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

Non- Destructive Testing (NDT) Methods

- Classification
- Procedure
- Applicability

Summary of the Testing Methods

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

NDT METHODS
for
- Mechanical Properties -

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

Testing For Mechanical Properties

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

Note - DT: Destructive Test, PDT: Partially Destructive Test , NDT – Non-destructive Test

1. Ultrasonic Pulse Velocity (USPV) Test

Indian Standard Code : IS 13311 (Part 1) : 1992
American Standard Code : ASTM C597 - 16

USPV Test could be used to qualitatively assess the:

1. **Homogeneity of the concrete,**
2. **Strength of the concrete**
3. **Gradation in different locations of structural members**
4. **Discontinuities in the cross-section, such as cracks, voids, concrete cover delaminations, etc.**
5. **Depth of surface cracks**

1. Ultrasonic Pulse Velocity (USPV) Test

Principle:

This test essentially consists of measuring travel time, *‘T’* of an ultrasonic pulse of 50-54 kHz, produced by an electro-acoustical transducer, penetrating into the concrete, reflecting and then receiving the same signal by similar transducer.

Testing For Mechanical Properties

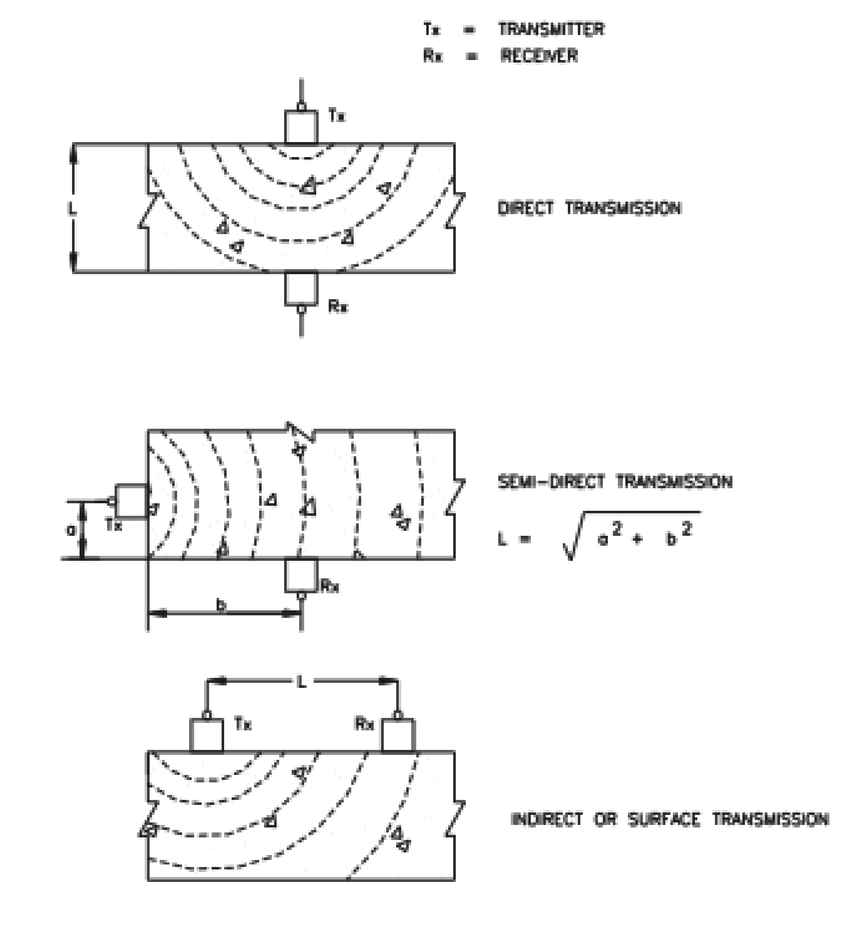
1. Ultrasonic Pulse Velocity (USPV) Test

Principle:

With the path length, *'L'* (i.e. the distance between the two probes) and time of travel. T the pulse velocity *(V = L/T)* is calculated .

L is calculated as per the figure.

(Ref: CPWD Handbook)



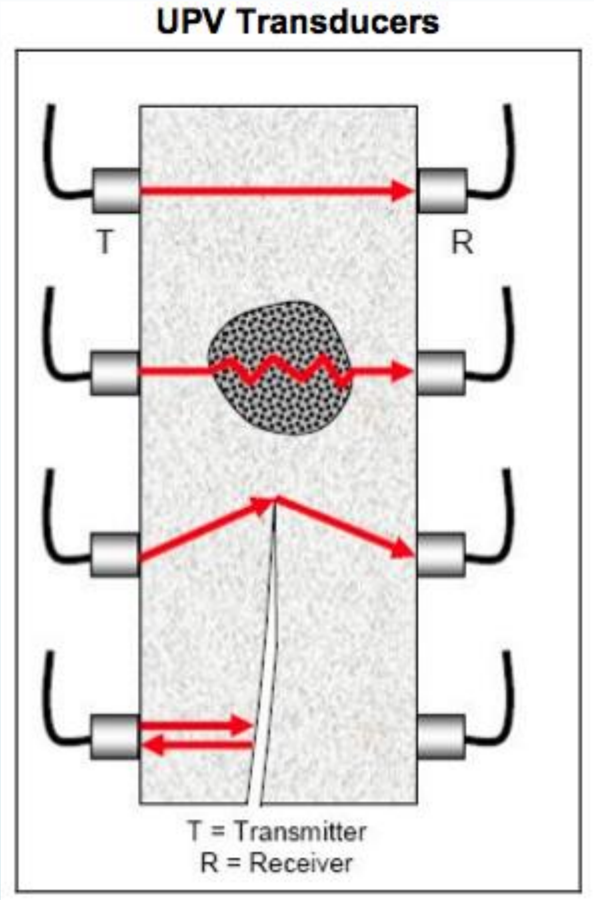
Testing For Mechanical Properties

1. Ultrasonic Pulse Velocity (USPV) Test

Factors Affecting the Pulse Velocity:

Higher the elastic modulus, density and integrity of the concrete, higher is the pulse velocity.

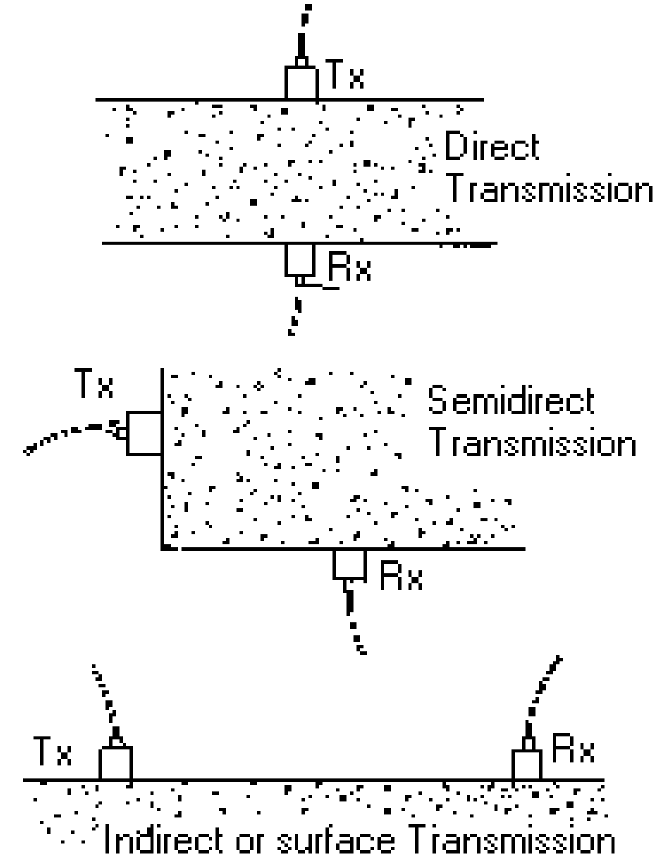
The ultrasonic pulse velocity depends on the density and elastic properties of the material being tested.



1. Ultrasonic Pulse Velocity (USPV) Test

Types of USPV tests based of transmission of the pulse:

- Direct transmission
- Semi-direct transmission
- Surface or indirect transmission

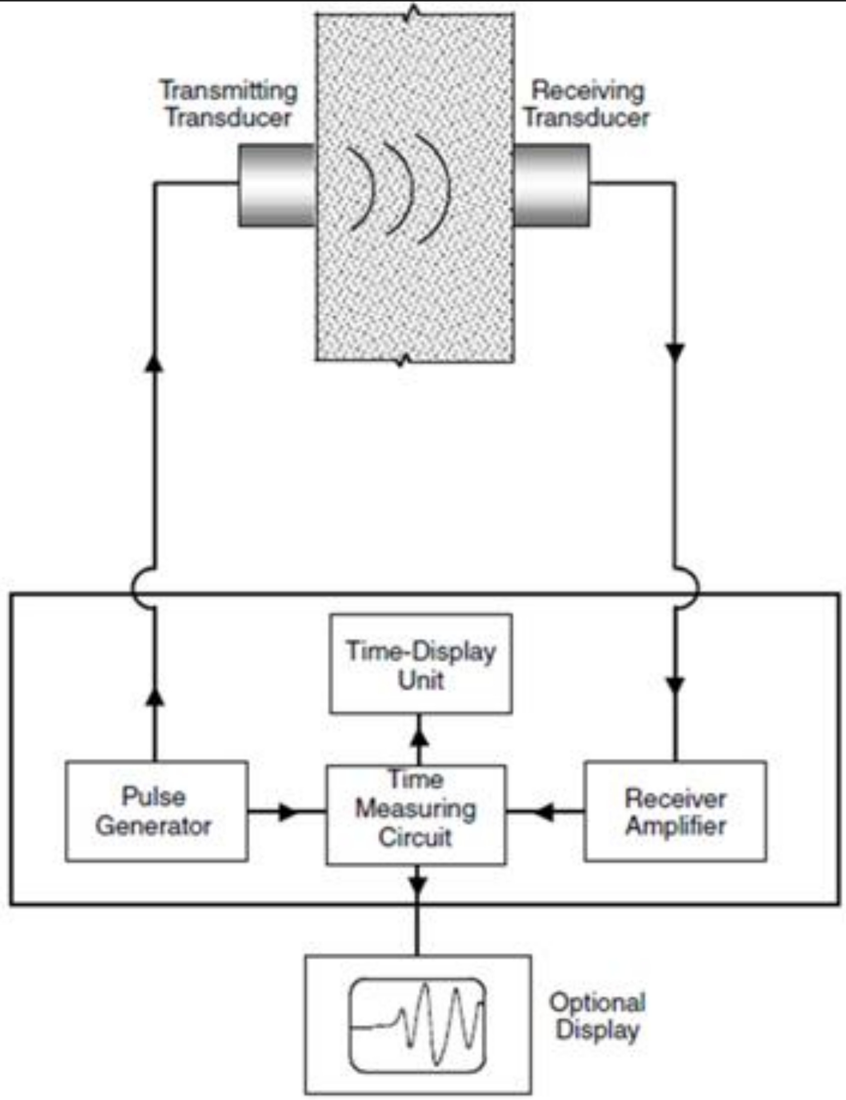


Methods of propagating ultrasonic pulses

1. Ultrasonic Pulse Velocity (USPV) Test

Instrument Components:

- E/A Pulse Generator
- Transmitting Transducer
- Receiving Transducer
- Amplifier
- Time measuring circuit
- Display components



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1. Ultrasonic Pulse Velocity (USPV) Test

Recommendation for Transducer Frequency based on path length – IS 13311 (Part1) – Table 1

Table 1 Natural Frequency of Transducers for Different Path Lengths

Path Length (mm)	Natural Frequency of Transducer (kHz)	Minimum Transverse Dimensions of Members (mm)
Up to 500	150	25
500-700	> 60	70
700-1 500	> 40	150
above 1 500	> 20	300

Testing For Mechanical Properties

1. Ultrasonic Pulse Velocity (USPV) Test

Assessment Criteria: IS 13311 (Part 1) – Table 2

Table 2 Velocity Criterion for Concrete Quality Grading

Sl No.	Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1.	Above 4·5	Excellent
2.	3·5 to 4·5	Good
3.	3·0 to 3·5	Medium
4.	Below 3·0	Doubtful

Note — In case of "doubtful" quality it may be necessary to carry out further tests.

2. Rebound Hammer Test

Indian Standard Code : IS 13311 (Part 2) : 1992
American Standard Code : ASTM C805/C805M – 13a

Also called as the Schmidt's Rebound Hammer Test.
Used for estimating:

1) The surface hardness
2) compressive strength – by correlation with the rebound number
3) the uniformity of concrete
4) the quality of one element of concrete in relation to another

Testing For Mechanical Properties

2. Rebound Hammer Test

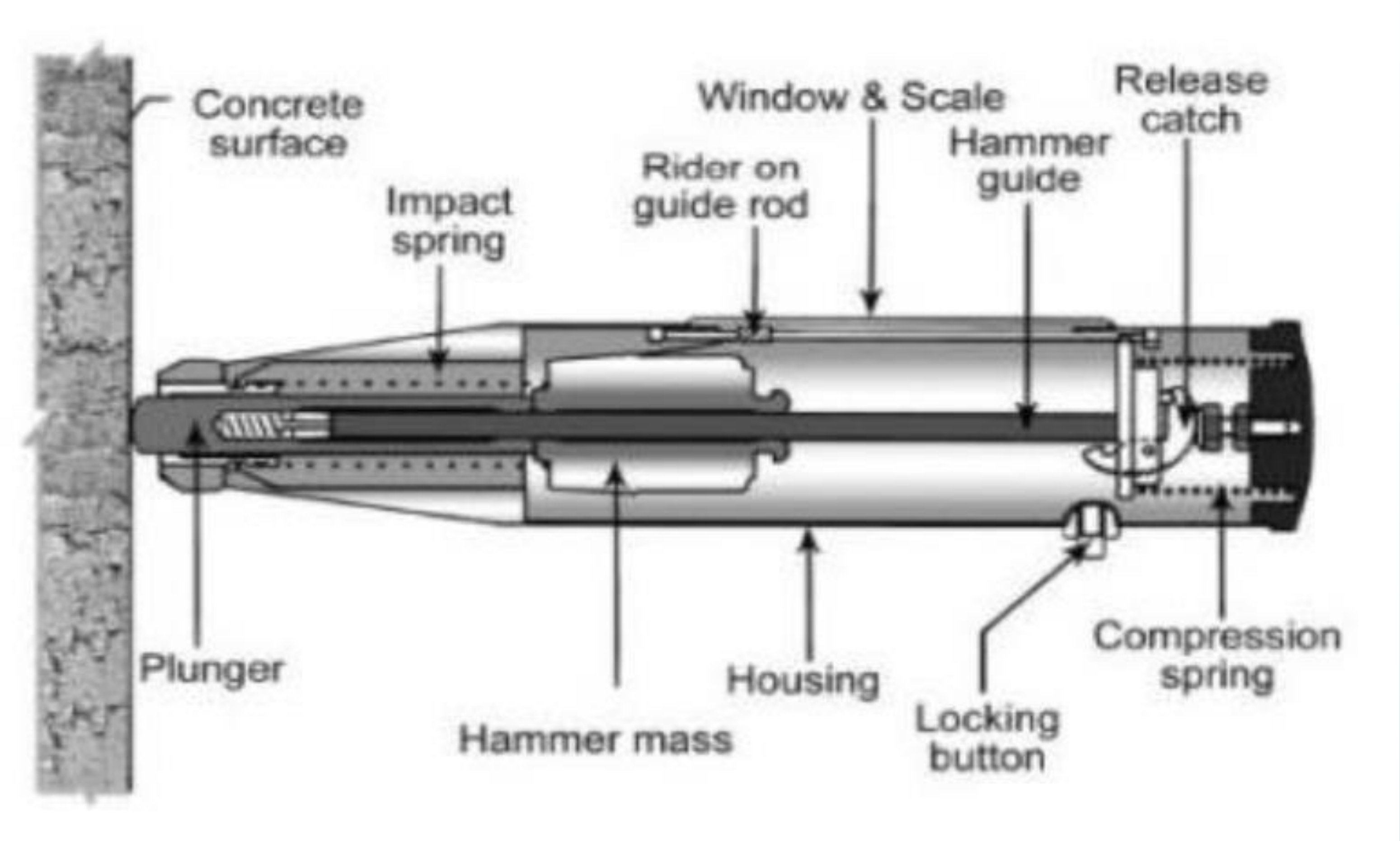
2. Rebound Hammer Test

Principle:

When the plunger of rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete.

The rebound is measured along a graduated scale and is designated as the Rebound Number or rebound index.

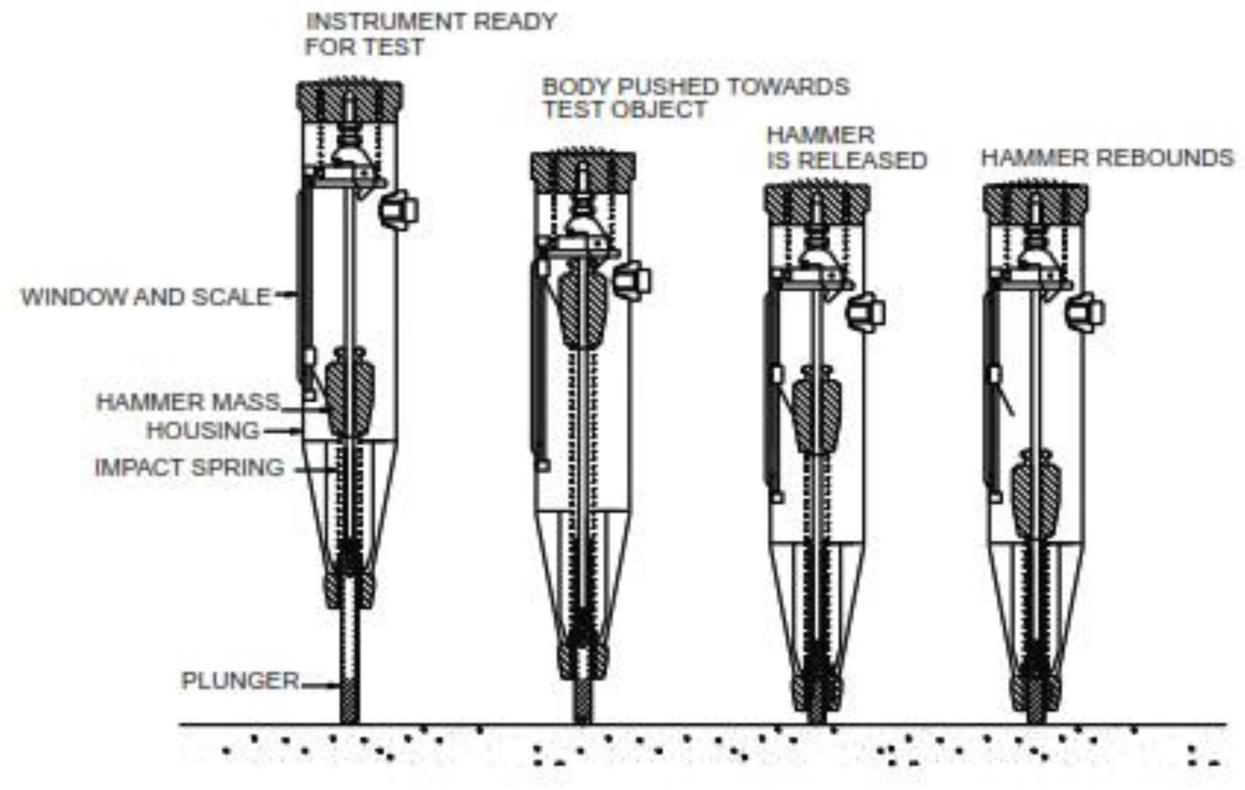
2. Rebound Hammer Test



Testing For Mechanical Properties

2. Rebound Hammer Test

Operation:



Testing For Mechanical Properties

2. Rebound Hammer Test

IS 13311 Pt-2-1992 as well as BS: 6089-81 and BS: 1881:Pt-202 explains the standard procedure for test and correlation between concrete cube crushing strength and rebound number. The results are significantly affected by the following factors :

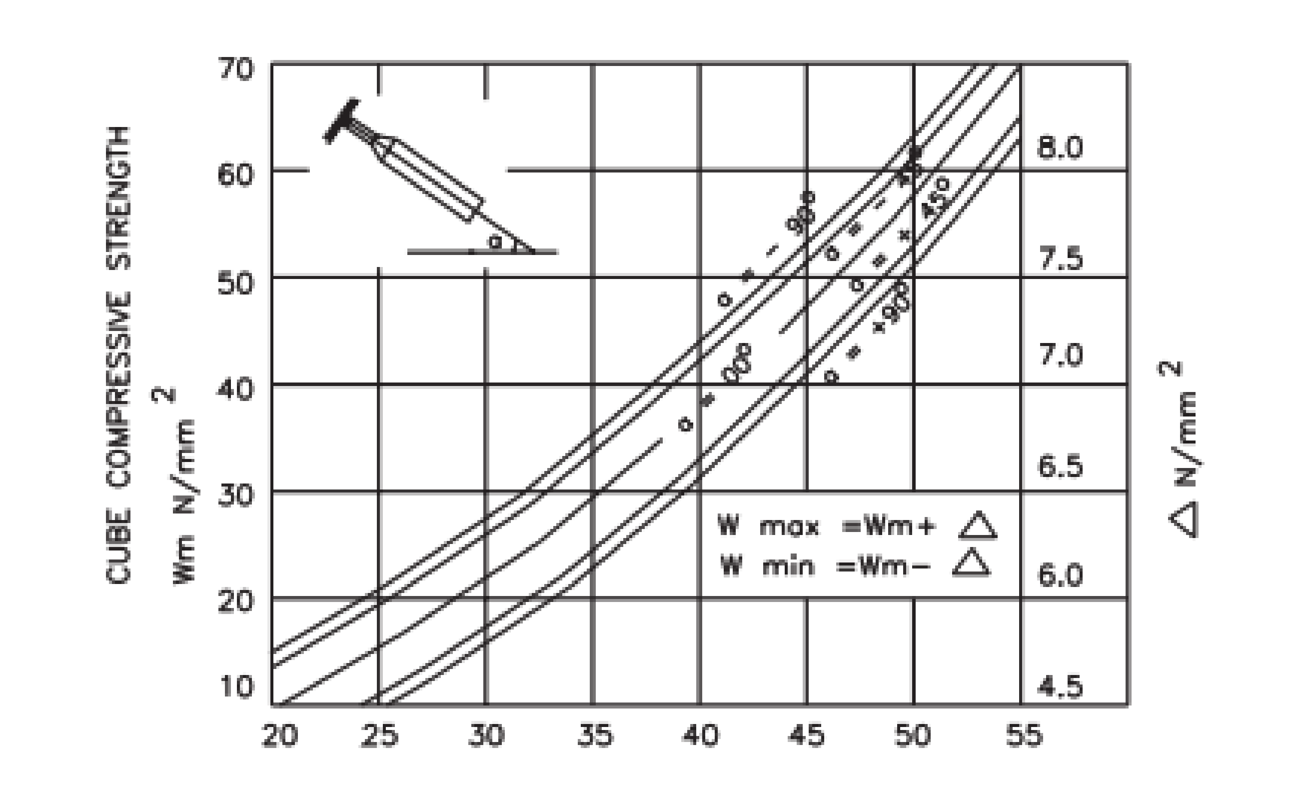
a. Mix characteristics :
   i. Cement type,
   ii. Cement Content,
   iii. Coarse aggregate type :

b. Angle of Inclination of direction of hammer with reference to horizontal (Fig 3.7)

c. Member Characteristics,
   i. Mass,
   ii. Compaction,
   iii. Surface type,
   iv. Age, rate of hardening and curing type,
   v. Surface carbonation,
   vi. Moisture Condition,
   vii. Stress state and temperature.

Testing For Mechanical Properties

2. Rebound Hammer Test



Correlation between cube compressive strength and the rebound number

Testing For Mechanical Properties

2. Rebound Hammer Test

Table-3.8: Quality of Concrete from Rebound Values Comparative Hardness

Average Rebound	Quality of Concrete
>40	Very Good
30-40	Good
20-30	Fair
<20	Poor and/or delaminated
0	Very Poor and/or delaminated

Taken from CPWD Handbook

Testing For Mechanical Properties

2. Rebound Hammer Test

Table 3.10 : Identification of Corrosion Prone Location based on Pulse Velocity and Hammer Readings

(Source: Indian Concrete Journal, June 1998)

Sl.No.	Test Results	Interpretations
1.	High UPV values, high rebound number	Not corrosion prone
2.	Medium range UPV values, low rebound numbers	Surface delamination, low quality of surface concrete, corrosion prone
3.	Low UPV, high rebound numbers	Not corrosion prone, however, to be confirmed by chemical tests, carbonation, pH
4.	Low UPV values, low rebound numbers	Corrosion prone-requires chemical and electrochemical tests.

Taken from CPWD Handbook

3. Ultrasonic Pulse Velocity (USPV) Test

Indian Standard Code : IS 13311 (Part 1) : 1992
American Standard Code : ASTM C597 - 16

USPV Test could be used to qualitatively assess the:

1. **Homogeneity of the concrete,**
2. **Strength of the concrete**
3. **Gradation in different locations of structural members**
4. **Discontinuities in the cross-section, such as cracks, voids, concrete cover delaminations, etc.**
5. **Depth of surface cracks**

NDT METHODS
for
- Chemical Effects-

Testing For Chemical Properties

Property	Test Method
Electro-Chemical Activity	Half cell potential, Electrical resistivity
Carbonation Depth	Phenolphthalein Solution Petrographic Analysis X-ray diffraction Infrared Spectroscopy
Alkali-Aggregate Reactions	Petrographic Analysis Uranyl Acetate Fluorescence Method
Chloride Content	Chloride meter

TESTING FOR CHEMICAL PROPERTIES

ELECTRO-CHEMICAL ACTIVITY (CORROSION ACTIVITY MEASUREMENTS)

Electrochemical Activity

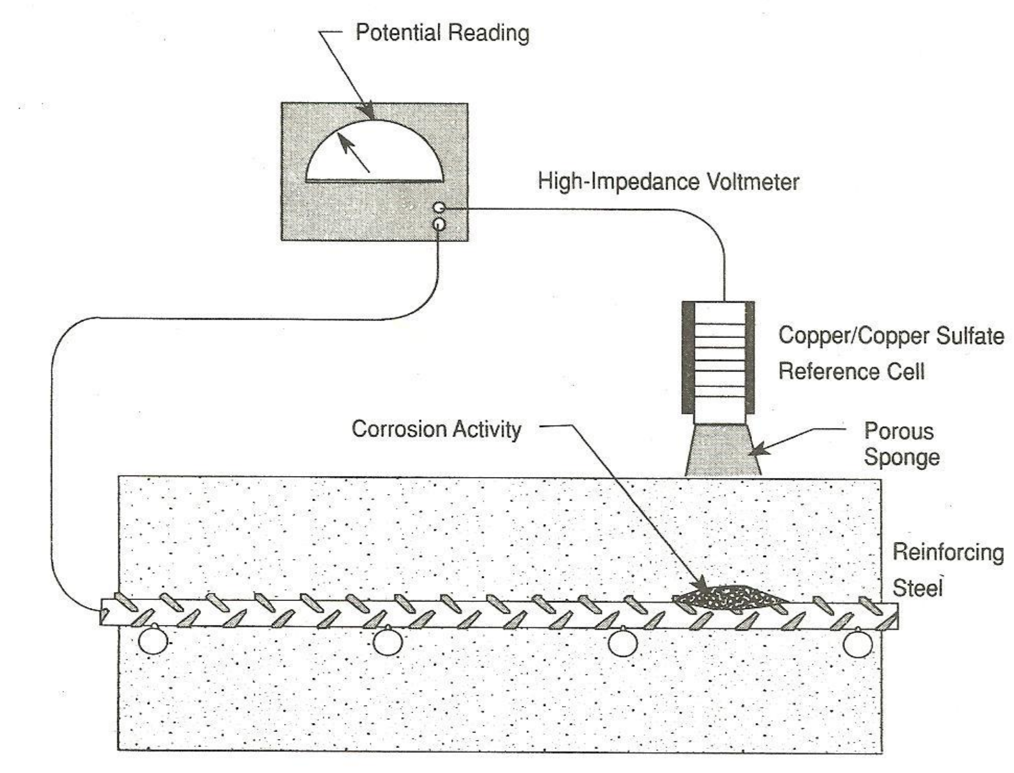
I. Half Cell Potential Method

(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.



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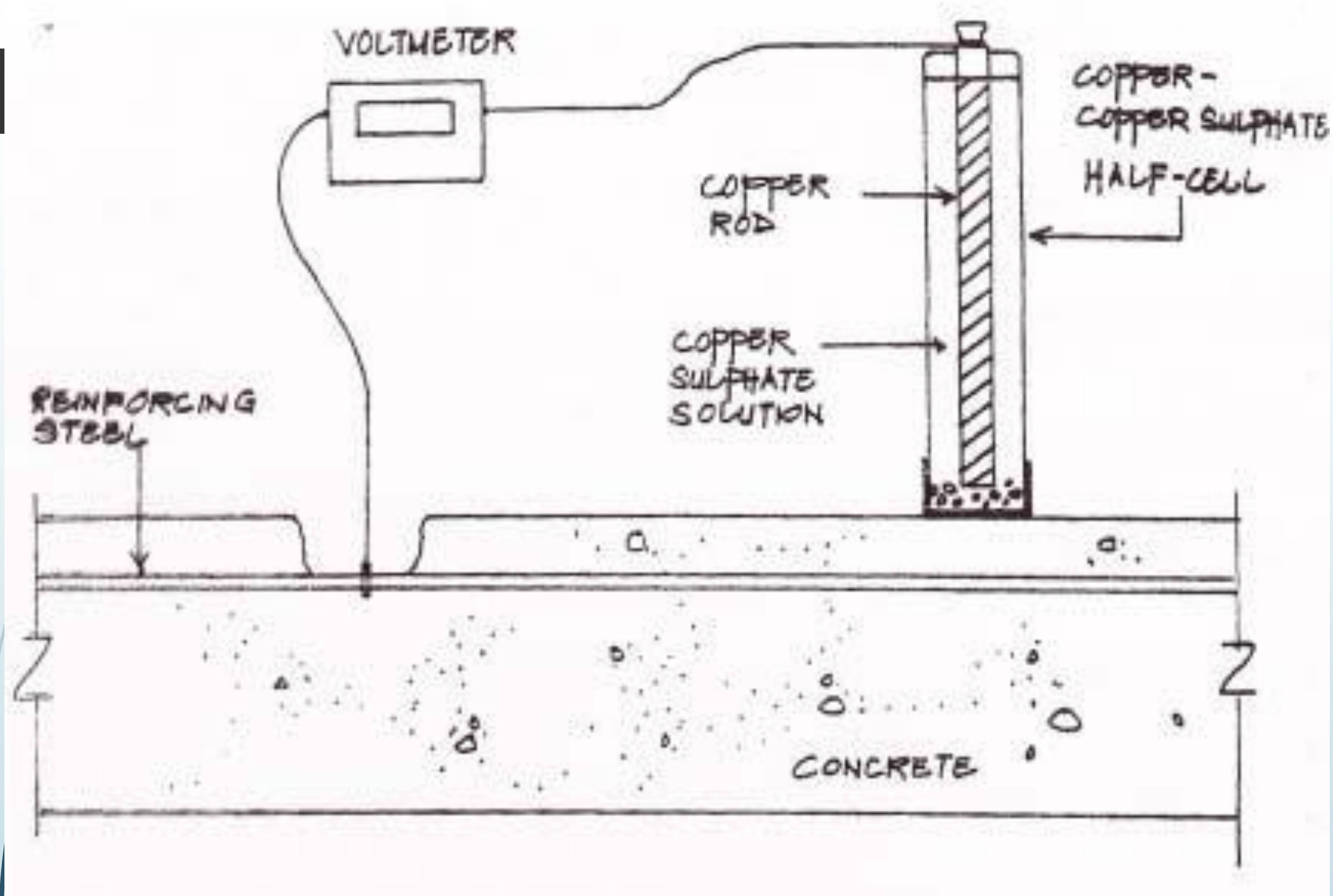


COPPER - COPPER SULFHATE
HALF - CELL CIRCUITRY

Electrochemical Activity

I. Half Cell Potential Method

(also called Open-Circuit Potential Measurement Technique)

The general interpretations of half-cell potential measurements:

Less negative than – 0.2 volts ⇒ No corrosion [90% probability]
Between – 0.35 and – 0.2 volts ⇒ corrosion activity [uncertain]
More negative than – 0.35 volts ⇒ corrosion [90% probability]

Positive value ⇒ insufficient moisture in the concrete (invalid reading)

The test does not indicate the rate of corrosion. It only gives an indication of the potential for corrosion at the time of measurement.

The test is difficult to apply for post-tension strands.

The test fails if there is discontinuity in the reinforcement.

Yet, simple and economical method for quick corrosion potential assessment.

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.

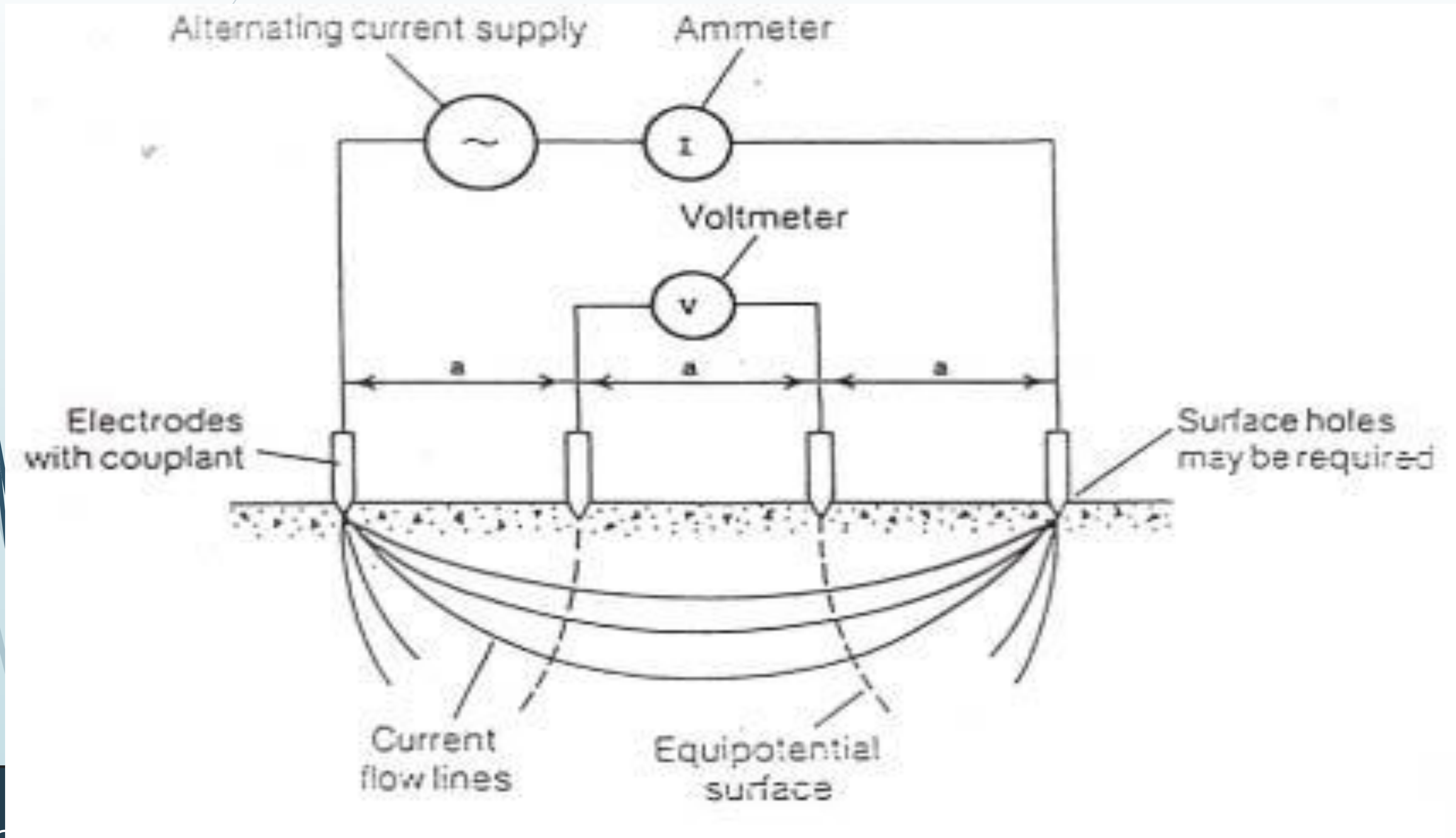
PRINCIPLE:

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.

Electrochemical Activity

II. Electrical Resistivity

Factors influencing Electrical Resistivity Measurements

1) Moisture 2) Salt content **3) Ambient temperature**,
4) Water/cement ratio and 5) Mix proportions.

The variations of moisture condition have a major influence on *in situ test readings*. Precautions need to be taken when comparing results of saturated concrete, e.g. those exposed to sea water or measurements taken after rain showers, with those obtained on protected concrete surfaces.

Ambient temperature: Concrete has electrolytic properties; hence, resistivity will increase as temperature decreases. Usually resistivity measurements are higher readings during the winter period than the summer period.

Electrochemical Activity

II. Electrical Resistivity

General Guidelines for Interpretation of Resistivity Measurements for Corrosion Assessment

Resistivity (ohm cm)	Likely Corrosion Rate
Less than 5,000	Very high
5,000 – 10,000	High
10,000 – 20,000	Low / Moderate
Greater than 20,000	Negligible

It is necessary to calibrate the technique, either through exposing the steel to assess its condition, or by correlating the resistivity values with data collected with other techniques, such as half-cell potential measurement.

Electrochemical Activity

III. Electrical Resistivity

OTHER METHODS for determining corrosion activity :

3. Surface Potential Measuring Technique
4. Polarization Resistance Technique
5. Electrochemical Noise Analysis

References for the above:

1) Sections 25.4.25, 25.4.26 and 25.4.27 from the book Concrete Technology – A R Santhakumar

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:

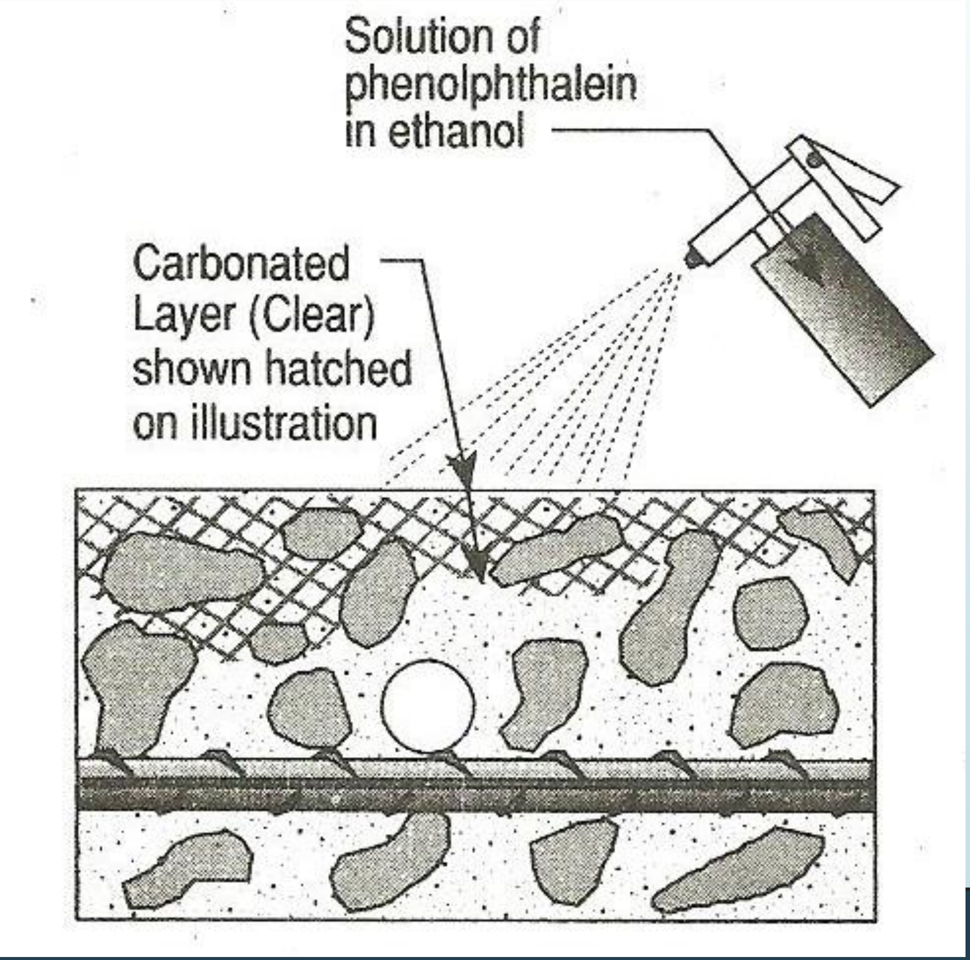
The 1% phenolpthalein solution is made by dissolving 1gm of phenolpthalein in 90 cc of ethanol. The solution is then made up to 100 cc by adding distilled water. On freshly extracted cores the core is sprayed with phenolphthalein solution, the depth of the uncoloured layer (the carbonated layer) from 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.

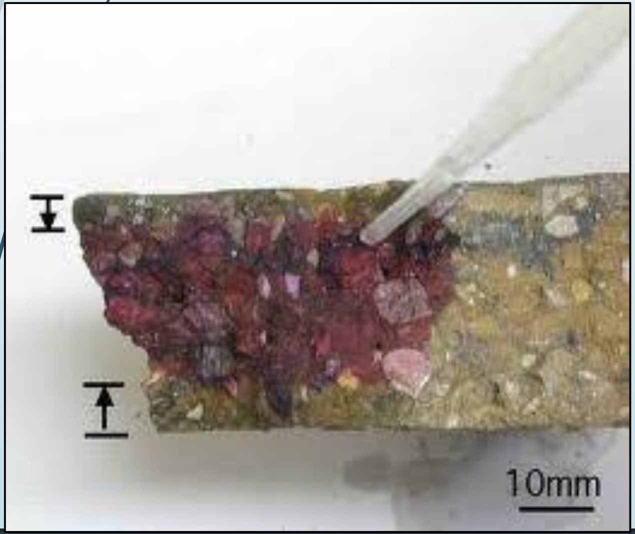
Carbonation Depth Measurement

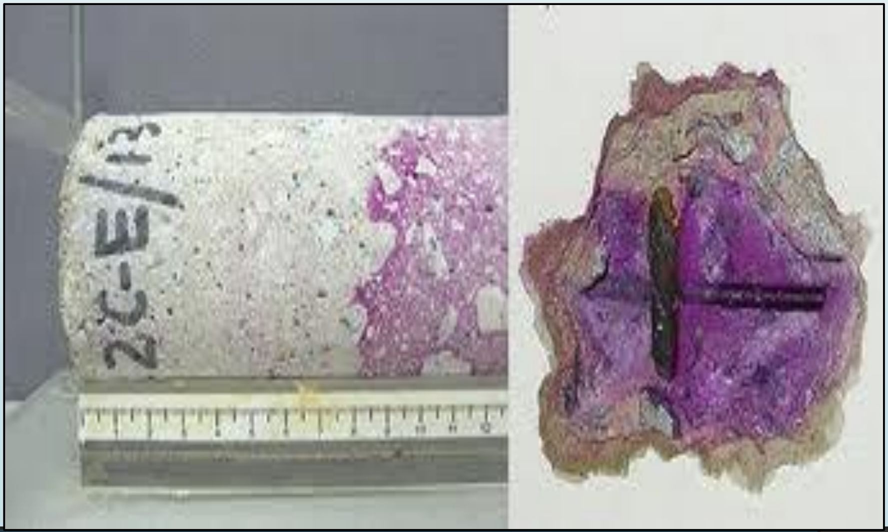
I. Acid Base Indicators

Method to Measure the Depth of Carbonation:



Carbonation Depth Measurement





Carbonation Depth Measurement

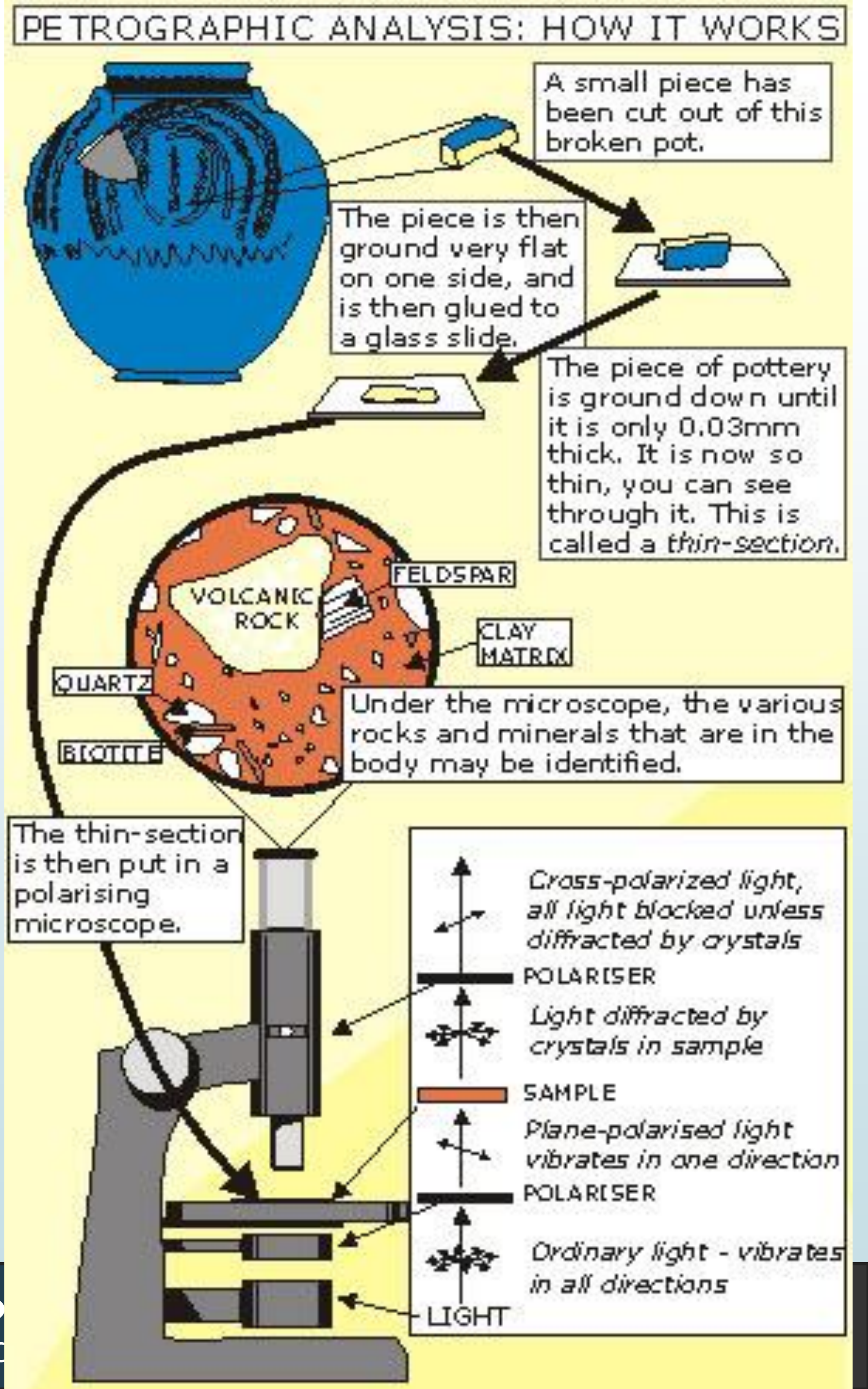
II. Petrographic Analysis

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

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

Alkali-Aggregate Reaction

I. Petrographic Analysis

Macroscopic Observations:

Several macroscopic signs of concrete deterioration, some of which are related to ASR, can be observed by examining the cores immediately after the extraction or in the laboratory in an as received condition. The observations can be made with naked eye or aided by a small magnifying lens (up to 10X magnification) that can be easily used in the field. These are……

Alkali-Aggregate Reaction

I. Petrographic Analysis

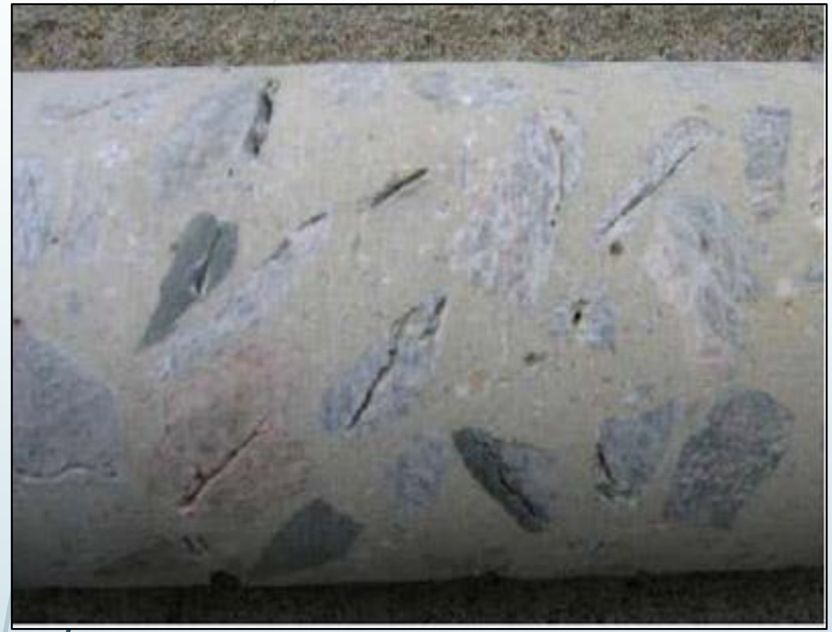
- **Symptom 1:** Macrocracks penetrating at different depths in the concrete member [Note: macro-cracks can be due to several mechanisms other than ASR]
- **Symptom 2:** Fine to-medium size cracks will stay damp while rewetting

Alkali-Aggregate Reaction

I. Petrographic Analysis

- **Symptom 3:** Gel staining surrounding surface cracks.
- **Symptom 4:** Dark reaction rims at the periphery of reacted aggregate particles; dark rims may appear at the periphery of weathered gravel particles and are consequently not fully indicative of ASR in the case of gravel aggregates.

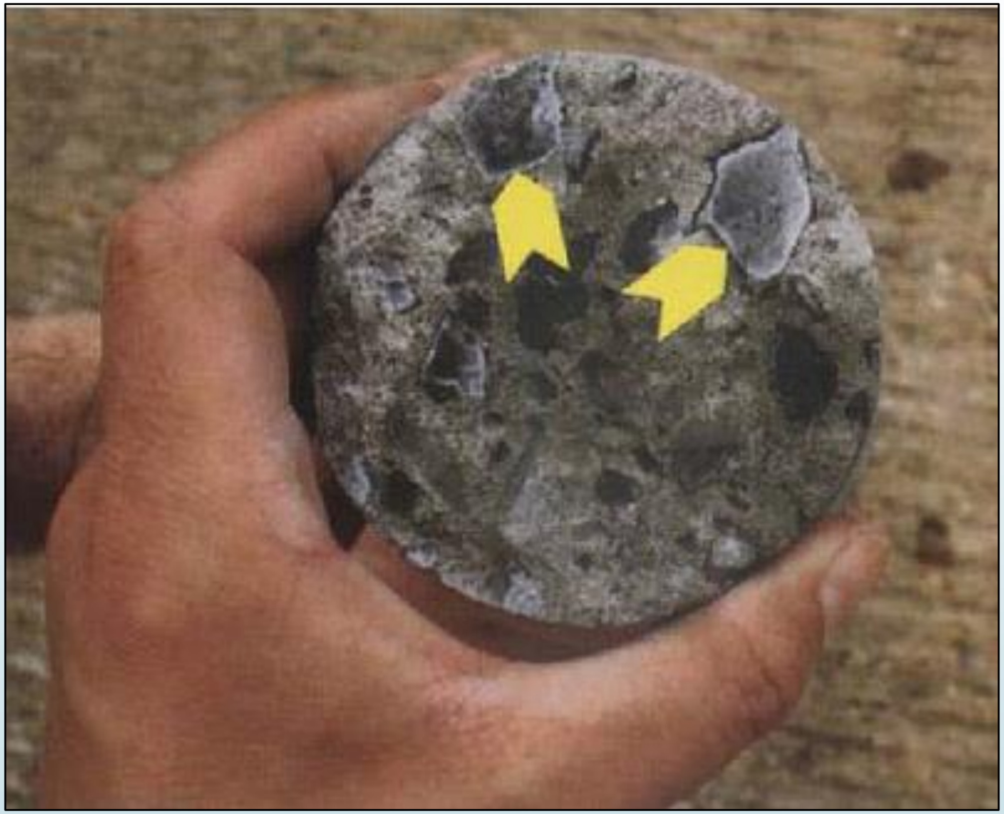
Alkali-Aggregate Reaction
I. Petrographic Analysis




- **Symptom 5:** Cracks within reactive aggregates, which extend sometimes in the cement paste, with/without reaction products gels.
- **Symptom 6:** Alkali-silica gel in voids of the cement paste.
- **Symptom 7:** Deposits of reaction products on the cracked surfaces of cores.

Alkali-Aggregate Reaction

I. Petrographic Analysis



- **Symptom 7: Deposits of reaction products on the cracked surfaces of cores.**

Alkali-Aggregate Reaction

II. Uranyl Acetate Fluorescence Method

Use of uranyl (uranium) acetate fluorescence method has been developed. This method can be used to monitor possible ASR prior to development of serious distress and to confirm ASR existence.

Alkali-Aggregate Reaction

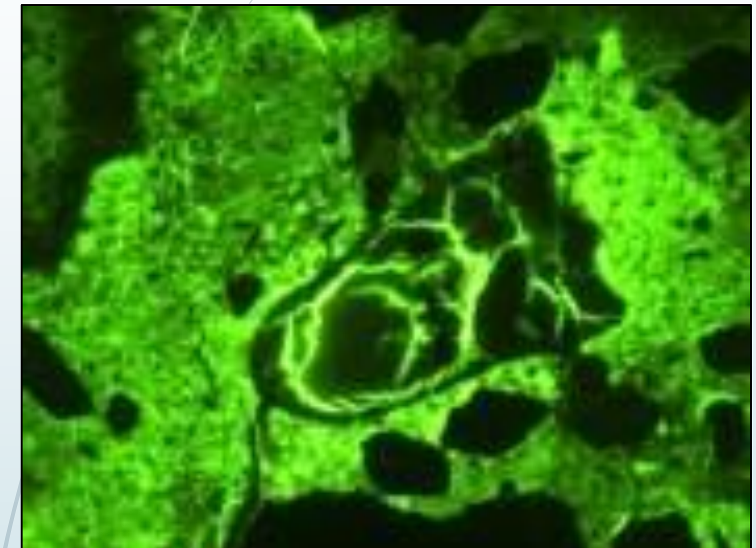
II. Uranyl Acetate Fluorescence Method

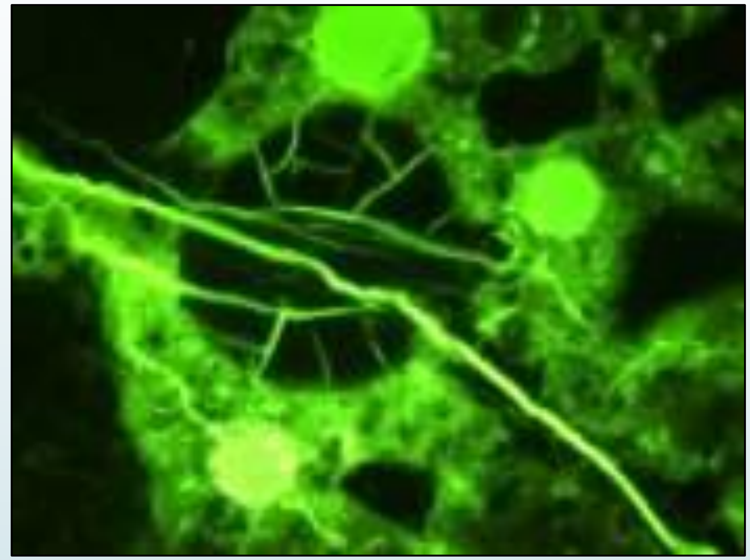
Principle and Method:

Alkali silica Reactivity is uniquely characterized by production of a gel-like reaction product. It is composed of essentially of silica, the alkalis (sodium and potassium), and calcium in the presence of water. Uptake of water by the gel is the primary factor determining volume changes associated with ASR. The gel may be present in large or minute amounts in aggregates, aggregate sockets, air voids, fractures, and on the surfaces of externally formed concretes. By application of uranyl acetate solution to a surface containing the gel, the uranyl ion substitutes for alkali in the gel, thereby imparting a characteristic yellowish-green glow when viewed in the dark using short wavelength (254 nanometer) ultraviolet light. ASR gel fluoresces much more brightly than the cement paste due to the greater concentration of alkali and, therefore, the uranyl ion in the gel.

Alkali-Aggregate Reaction

II. Uranyl Acetate Fluorescence Method

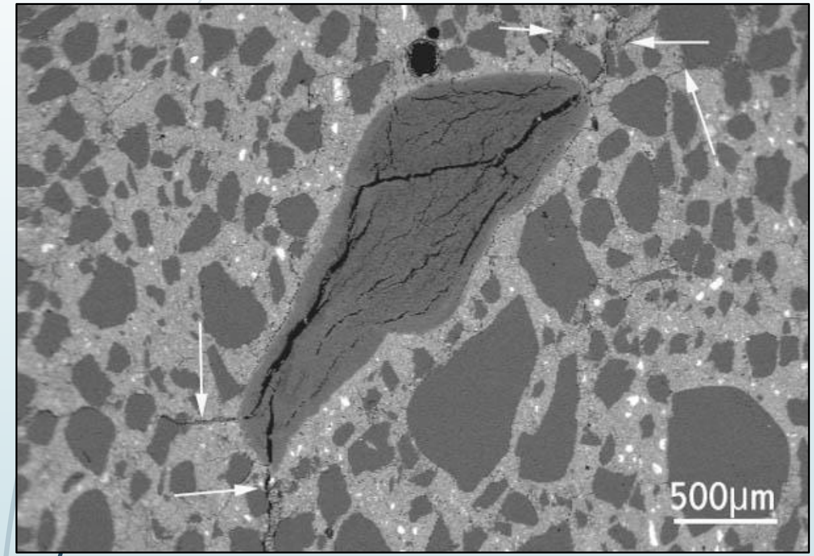


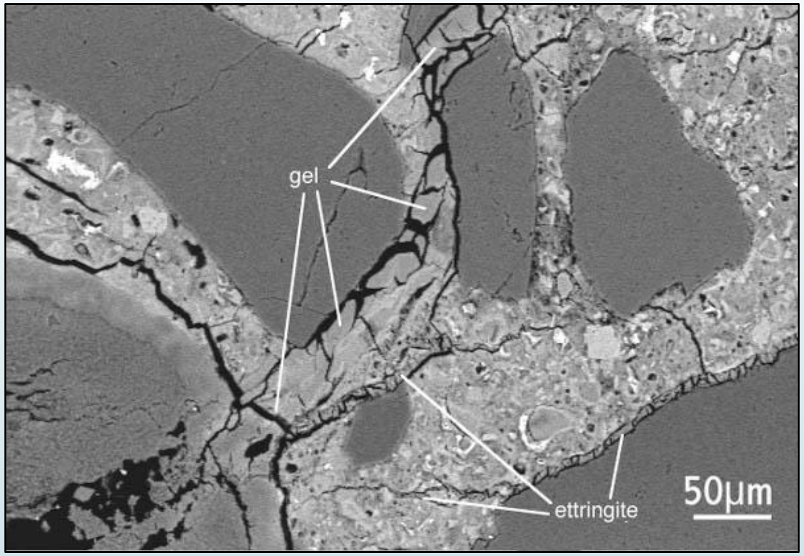


OBSERVATION: The presence of ASR gel will be revealed in UV light by a yellowish-green fluorescent glow. Deposits will be localized in cracks, air voids, certain aggregate particles and, in severe cases, as broad films in aggregate particles and fractured surfaces. Such films on sawed and cored surfaces may reflect as "smear" from sawing or cutting. Fractured surfaces eliminate this effect and most clearly reveal undisturbed ASR gel deposits.

Alkali-Aggregate Reaction

III. Observation under Petrographic Microscopes

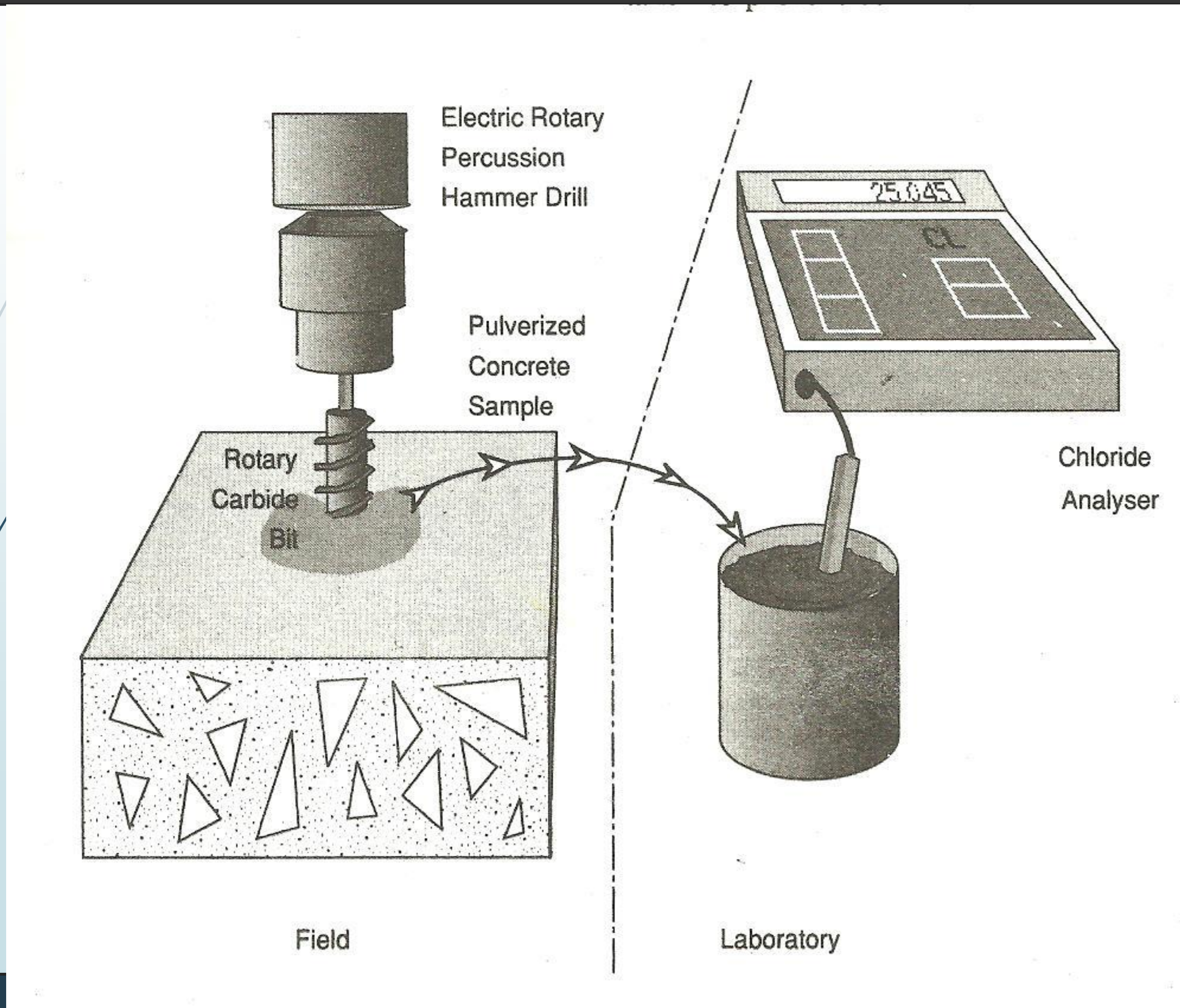




TESTING FOR CHEMICAL PROPERTIES

CHLORIDE CONTENT

Chloride Content Measurement



Chloride Content Measurement

It is done by taking a sample of concrete from the structure, either by drawing pulverized concrete using a rotary-percussion hammer (preferably electric), or by taking cores and then pulverizing the concrete in the laboratory.

At each level of sampling, the pulverized material is collected and stored in a clean container, the hole is vacuum cleaned, and the next sample is drawn at the next desired depth. Where deep holes are to be drilled, care must be taken to prevent contamination of the sample from the abrasion of the rotary drill bit against the side of the hole. Using a drill bit with a stepped-down bit diameter will reduce the chance of contamination. Powdered samples are analyzed using a wet chemical method.

The **Chloride Field Test System** measures the amount of chloride present in wet or dry concrete.

The **C-CL-2000** produces results on-site, within minutes that are accurate and comparable to expensive laboratory tests. It measures the electrochemical reaction of a weighted sample placed in an extraction liquid. It automatically shows a temperature compensated reading of percent of chlorides on its digital display. A wide range - from 0.002 to 2% chloride by weight - is covered.

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.

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

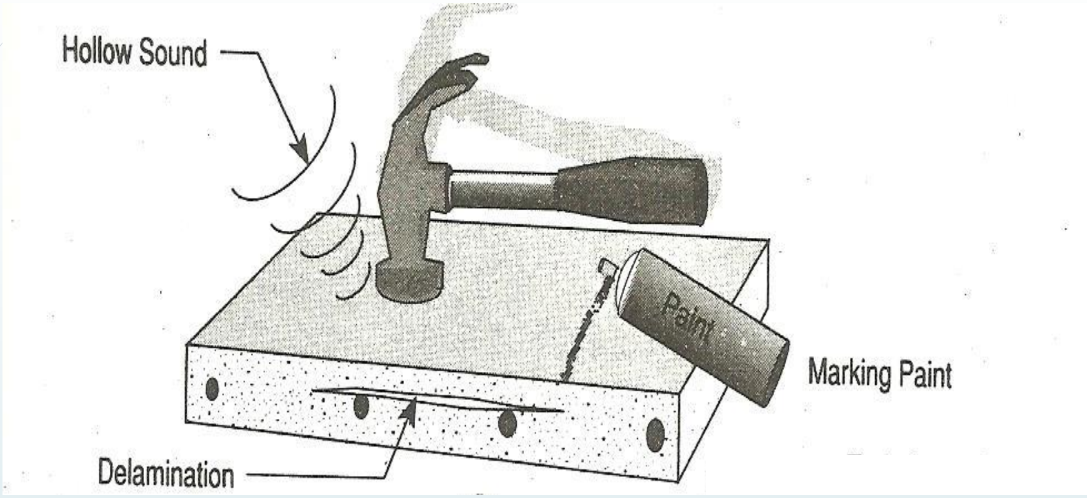
DELAMINATION / VOIDS DETECTION

TESTING METHODS:

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

DELAMINATION / VOIDS DETECTION

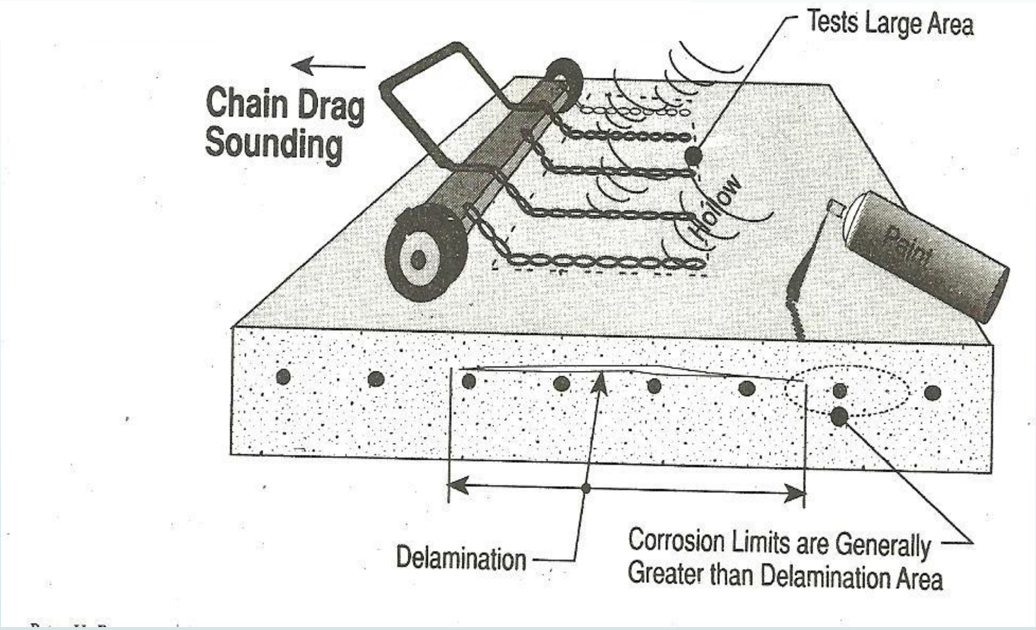
I. Hammer Sounding



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.

DELAMINATION / VOIDS DETECTION
II. Chain Drag Method

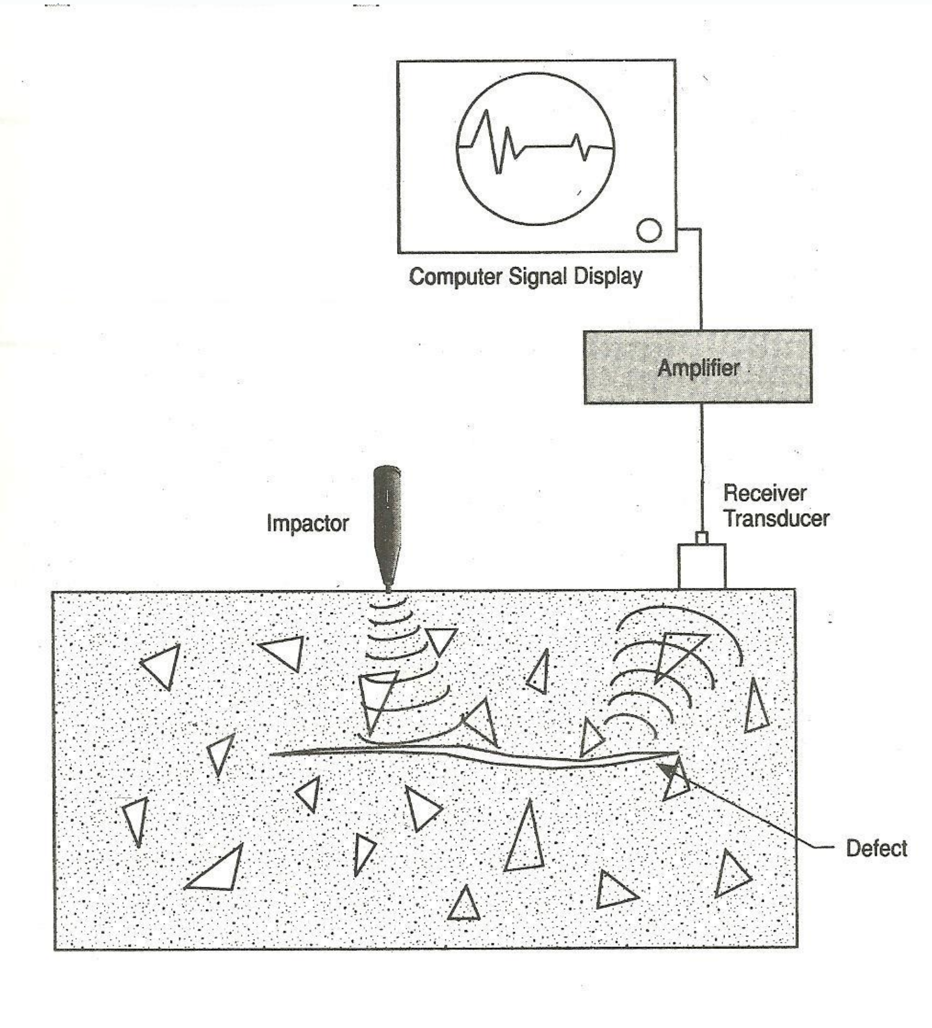


Same as hammer sounding method but covers a larger area. Distinctly different sound heard over delamination areas.

Dr. Akshay Naidu, Professor,
Civil Engineering, Methodist College of Engineering and Technology, Hyderabad – 500001

DELAMINATION / VOIDS DETECTION

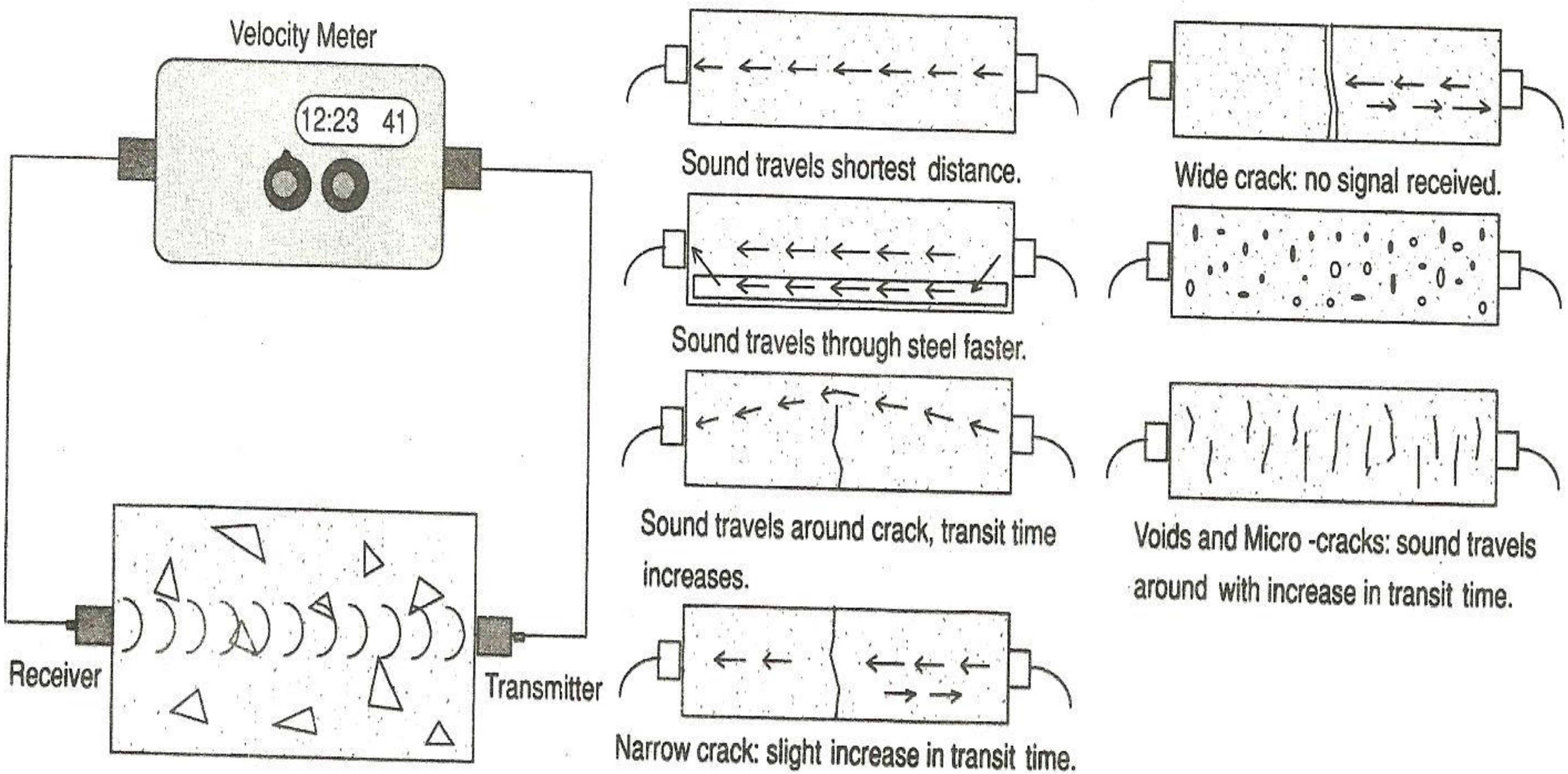
III. Impact Echo Method



The impact-echo technique works by impacting the concrete surface with a short duration stress pulse that is reflected from defects and external boundaries back to a receiver (transducer). The signals received are converted into a frequency spectrum and are displayed on a computer screen. Artificial intelligence software is used to analyze these signals, predicting the probability and depth of defects. The system works quickly, caking approximately two seconds to process each reading.

DELAMINATION / VOIDS DETECTION

IV. Ultrasonic Pulse Velocity Method



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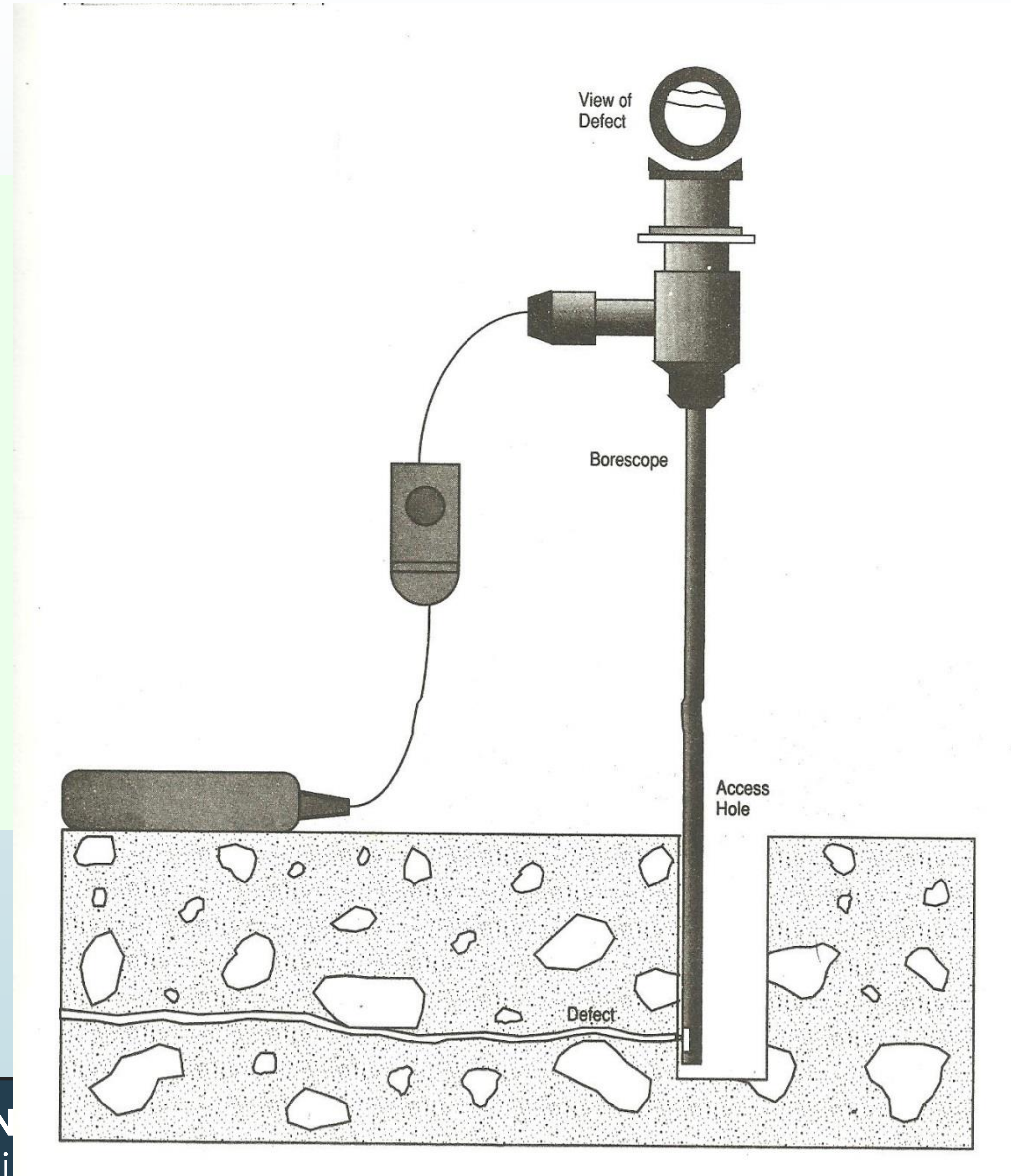
DELAMINATION / VOIDS DETECTION

VI. Remote Viewing

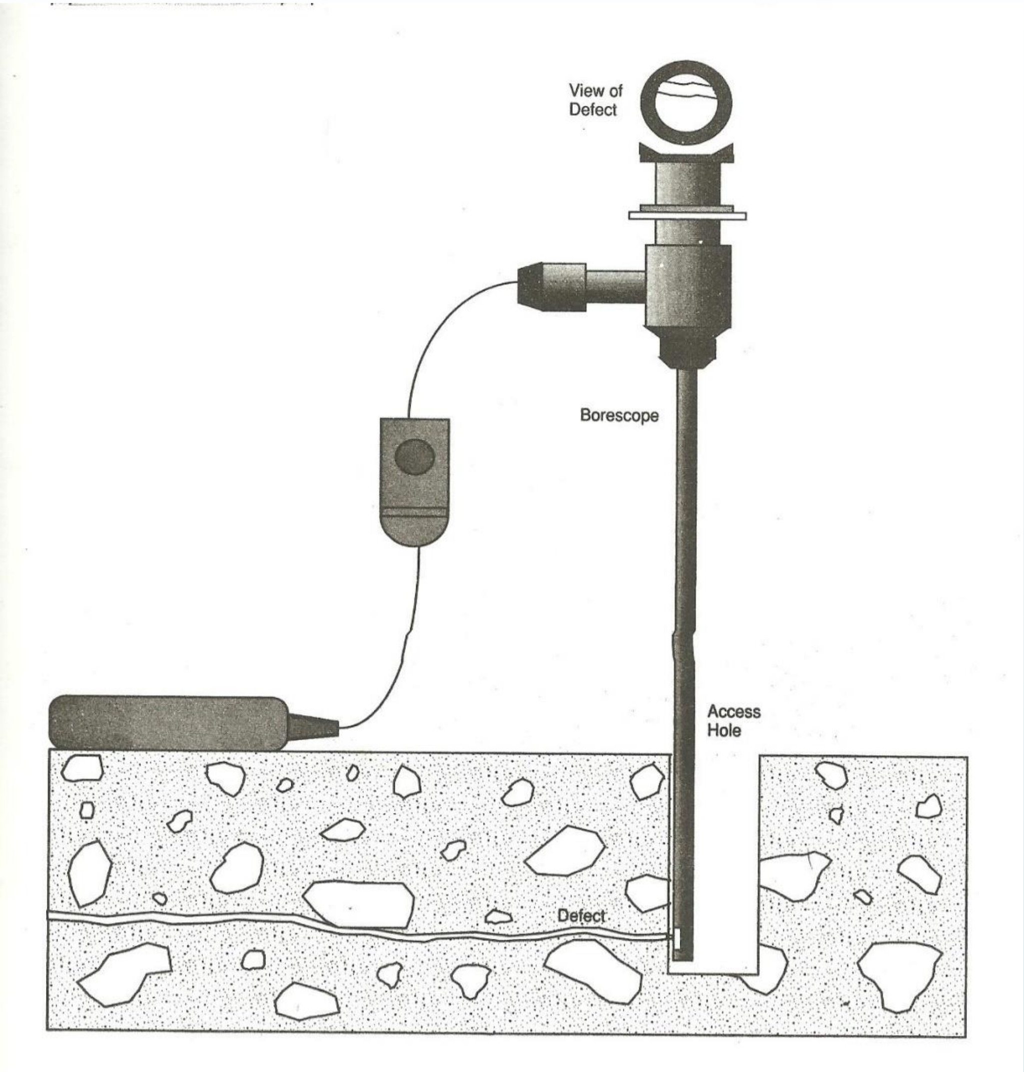
Since access to certain parts of structures may be limited, remote viewing may be the only way to inspect these areas. Fiber optics (borescope), video cameras, and periscopes are tools that allow for remote viewing. The fiber optics method utilizes a bundle of glass fibers that transmit light to the subject being viewed. Images are then transmitted back to a lens for viewing by eye or camera.



DELAMINATION / VOIDS DETECTION

VI. Remote Viewing

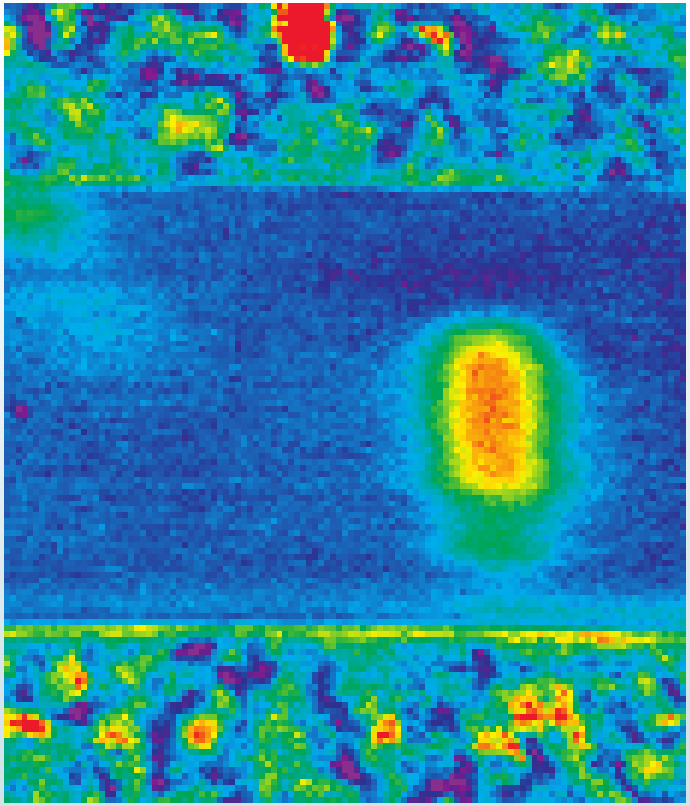
With this method, views are limited to small areas, since drilled holes can be as small as 1/2” (1.27 cm) for penetration of the bores- cope. Use of video cameras and periscopes requires larger drilled holes and provide a larger viewing area of the subject.



DELAMINATION / VOIDS DETECTION

VII. Infrared Thermography

IR thermography is a method for measuring the temperature distribution of a surface. It permits to detect regions of heat production (e.g. due to a crack under cyclic loading or a hot spot in a defective IC) or regions of inhomogeneous cooling (e.g. due to blisters or air voids in a pavement or under waterproof membranes). In the building phase of road constructions, IR thermography can be used to control the temperature of the single components.



DELAMINATION / VOIDS DETECTION
VII. Infrared Thermography

Principle

All objects above absolute zero temperature emit infrared radiation. (Humanly visible radiation only above about 500^{o}C).

Infrared monitoring equipment can detect infrared emission in the range between 2 and 14 microns.

[The 2-5.6 micron range is generally used to visualize temperatures between 40^{o}C and 2000^{o}C the 8-14 micron range is used for temperature between -20^{o}C and ambient temperatures.]

The thermograms taken with an infrared camera measure the temperature distribution at the surface of the object at the time of the test.

DELAMINATION / VOIDS DETECTION
VII. Infrared Thermography

Factors affecting temperature measurements

Since the infrared system measures surface temperatures only, the temperatures measured are influenced by three factors: (1) subsurface configuration, (2) surface condition; and (3) environment. As an NDT technique for inspecting concrete, the effect of the subsurface configuration is usually most interesting. All the information revealed by the infrared system relies on the principle that heat cannot be stopped from flowing from warmer to cooler areas, it can only be slowed down by the insulating effects of the material through which it is flowing. Various types of construction materials have different insulating abilities or thermal conductivities. In addition, differing types of concrete defects have different thermal conductivity values. For example, an air void has a lower thermal conductivity compared with the surrounding concrete. Hence the surface of a section of concrete containing an air void could be expected to have a slightly different temperature from a section of concrete without an air void.

DELAMINATION / VOIDS DETECTION
VII. Infrared Thermography

Factors affecting surface temperature measurements

SOLAR RADIATION: testing should be performed during times of the day or night when the solar radiation or lack of solar radiation would produce the most rapid heating or cooling of the concrete surface.

CLOUD COVER: clouds will reflect infrared radiation, thereby slowing the heat transfer process to the sky. Therefore, night-time testing should be performed during times of little or no cloud cover in order to allow the most efficient transfer of energy out of the concrete.

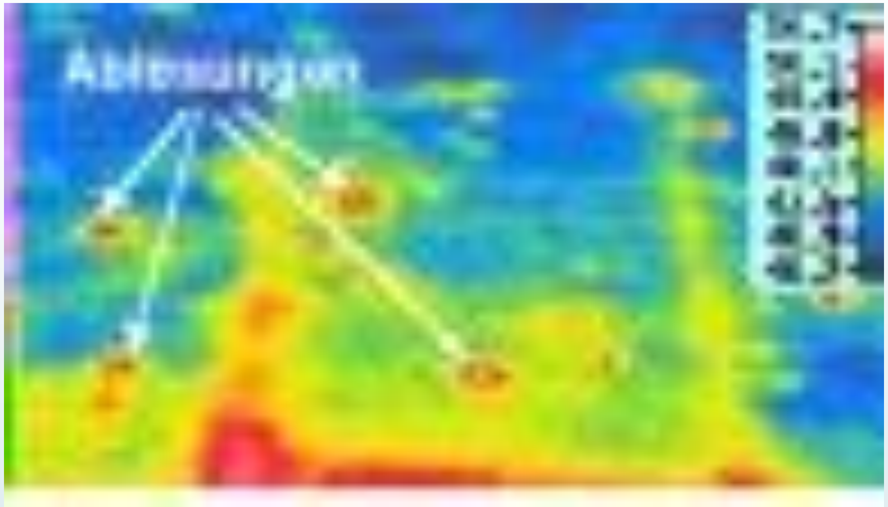
AMBIENT TEMPERATURE: This should have a negligible effect on the accuracy of the testing since one important consideration is the rapid heating or cooling of the concrete surface. This parameter will affect the length of time (i.e. the window) during which high contrast temperature measurements can be made. It is also important to consider if water is present. Testing while ground temperatures are less that $0^{o}C$ should be avoided since ice can form, thereby filling subsurface voids.

WIND SPEED: High gusts of wind have a definite cooling effect and reduce surface temperatures. Measurements should be taken at wind speeds of less than 15 mph (25 km/h).

SURFACE MOISTURE: Moisture tends to disperse the surface heat and mask the temperature differences and thus the subsurface anomalies. Tests should not be performed while the concrete surface is covered with standing water or snow.

DELAMINATION / VOIDS DETECTION

VII. Infrared Thermography



When flashes or a sine-modulated radiator heat an object, voids and debondings buried below the surface hinder the heat transfer. The resulting transient thermal contrast on the surface is made visible with pulse or lock-in thermography.

TESTING FOR PHYSICAL CONDITION

EMBEDDED METAL DETECTION AND EVALUATION

EMBEDDED METAL DETECTION

TESTING METHODS:

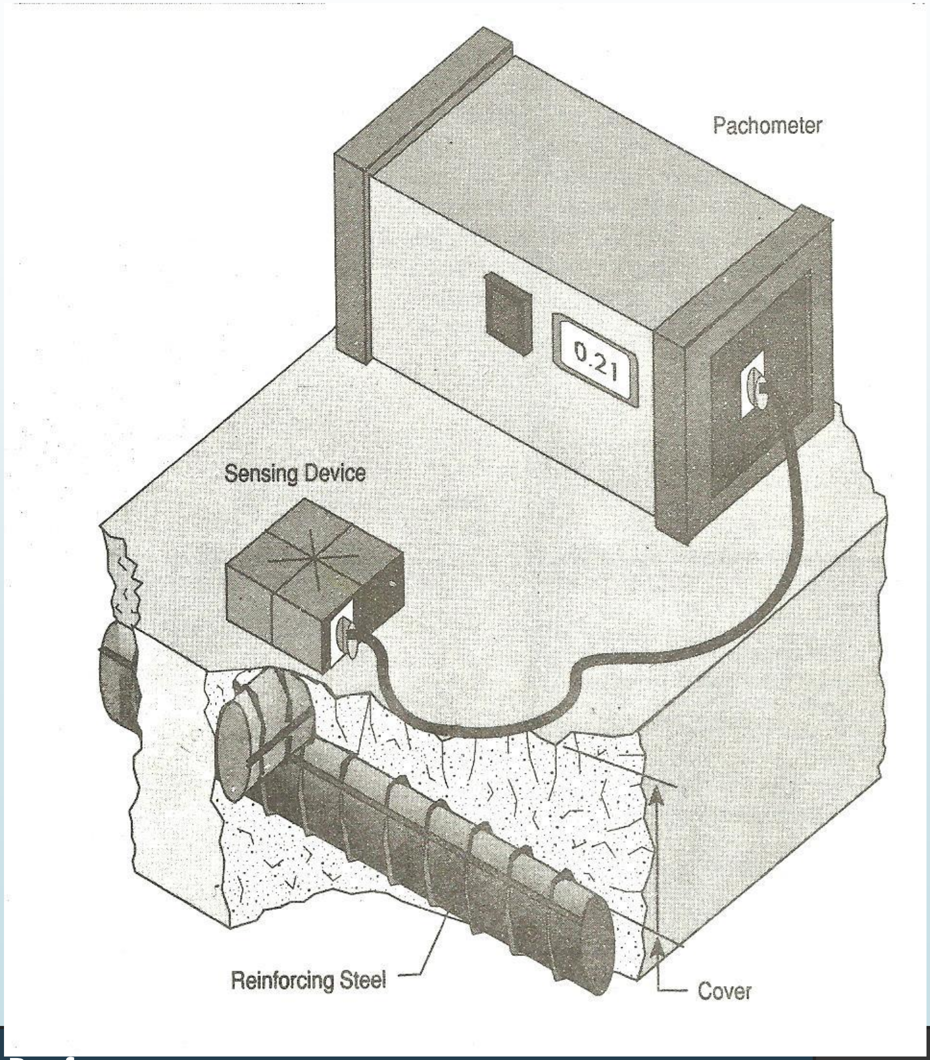
- Electromagnetic Methods (Pachometer)
- Radiography
- Ground Penetrating Radar
- Exploratory Removal

EMBEDDED METAL DETECTION
I. Pachometer

Magnetic devices, known as *pachometers* or *covermeters,* are used to determine the location of embedded steel reinforcement in concrete.

If the size of reinforcement is known, the amount of concrete cover can be determined. In general, these devices can measure cover within 1/4" (6 mm) at 0 to 3” (0 to 75 mm) from the surface.

The accuracy of the devices is dependent on the amount of reinforcing steel that is present in concrete. The more congested the reinforcing, including multiple layers, the less accurate the device becomes. In some cases, when other bars interferer, the device cannot identify either location or depth of cover.



TESTING FOR PHYSICAL CONDITION

AIR AND MOISTURE PENETRATION & PERMEABILITY

1) Initial Surface Absorption Test (ISAT)
2) Modified Figg's Permeability Test

PERMEABILITY TESTS

I. Initial Surface Absorption Test (ISAT)

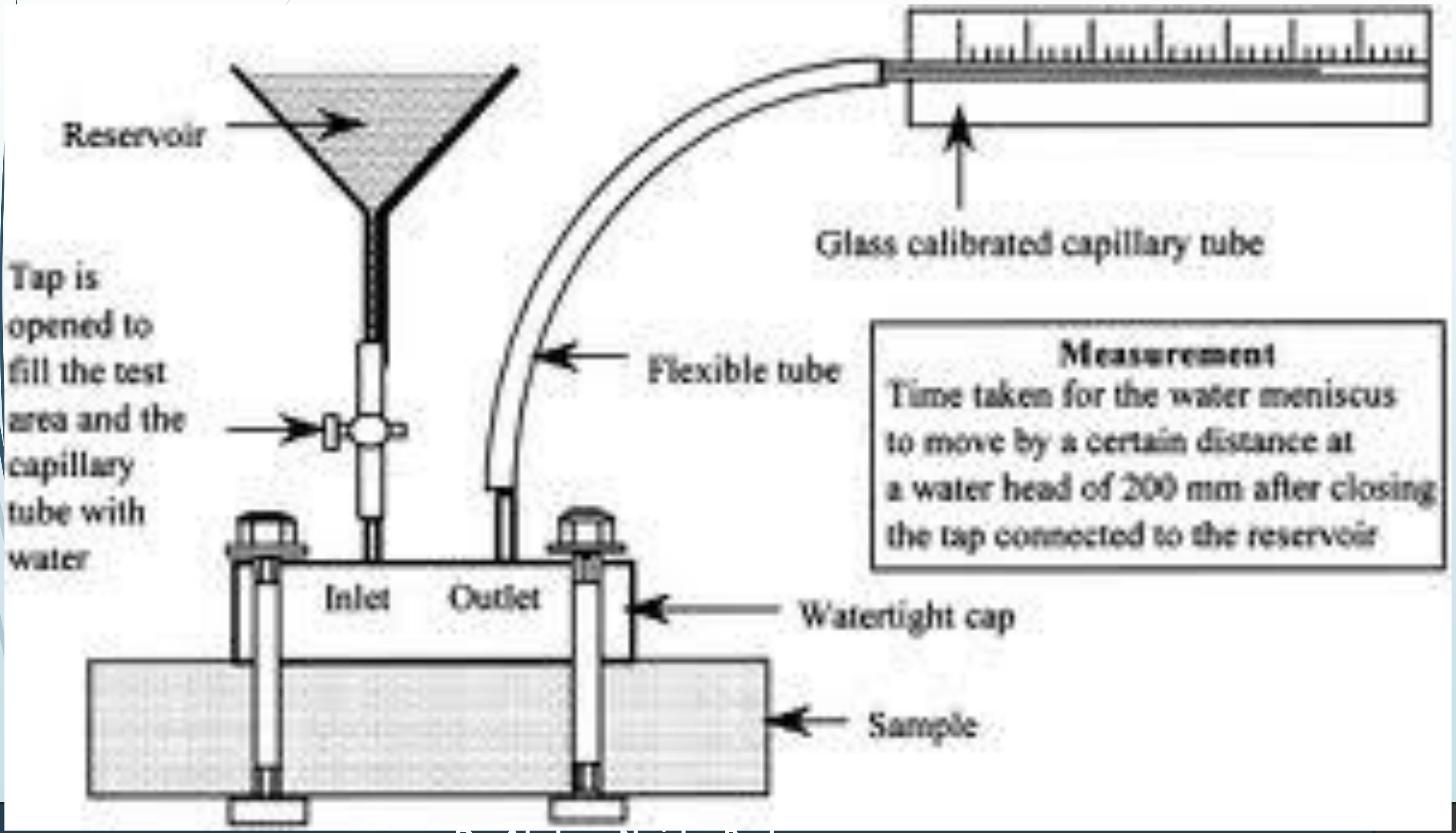
ISAT measures the ease of water penetration into the surface layer of the concrete (also called covercrete).

BS 1881:Part 5

In this method, a cup with a minimum surface area of 5000 mm is sealed to the concrete surface and filled with water. The rate at which water is absorbed into the concrete under a pressure head of 200 mm is measured by movement along a capillary tube attached to the cup. When water comes into contact with dry concrete it is absorbed by capillary action initially at a high rate but at a decreasing rate as the water filled length of the capillary increases. This is the basis of initial surface absorption, which is defined as the rate of water flow into concrete per unit area at a stated interval from the start of test at a constant applied head at room temperature.

PERMEABILITY TESTS

I. Initial Surface Absorption Test (ISAT)



PERMEABILITY TESTS

I. Initial Surface Absorption Test (ISAT)

Levitt has given the following relation:

$$P = a / t^{n}$$

where 'P' is the initial surface absorption, 't' is the time from the start, 'a' is a constant and 'n' is a parameter between 0.3 and 0.7 depending on the degree of silting or flushing mechanisms, but constant for a given specimen.

PERMEABILITY TESTS

II. Modified Figg's Permeability Test

The test can be used to determine the rate of water as well as air penetration into the surface layer of the concrete.

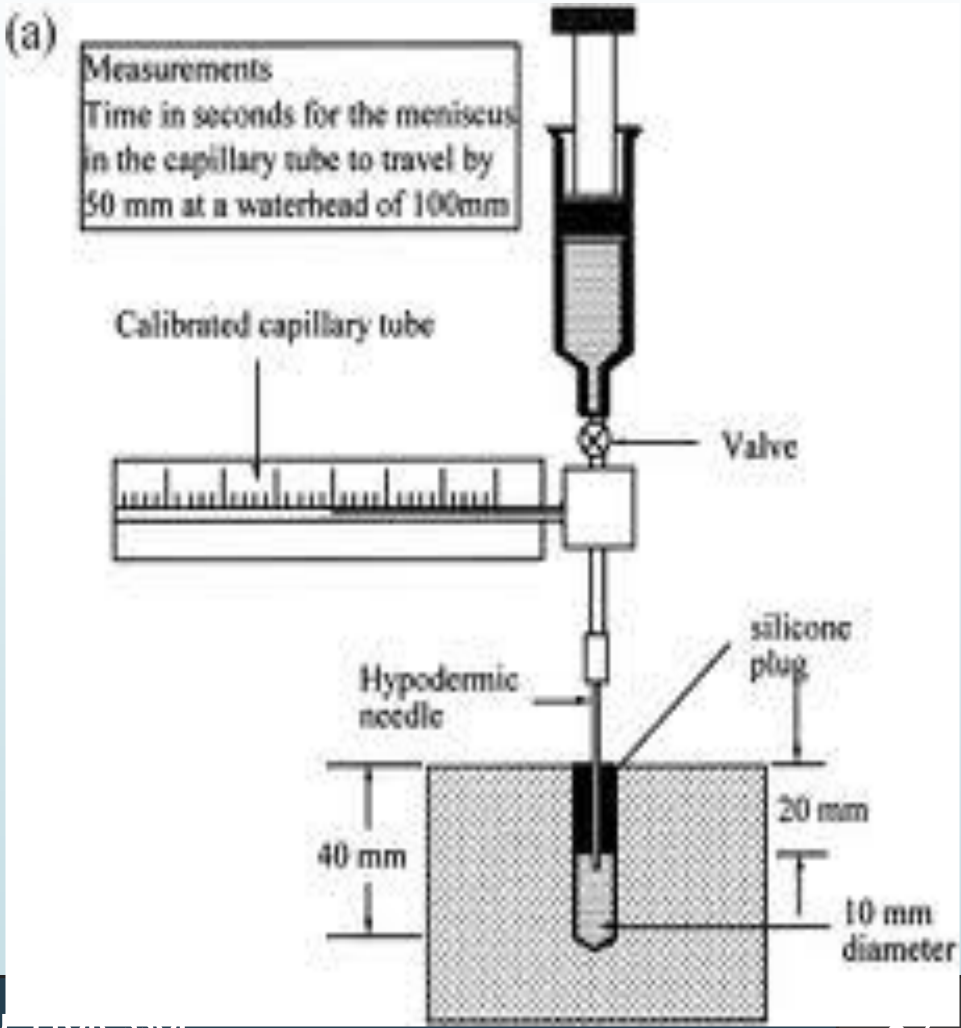
A hole of 10 mm diameter is drilled 40 mm deep normal to the concrete surface. A plug is inserted into this hole to form an airtight cavity in the concrete.

In the air permeability test, the pressure in the cavity is reduced to –55 kPa using a hand operated vacuum pump and the pump is isolated. The time for the air to permeate through the concrete to increase the cavity pressure to –50 kPa is noted and taken as the measure of the air permeability of the concrete.

PERMEABILITY TESTS

II. Modified Figg's Permeability Test

Water permeability is measured at a head of 100 mm with a very fine cannula passing through a hypodermic needle to touch the base of the cavity. A two-way connector is used to connect this to a syringe and to a horizontal capillary tube set 100 mm above the base of the cavity. Water is injected through the syringe to replace all the air and after one minute the syringe is isolated with a water meniscus in a suitable position. The time for the meniscus to move 50 mm is taken as a measure of the water permeability of the concrete.



TESTING FOR PHYSICAL CONDITION

HYDRATION CHARACTERISTICS OF HARDENED CONCRETE

(A) X-ray diffractrometry (XRD)

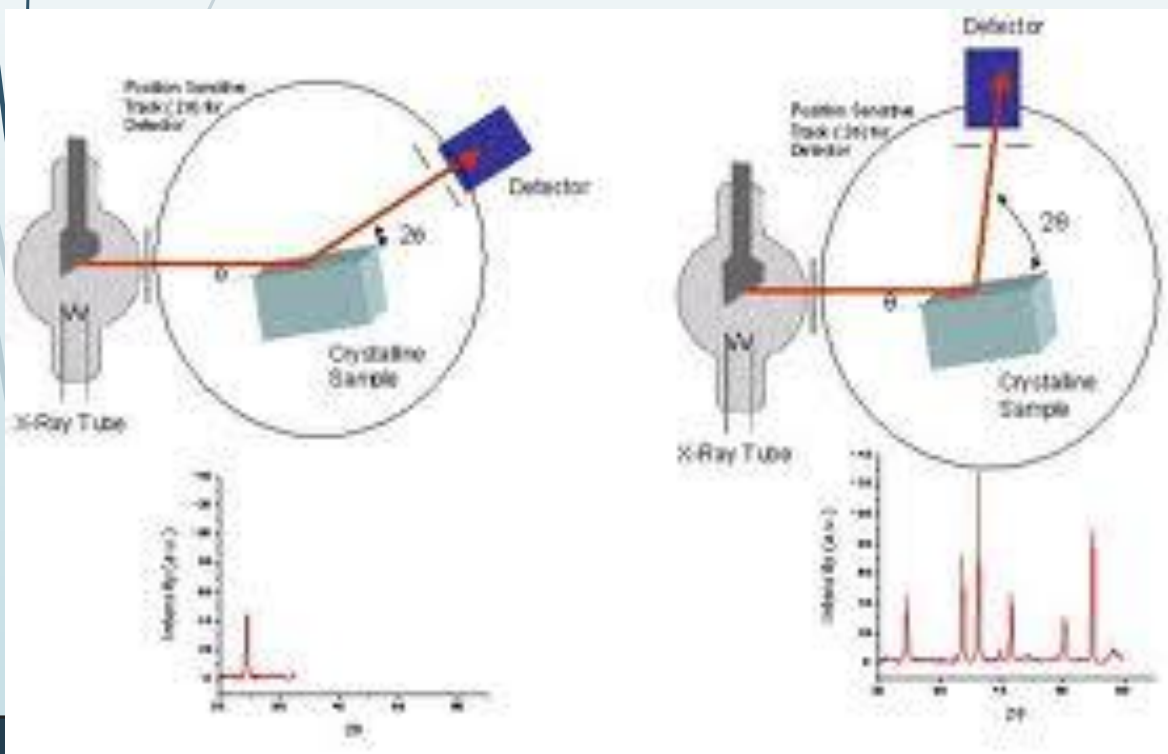
(B) X-ray fluorescence spectroscopy (XRF)

(C) Differential Thermal Analysis (DTA)

HYDRATION CHARACTERISTICS

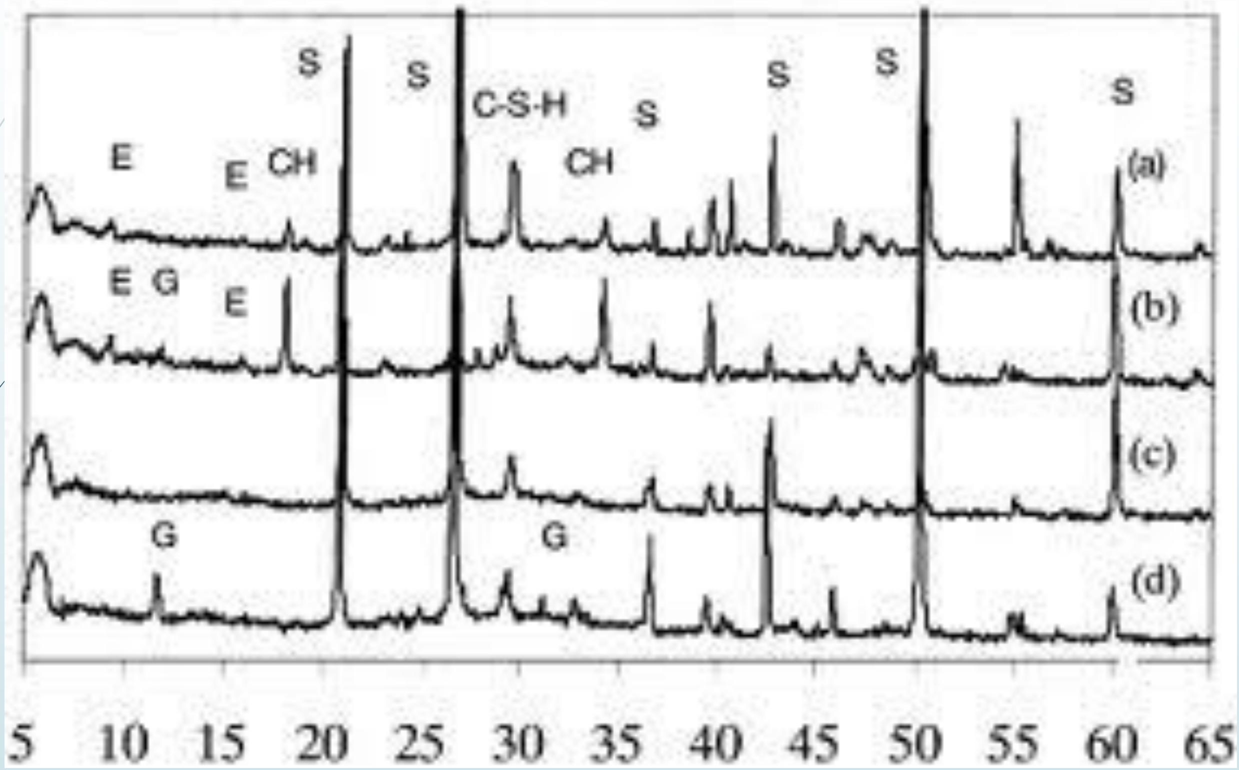
I. X-ray Diffractrometry (XRD)

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

NDT FOR CONCRETE

SUMMARY

NDT SUMMARY

What are you looking for? → **What test should you adopt?**

Compressive Strength

- Core testing (Semi-destructive test)
- Windsor probe test (Semi-destructive test)
- Schmidt (Swiss) Rebound hammer (Non- Destructive Test)
- Pull-out test
  - LOK Test
  - CAPO Test
  - NA pull out test
- Ultrasonic Pulse Velocity (Non- Destructive Test)

Tensile Strength	Pull off test, Splitting tensile test
Flexural Strength	Centre-point & third-point load test
Bond Strength	Pull off testing

Corrosion of reinforcement

- Half-Cell Potential Method (NDT)
- Electrical Resistivity (4 probe resistivity test)
- Surface Potential Technique (NDT)
- Polarization Resistance
- Electrochemical Noise Analysis

Carbonation Depth Measurement

- Acid-base indicators (Phenolphthalein Solution)
- Petrographic Analysis (Semi-destructive test)
- X-ray diffraction test (Semi- Destructive Test)
- Infrared Thermography

Alkali-Aggregate Reaction

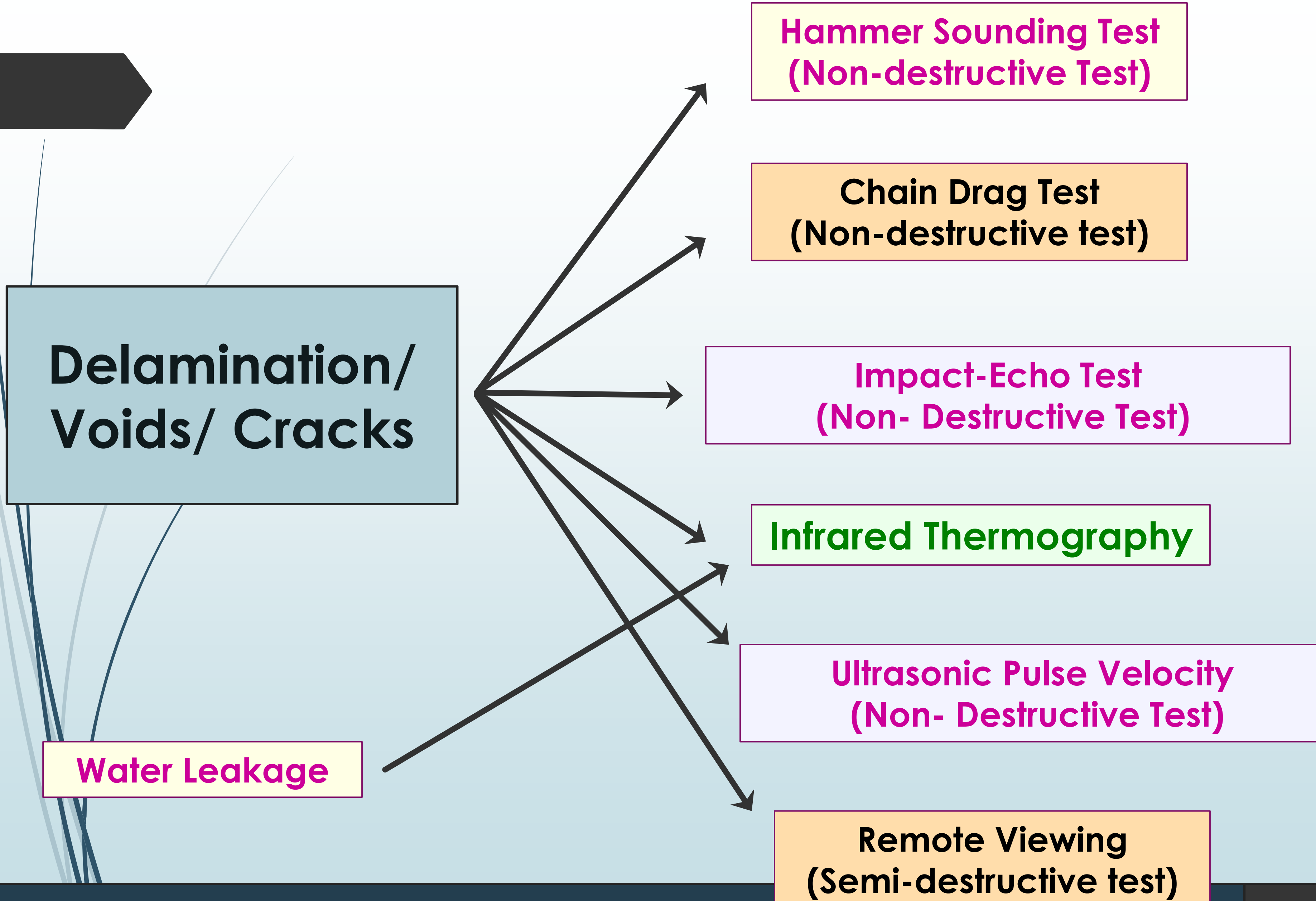
- **Petrographic Analysis (Semi-destructive test)**
- **Uranyl Acetate Fluorescence Method**

Chloride Content

- **Chlorimeter (Quantab Method)**

Concrete Uniformity

- Core testing (Semi-destructive test)
- Windsor probe test (Semi-destructive test)
- Schmidt (Swiss) Rebound hammer (Non- Destructive Test)
- Petrographic Analysis (semi-destructive test)
- Ultrasonic Pulse Velocity (Non- Destructive Test)


Delamination/ Voids/ Cracks
Hammer Sounding Test (Non-destructive Test)
Chain Drag Test (Non-destructive test)
Impact-Echo Test (Non- Destructive Test)
Infrared Thermography
Ultrasonic Pulse Velocity (Non- Destructive Test)
Remote Viewing (Semi-destructive test)
Water Leakage

Embedded Metal Detection

- Pachometer or Covermeter (Non-destructive test)
- Radiography (Non-destructive test)
- Ground Penetrating Radar (Non- Destructive Test)