Tests- a Comparative Assessment

Test Method	Cost	Speed of Operation	Damage to Concrete	Representativeness	Reliability of Strength Prediction
Cores	Moderate to High	Slow	Moderate	Good	Good
Rebound Hammer	Very low	Fast	Nil	Surface only	Poor to Fair
Ultrasonic	Low	Fast	Nil	Good to Moderate	Fair to Good
Pullout	Moderate	Fast	Minor	Near Surface	Moderate
Breakoff/Pulloff	Moderate	Slow	Moderate	Moderate to Good	Moderate
Lok Test	Moderate	Moderate to Fast	Moderate	Moderate	Good to Moderate
Capo Test	Moderate	Slow	Moderate	Moderate to Good	Good to Moderate
Penetration	Moderate	Fast	Minor	Near Surface	Moderate

NDT Non-Destructive Testing of RC Components

NDT Equipments

NDT Carried out during the Site Visits using the following Equipments:

REBOUND HAMMER (Concrete Test Hammer)
Ultrasonic Instrument (PUNDIT)
PROFORMETER (Rebar Locator)
CORE CUTTING TEST

Rebar Locator

Laboratory Testing

Lab Testing Carried out for the Basic Materials at CBRI, Roorkee

- Reinforcement
- Concrete Samples
- Chloride Content
- Sulphates
- pH
- Aggregates
- Cement
- Bricks
- Blocks

CUBE TEST

- INDICATES ONLY POTENTIAL STRENGTH
- SUBJECT TO UNINTENTIONAL DEVIATIONS
- DELIBERATE DEVIATION ?
- NOT A TRUE REPRESENTATIVE OF THE STRUCTURE DUE TO PRESENCE OF STEEL, VOIDS, CRACKS & DIFFERENT DIMENSIONS
- CANNOT BE VERIFIED
- CAN BE ONLY PERFORMED DURING CONSTRUCTION STAGE

N D T - OBJECTIVES

- TO ESTABLISH HOMOGENEITY OF CONC.
- COMPARISON OF CONCRETE QUALITY w.r.t. A STANDARD
- DETECTION OF CRACKS, VOIDS/ OTHER IMPERFECTIONS
- MONITORING CHANGES IN CONCRETE WITH PASSAGE OF TIME
- TO ESTABLISH QUALITY OF ONE ELEMENT w.r.t. ANOTHER

N D T - OBJECTIVES

- ASSESSMENT OF EXISTING STRUCTURE FOR REHABILITATION PLANNING
- AS AN ALTERNATIVE TESTING METHOD IF CUBE RESULTS RAISE DOUBTS ABOUT CONCRETE QUALITY (POST MORTEM)

N D T - METHODS

- VISUAL INSPECTION
- REBOUND HAMMER
- ULTRASONIC PULSE VELOCITY METER
- PENETRATION RESISTANCE
- PULL OUT STRENGTH
- COVER METER
- CARBONATION DEPTH
- CORROSION MAPPING
- MATURITY METER
- PERMEABILITY TEST
- RADIOGRAPHY

Surface Hardness Method

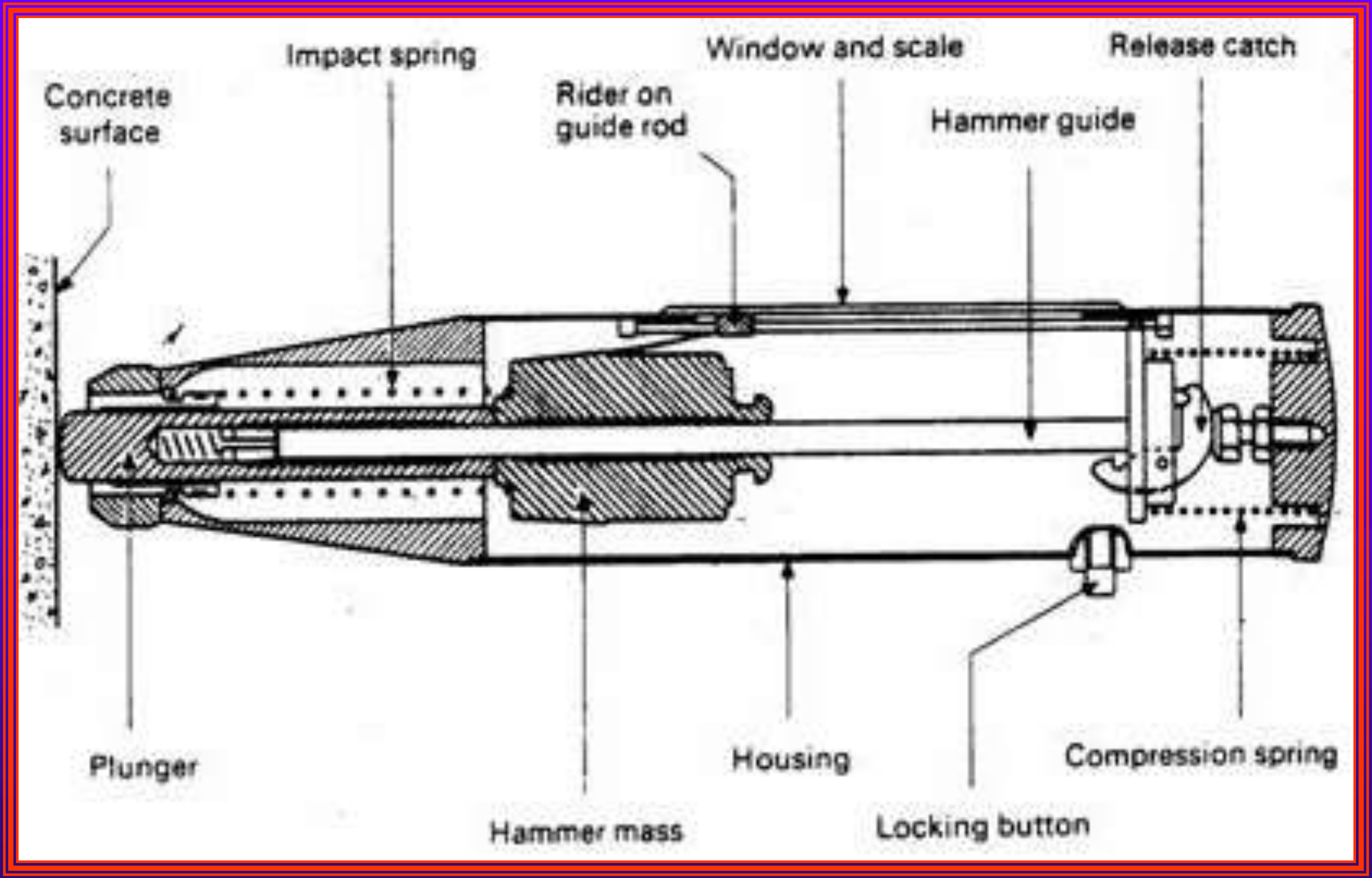
- Popularity known as Schmidt Hammer
- Widely used ; truly nondestructive
- Easy to use ; not reliable for f_c'

Rebound / Schmidt hammer

Average rebound number	Quality of concrete
> 40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor concrete
0	Delaminated


ELE International Limited

Testing of Concrete in Structures



Typical rebound hammer

Procedure

- Make surface smooth, if necessary, and dry
- Use grids points over an area to avoid bias
- Hold hammer **normal** to the surface
- Take as many readings as possible
- Convert readings to comp. strength (calibration)
- Note correction for inclined surfaces

REBOUND HAMMER

- MOST COMMON NDT METHOD
- DEVELOPED IN 1948
- MEASURES REBOUND HARDNESS OF CONCRETE
- NO THEORETICAL RELATIONSHIP AVAILABLE FOR ASSESSMENT OF STRENGTH
- EMPIRICAL RELATIONSHIP BETWEEN REBOUND HARDNESS AND STRENGTH DEVELOPED

REBOUND HAMMER - GUIDELINES

- CONDUCT ON SMOOTH AND UNIFORM FACE
- AVOID ROUGH SPOTS, HONEY COMBS
- AVOID TROWELLED SURFACES
- THIN SECTIONS (< 100 mm) SHOULD BE BACKED UP TO AVOID DEFLECTIONS
- TAKE ATLEAST 15 REBOUND READINGS IN ANY ONE TEST

REBOUND HAMMER - GUIDELINES

- CALCULATE THE MEAN
- COMPARE DEVIATION OF READINGS FROM THE MEAN
- TEST IS CONSIDERED RELIABLE IF THE DEVIATION OF TEN READINGS IS NOT MORE THAN THE FOLLOWING:

REBOUND VALUE	15	30	45
DEVIATION	2.5	3	3.5

REBOUND HAMMER - GUIDELINES

- USE BEST 10 READINGS FOR CALCULATING THE MEAN
- DETERMINE COMPRESSIVE STRENGTH BY REFERRING TO REBOUND NUMBER Vs STRENGTH CHARTS AGAINST THE MEAN VALUE
- BEST ACCURACY ACHIEVEABLE IS WITHIN $\pm$ 20%

FACTORS AFFECTING REBOUND VALUE

- TYPE OF AGGREGATES
- DEGREE OF COMPACTION
- AGE OF CONCRETE
- DRYNESS/WETNESS OF THE SURFACE
- RIGIDITY OF THE MEMBER
- SURFACE FINISH OF CONCRETE- MOULDED/ TROWELED
- MAINTENANCE OF REBOUND HAMMER
- INCLINATION OF THE REBOUND HAMMER
- TYPE OF CEMENT
- CARBONATION
- COVER

Calibration of Concrete Test Hammer

Ultrasonic Pulse Velocity

- Widely used
- Good reliability ; truly NDT
- Portable equipment ; easy to use

PULSE VELOCITY METHOD

- DEVELOPED IN 1940s
- BASED UPON PROPOGATION OF ULTRASONIC WAVES IN ELASTIC MEDIUM
- MEASURES VELOCITY OF PROPOGATION OF ULTRASONIC WAVES
- VELOCITY RELATED TO THE DENSITY OF THE MEDIUM $V=(E/p)^{1/2}$
- STRENGTH IS DEDUCED FROM THE DENSITY OF THE MEDIUM
- FREQUENCY OF WAVES USED - 20 - 150 kHz

Procedure

- Good coupling between concrete and transducers (no gap, void)
- Select a suitable transmitting station
- Select receiving stations
- Take readings (time for travel of pulse)
- Calculate velocity (pulse velocity)
- From calibration, find concrete strength

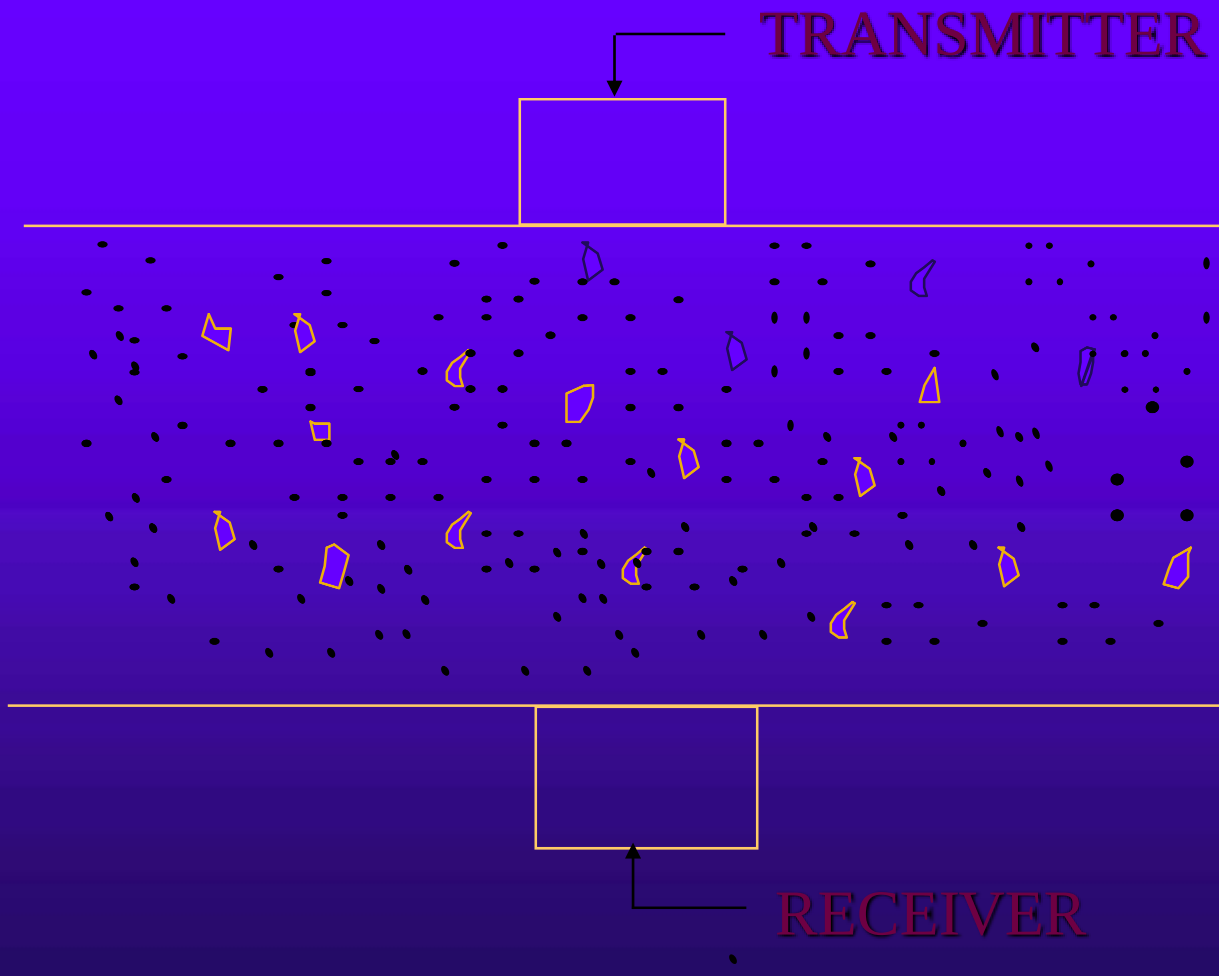
PULSE VELOCITY METHOD

- TYPES OF TESTING METHOD
  - ➔DIRECT TRANSMISSION
  - ➔SEMI DIRECT TRANSMISSION
  - ➔SURFACE TRANSMISSION
- DIRECT TRANSMISSION METHOD IS THE BEST BUT IT REQUIRES ACCESS TO TWO OPPOSITE SIDES OF CONCRETE MEMBER

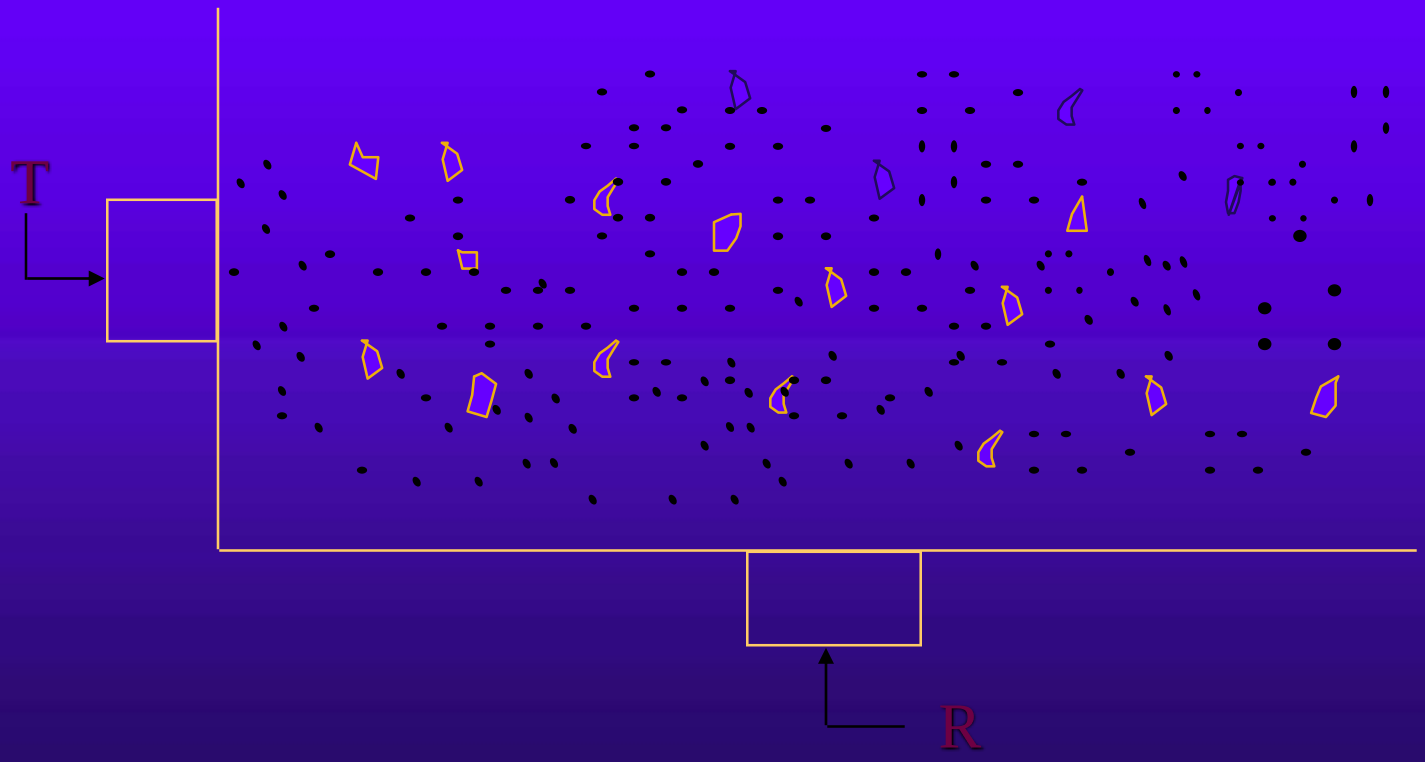
Ultrasonic Pulse Velocity Test

Velocity	Concrete quality
> 4.0 km/s	Very good to excellent
3.5 to 4.0 km/s	Good to very good, slight porosity may exist
3.0 to 3.5 km/s	Satisfactory but loss of integrity is suspected
< 3.0 km/s	Poor and loss of integrity exists

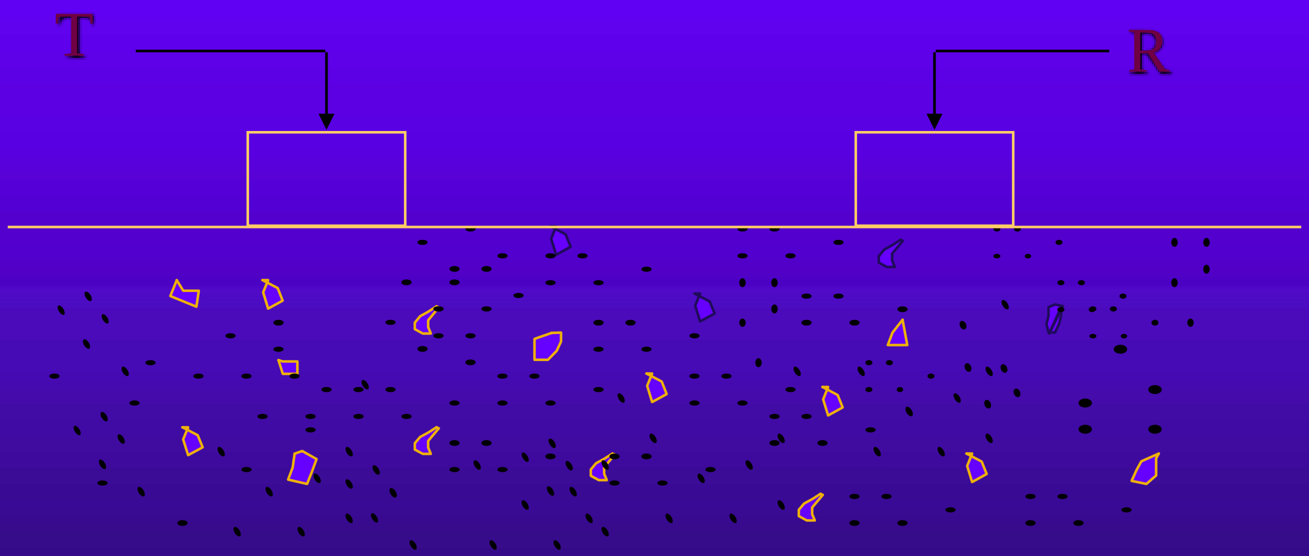
DIRECT TRANSMISSION



SEMI DIRECT TRANSMISSION



SURFACE TRANSMISSION



PULSE VELOCITY RATINGS

QUALITY	PULSE VELOCITY km/sec
Excellent	> 4.6
Good	3.7 to 4.6
Fair	3.0 to 3.7
Poor	2.1 to 3.0
Very poor	< 2.1

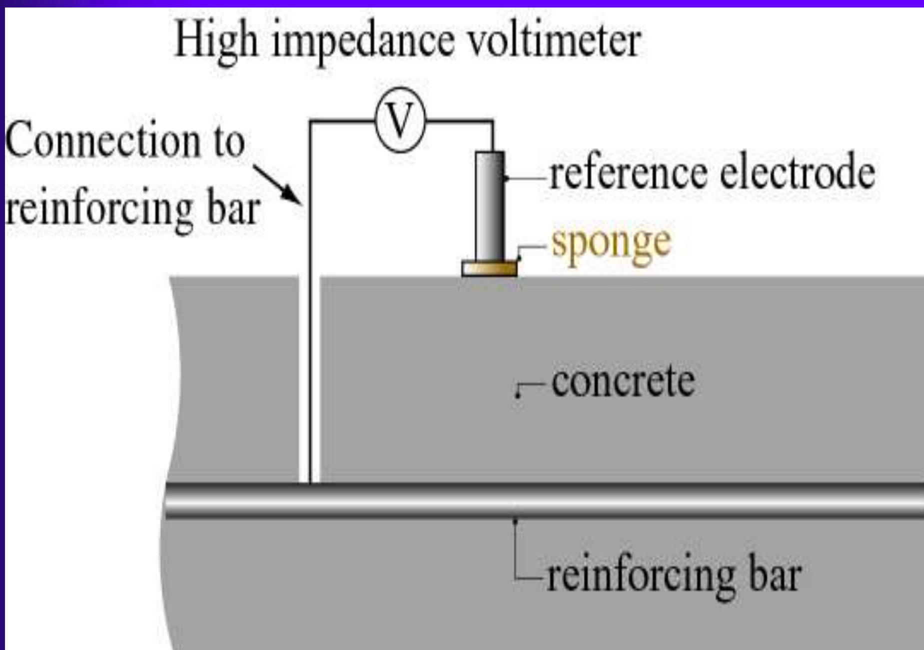
FACTORS AFFECTING PULSE VELOCITY

- DEGREE OF COUPLING
- PRESENCE OF REINFORCEMENT
- CONCRETE TEMPERATURE
- MOISTURE CONTENT
- MIX PROPORTION
- AGE OF CONCRETE
- STRESS LEVEL IN CONCRETE
- CONCRETE STRENGTH CAN BE PREDICTED WITHIN $\pm$ 20% PROVIDED CALIBRATION CURVE IS ESTABLISHED

APPLICATIONS OF PULSE VELOCITY METHOD

- MAIN APPLICATION FOR ASSESSMENT OF CONCRETE UNIFORMITY
- TO ESTABLISH AREAS OF DETERIORATED CONCRETE
- DETECTION OF CRACKS
- CALCULATION OF DYNAMIC YOUNG'S MODULUS

System for measuring the Half-cell potential



The potential recorded in the half-cell measurement can be used to indicate the probability of corrosion of the steel reinforcement

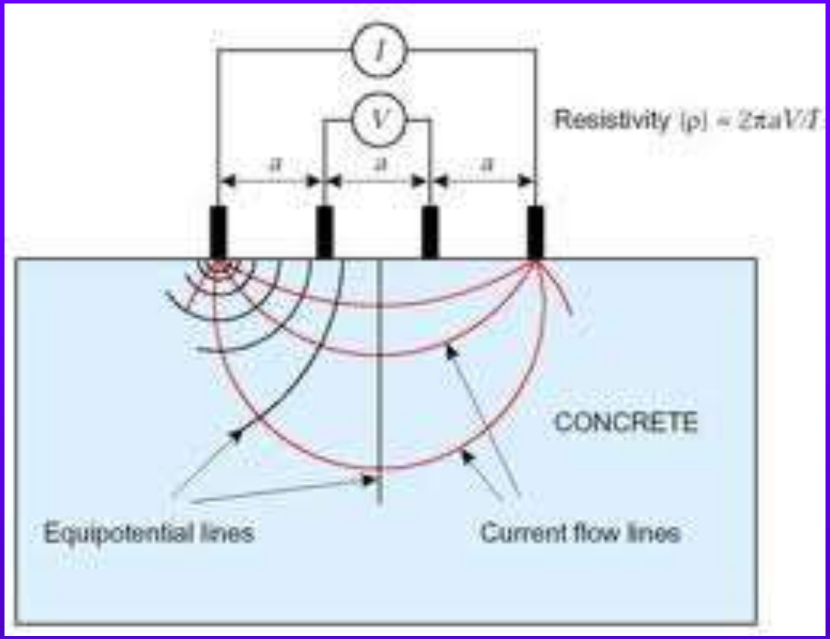
Qualitative manifestation and interpretation

Less negative than □ 0.20 volts --- 90% probability of no corrosion

Between □ 0.20 and □ 0.35 volts --- corrosion is uncertain

More negative than □ 0.35 volts --- 90% probability of corrosion occurring

Four-probe resistivity test



Resistivity (ohm cm)	**Corrosion probability**
Greater than 20,000	Negligible
10,000 – 20,000	Low
5,000 – 10,000	High
Less than 5,000	Very high

COVER METER

- COVER IS A VERY IMPORTANT PARAMETER DICTATING DURABILITY OF CONCRETE
- COVER PROVIDED IS INADEQUATE MORE OFTEN THAN NOT
- CONVENTIONALLY PROVISION OF COVER IS CHECKED PRIOR TO CONCRETING
- POST FACTO ASSESSMENT OF COVER IS POSSIBLE THROUGH COVER METERS

COVER METER

- BASED ON MAGNETIC PRINCIPLE
- RANGE OF MEASUREMENT POSSIBLE IS 0-75 mm
- ACCURACY WITHIN 6 mm
- NOT VERY EFFECTIVE IN HEAVILY REINFORCED MEMBERS OR MEMBERS WITH SPIRAL REINFORCEMENT
- SIZE OF THE REINFORCEMENT BAR IS REQUIRED TO BE KNOWN FOR ACCURATE ASSESSMENT OF COVER

APPLICATION OF COVER METER

- REHABILITATION PLANNING
- ASSESSMENT OF RESIDUAL TIME TILL INITIATION OF CORROSION
- TO IMPROVE QUALITY CONTROL DURING CONSTRUCTION
- IDENTIFICATION OF LOCATION OF REINFORCEMENT BAR WITH THE FOLLOWING APPLICATIONS
  - HELPS IN AVOIDING DRILLING INTO THE REINFORCEMENT
  - TO AVOID REINFORCEMENT IN PULSE VELOCITY MEASUREMENTS

CARBONATION DEPTH

- CARBONATION IS CHEMICAL REACTION BETWEEN $Ca(OH)_2$ AND CO_2 OF THE ATMOSPHERE
- CARBONATION DESTROYS PASSIVE PROTECTION PROVIDED BY CONCRETE TO THE REINFORCEMENT
- CARBONATION PROCEEDS FROM THE SURFACE INTO THE CONCRETE
- WHEN DEPTH OF CARBONATION EQUALS CONCRETE COVER REINFORCEMENT CORROSION IS IMMINENT

CARBONATION DEPTH

- METHOD OF ASSESSMENT
  - DRILL INTO CONCRETE
  - SPRAY PHENOLPHTHALEIN SOLUTION
  - UNCARBONATED CONCRETE WILL SHOW BRIGTH PINK STAIN
  - CARBONATED CONCRETE WILL NOT CHANGE COLOUR
  - WITH THE ABOVE VISUAL INDICATION DEPTH OF CARBONATION CAN BE EASILY MEASURED

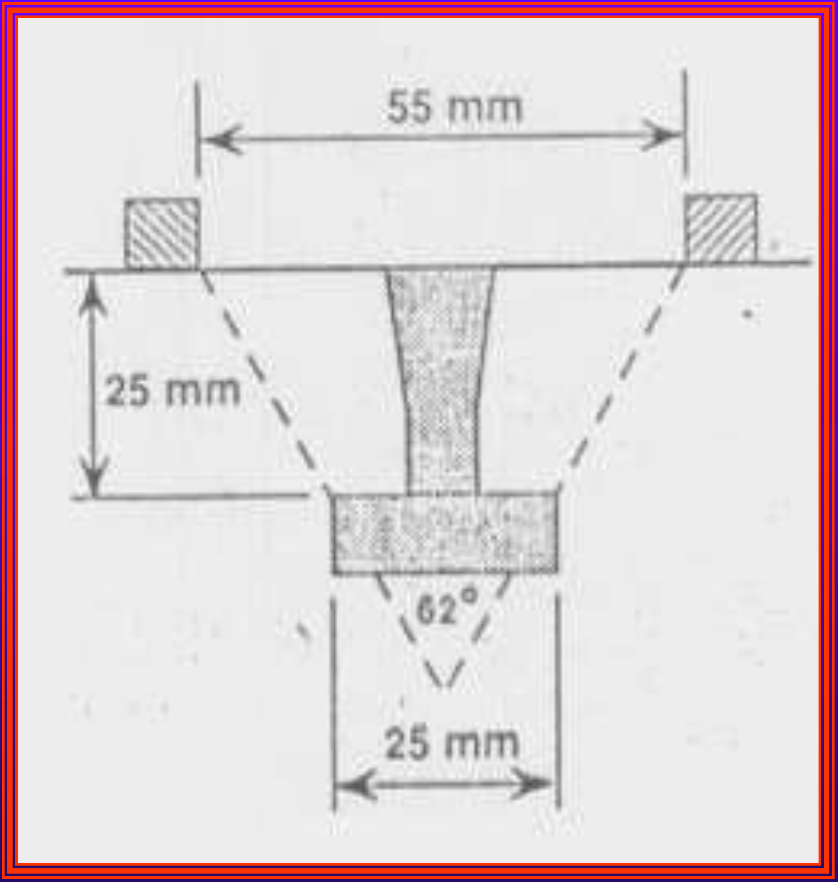
LIMITATIONS OF N D T

- ALL NDT METHODS ARE INDIRECT
- CORELATION BETWEEN MEASURED PARAMETER AND CONCRETE STRENGTH IS NEVER EXACT.
- EFFECTIVENESS OF NDT REDUCES WITH HETEROGENEITY OF THE MATERIAL
- RESULTS ARE DEPENDENT ON TOO MANY PARAMETERS
- NORMALLY ACHIEVEABLE LEVEL OF ACCURACY IS $\pm$ 25%
- INTERPRETATION OF RESULTS REQUIRE INTUITIVE JUDGEMENT

Pull-out Tests

Lok Test (developed in Denmark)

Capo Test

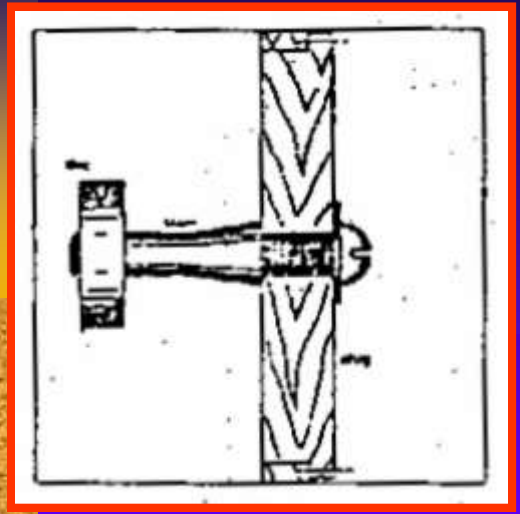


Lok – Test

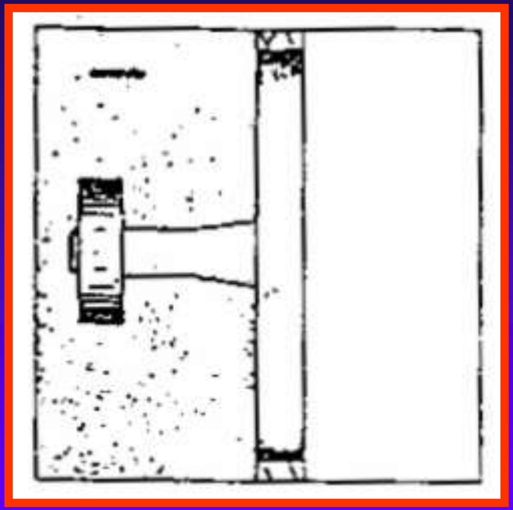
(Preplanned tests – new structures)

- Attach the head and shaft to the formwork
- Concrete is cast
- Remove formwork at test location
- All parts except disc is removed
- A pull-rod is treaded to disc
- Pull-rod attached to testing equipment
- Pull rod pulled and the force to pull out is noted
- Calibration provided to convert into strength

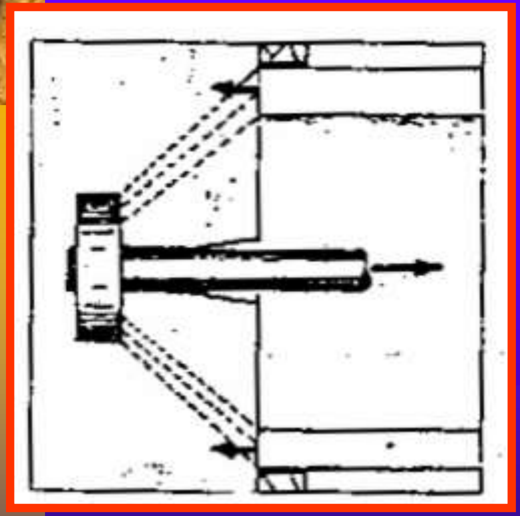
a



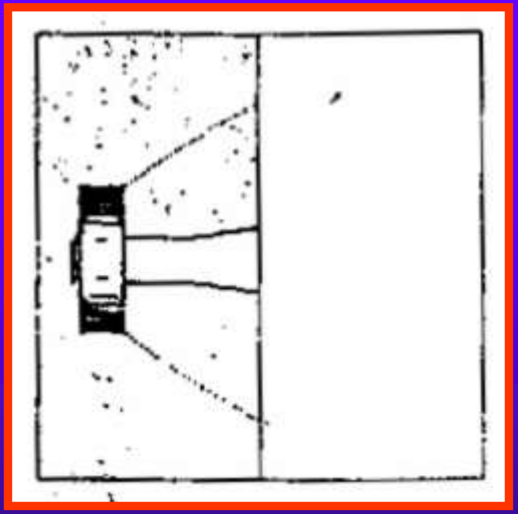
b



c



d

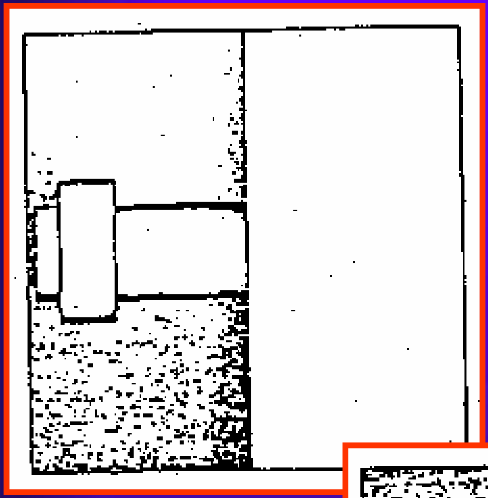


Lok Test procedure

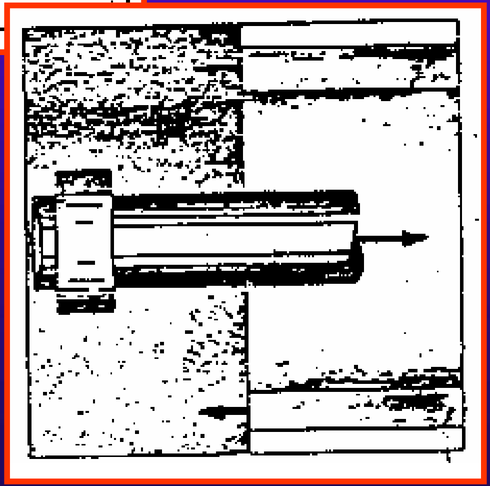
Capo-test

(For existing structure)

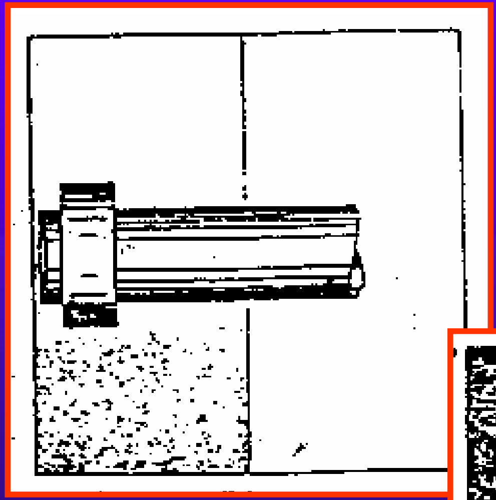
Similar concept as Lok-test, except hole is made and disc is inserted



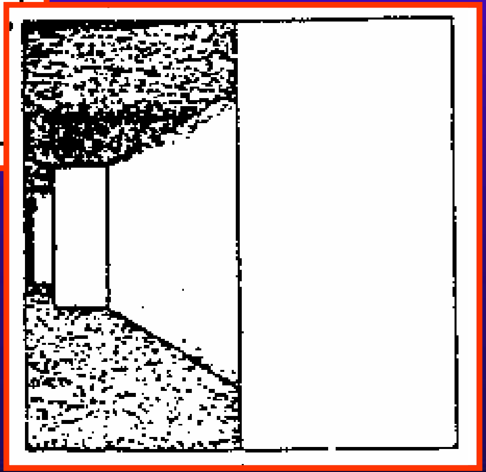
a



c



b



d

Remarks

- Capo-test has good reliability
  for estimation of strength
- Equipment available (Portable)
- Needs some practice

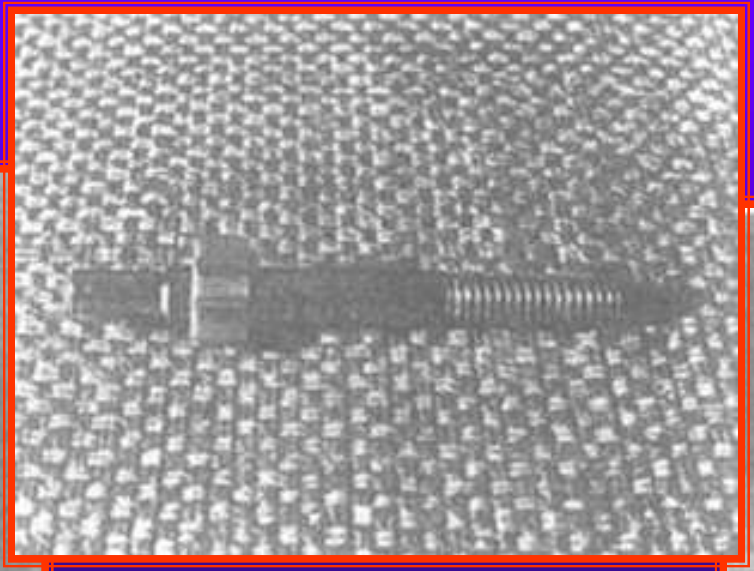
Other Methods

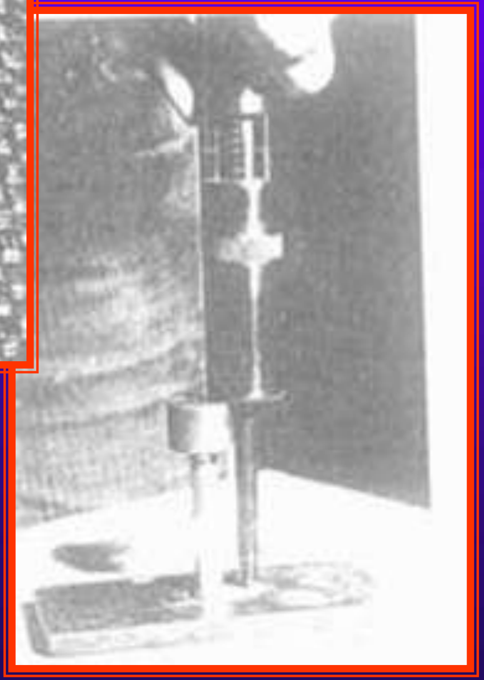
- Penetration Method
- Pull-off Tests
- Break-off Tests

(These are not widely used)

Penetration Method

- Popularly known as ‘Windsor probe’



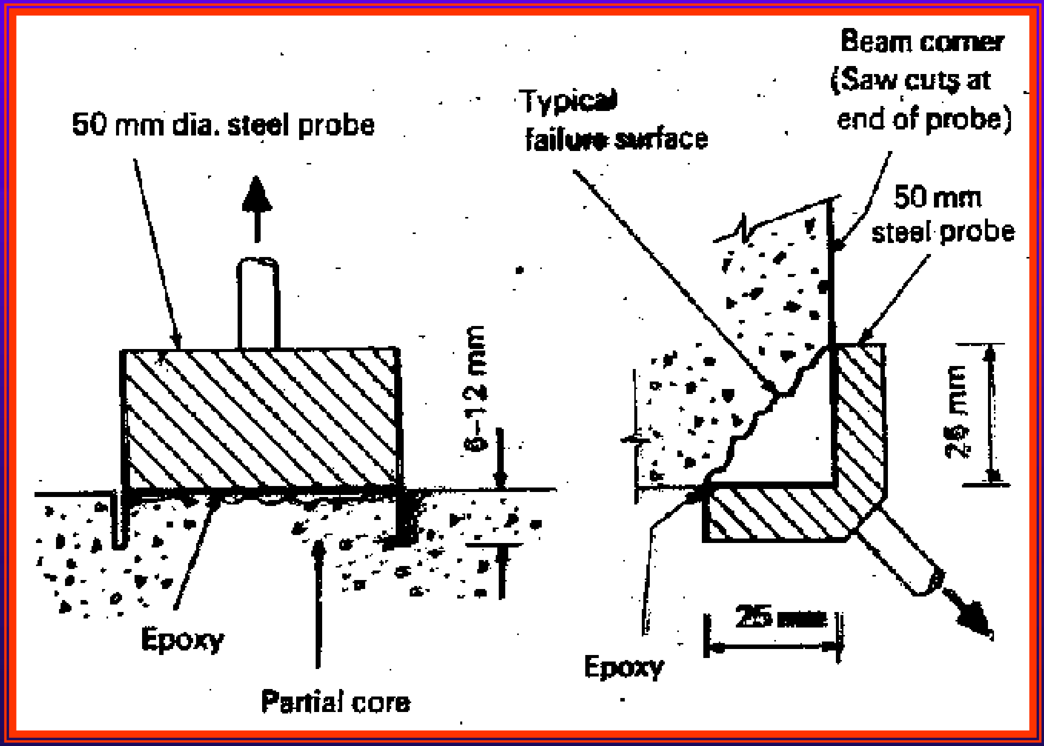


Procedure

- A probe is prepared by attaching firing head
- Place the probe into the driver (gun)
- Fire the driver, holding against a steel locating plate
- Measure the depth of penetration by measuring the exposed length
- Dept of penetration is a measure of strength

Pull-off Method

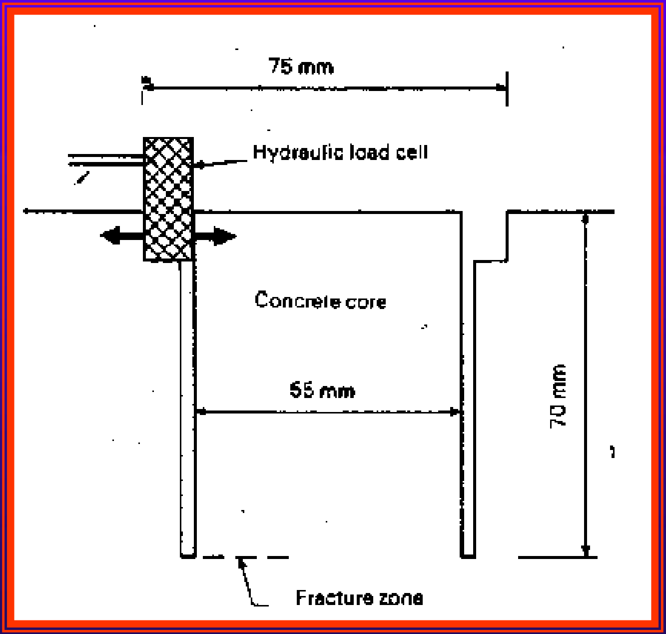
- Arrangement as shown
- Direct pull-off using epoxy is not recommended
- Partial coring recommended



Break-off

Arrangement shown

- Modulus of rupture is estimated
- High degree of variability



Core Tests

- Most accurate test, if performed correctly
- An essential component of in-situ investigation
- Other than strength, can be used for visual inspection, crack depth, chemical analysis, permeability
- Location, size and numbers

Location

- If concrete is in suspect, use weakest area
- For compliance, avoid unrepresentative areas
- Avoid reinforcement
- Avoid critical areas

Size

- Desirable 100 mm dia for strength;

  though 70-75 mm dia widely used

- Generally size affects strength

  (if small dia, less than 70 mm, use correction factor)

- L/d ratio ~ 2 ; for smaller L/d ratio, use correction factor

- Accuracy decreases as agg/core dia increases

  (use at least 3 * maxm. size)

No. of Cores

- Depends on purpose
- For strength verification, use statistically significant numbers
- Minm. 3 to 4 cores for strength
- Compromise between cost, damage and accuracy

Trimming, Capping and Measurement

- Trim edges with a saw to make ends square
- Cap properly with horizontal face
- Measure length, average diameter

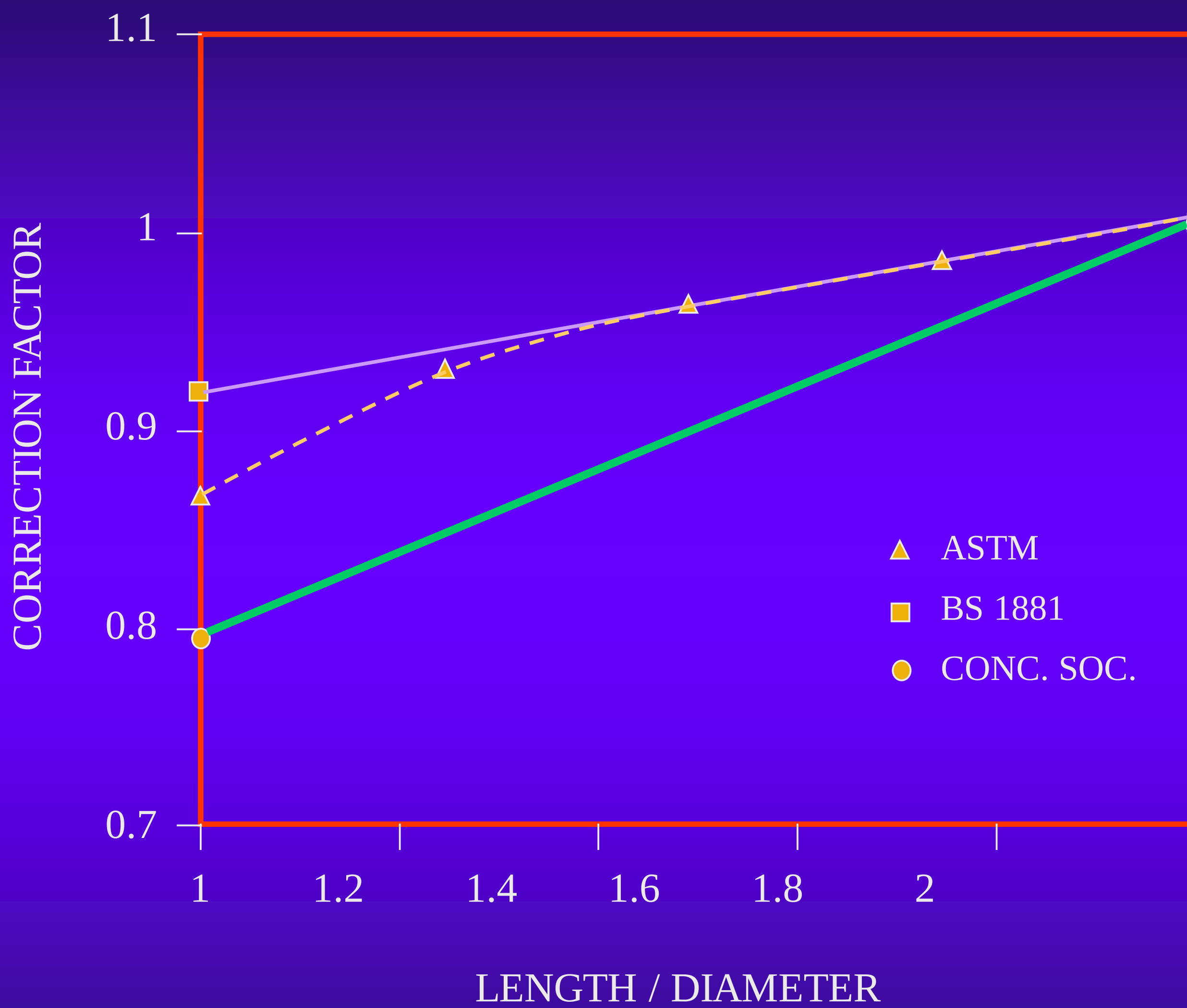
  (cross readings at mid-height and at ¼ points)
- Calculate density

Testing

- Test in dry or wet condition as required
  (dry cores 10-15% stronger than wet cores)
- Test under a comp. machine, neither too
  slow or too fast (15 $N/mm^2/min$)
- Avoid eccentricity

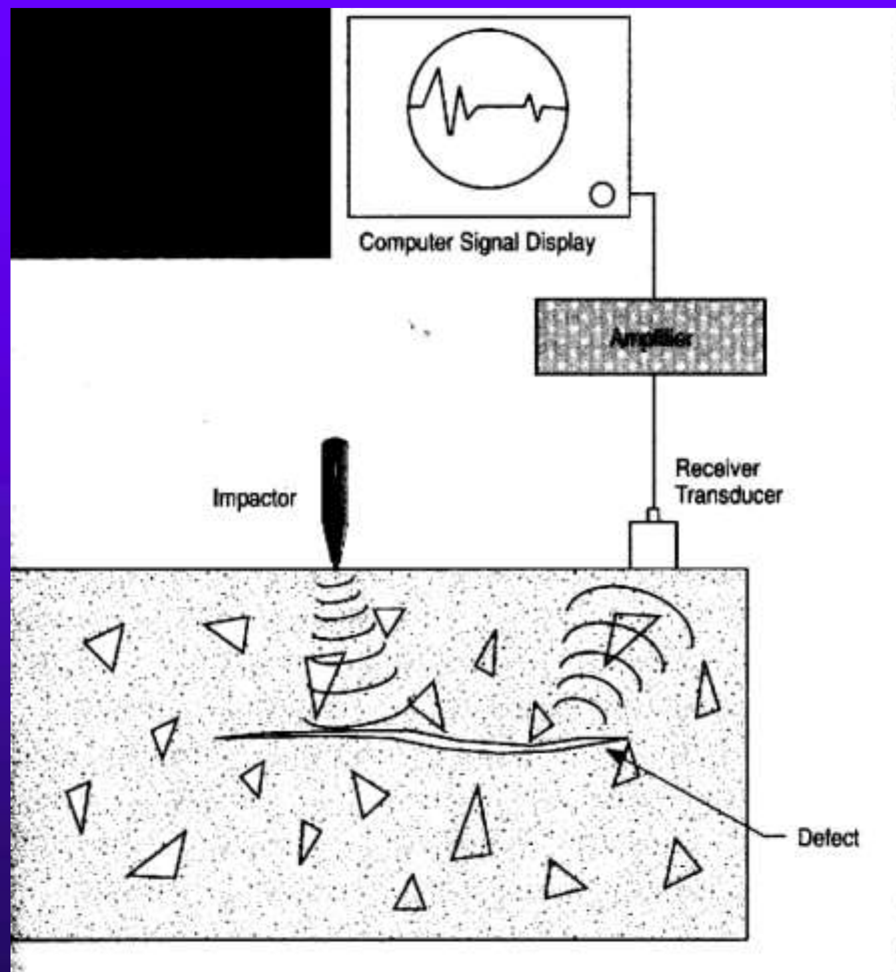
Correction Factors

- L/d ratio
- Reinforcement (not recommended)
- Small diameter cores



Effect of length / diameter ratio on core strength

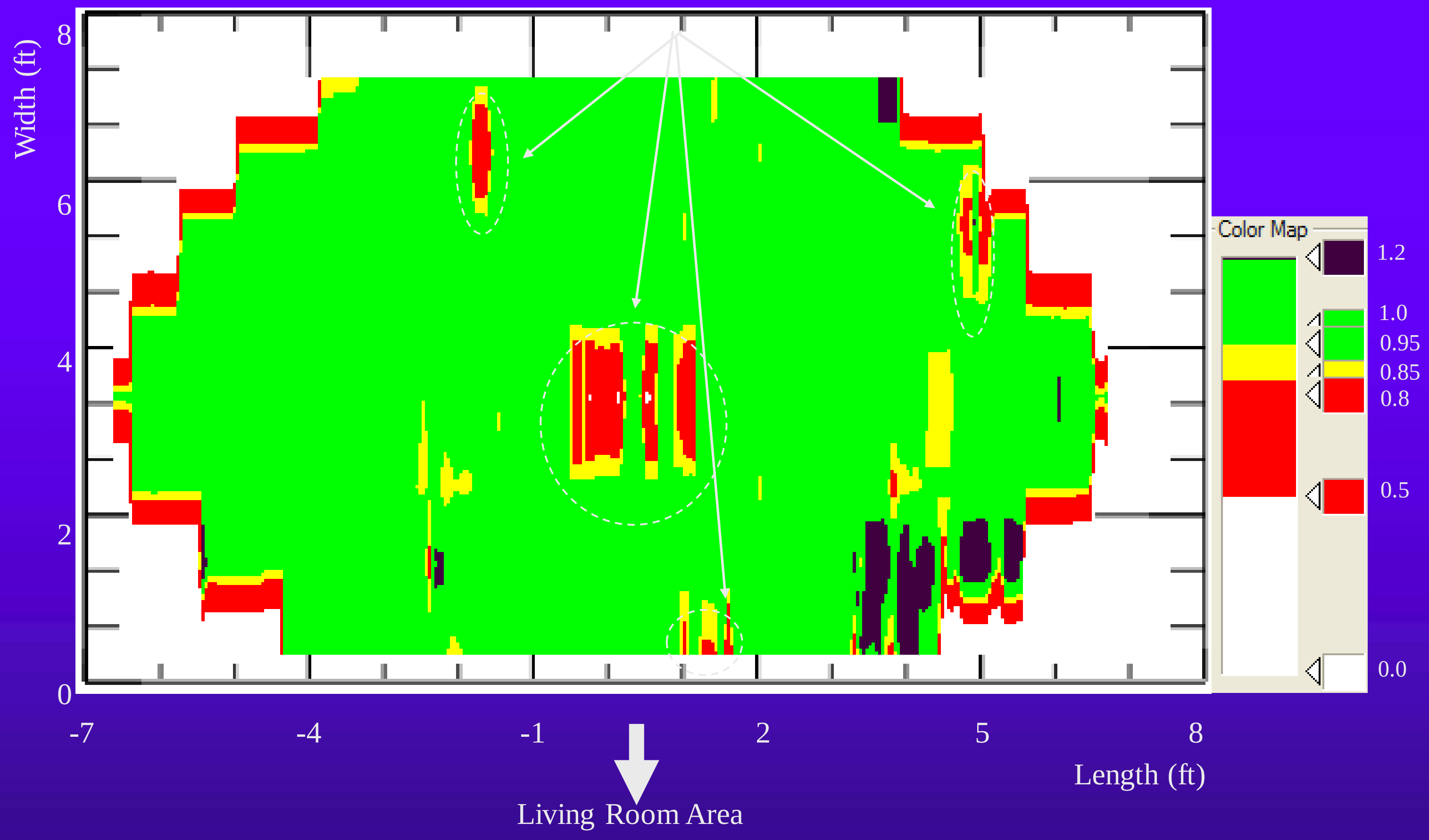
Impact Echo Testing



Impact Echo Scanning from the top

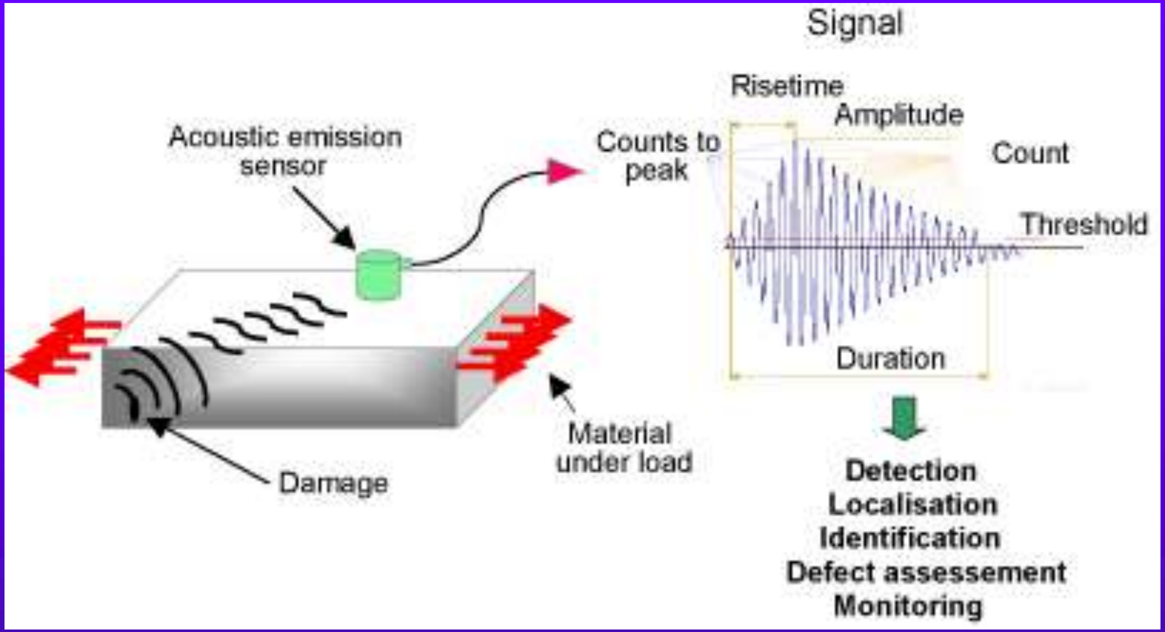
- To locate top and bottom delamination caused by corrosion at the top and bottom reinforcement
- An Impact Echo Scanner was used to scan on the top of the balcony deck
- A “point by point” Impact Echo test was used from the underside to confirm the top delamination

Impact Echo Test (point by point) from tl



Graphical IES Test Results (Normalized Thickness) from the Balcony Deck

Acoustic Emission



Acoustic emission correlated with the presence of rebar corrosion

SUMMARY

- A number of test methods that can be applied to determine strength of in-situ concrete have been presented.
- Core test must be included in a test program to lend confidence in the measured strength.
- Hammer rebound numbers are least accurate. Only a notional estimate can be obtained.
- High strength does not necessarily mean high quality concrete, though it is expected in most cases.