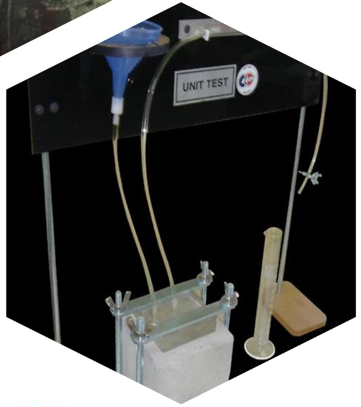
ASSESSMENT METHODS

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Research interest: sustainable waste material, concrete technology, Lightweight concrete, green concrete, **Concrete durability**, sustainable development, sustainable energy production, Geopolymer concrete, Building Information Modelling (BIM).

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What test that you used to check corrosion of steel reinforcement and deterioration of concrete?

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Assessment

Strength
- Assessment on concrete strength

Integrity
- Determination of localised integrity or generalised assessment of behaviour of whole structure.

Durability
- Identifying nature & extent of observed or suspected deterioration including reinforcement corrosion.

Assessment

Strength

- Coring
- Windsor Probe
- Pull-Out
- Pull-Off

Integrity

- Rebound Hammer
- Ultrasonic Pulse Velocity
- Thermography
- Radiography

Durability

- Carbonation
- Chloride content
- Sulphate content

Corrosion

- Measurement of steel reinforcement corrosion in concrete is essential to analyze the strength and durability of a structure.
- Steel corrosion reduce the life span of the structure but also increases the cost for inspection and maintenance significantly.
- Currently, no instrument or technique is available which can measure the extent of corrosion of steel.
- However, measurement of concrete properties, such as resistivity and half-cell potential of concrete can assess the probability of corrosion of reinforcing steel.

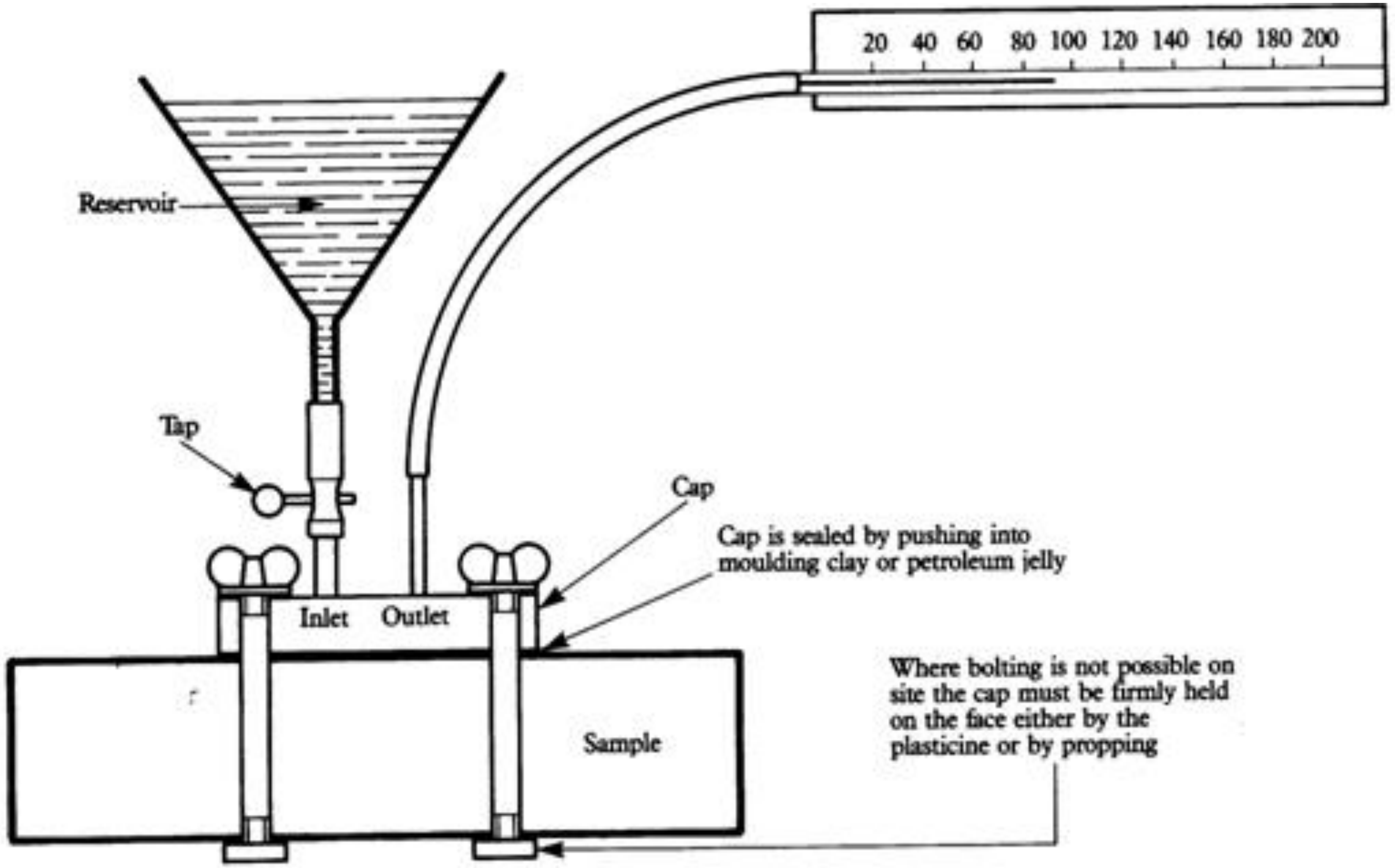
Basis for Corrosion Measurement

- ions penetrate into concrete through pores which render concrete to act as an electrolyte.
- As electrons move in concrete, an electrical potential field inside concrete over steel bars is generated.
- The majority of corrosion measurement techniques are based on examining the electrochemical condition of the rebar-concrete interface.
- This examination is generally conducted from the surface of concrete.
- Different techniques have been developed and used for measurement of steel corrosion, for instance- Resistivity meter and Half-cell potential.

Initial Surface Absorption Test (ISAT)

- Involves measurement of rate of flow of water per unit area into a concrete surface when subjected to a constant head of 200mm.
- A watertight cap is sealed to the concrete surface to provide water contact of at least 5000mm^2 & connected to a reservoir & calibrated horizontal capillary tube & scale.
- At specified intervals from start of test, the tap between cap & reservoir is closed & movement of water in capillary is measured.
- The test method is covered by BS 1881-208.

Initial Surface Absorption Test (ISAT)

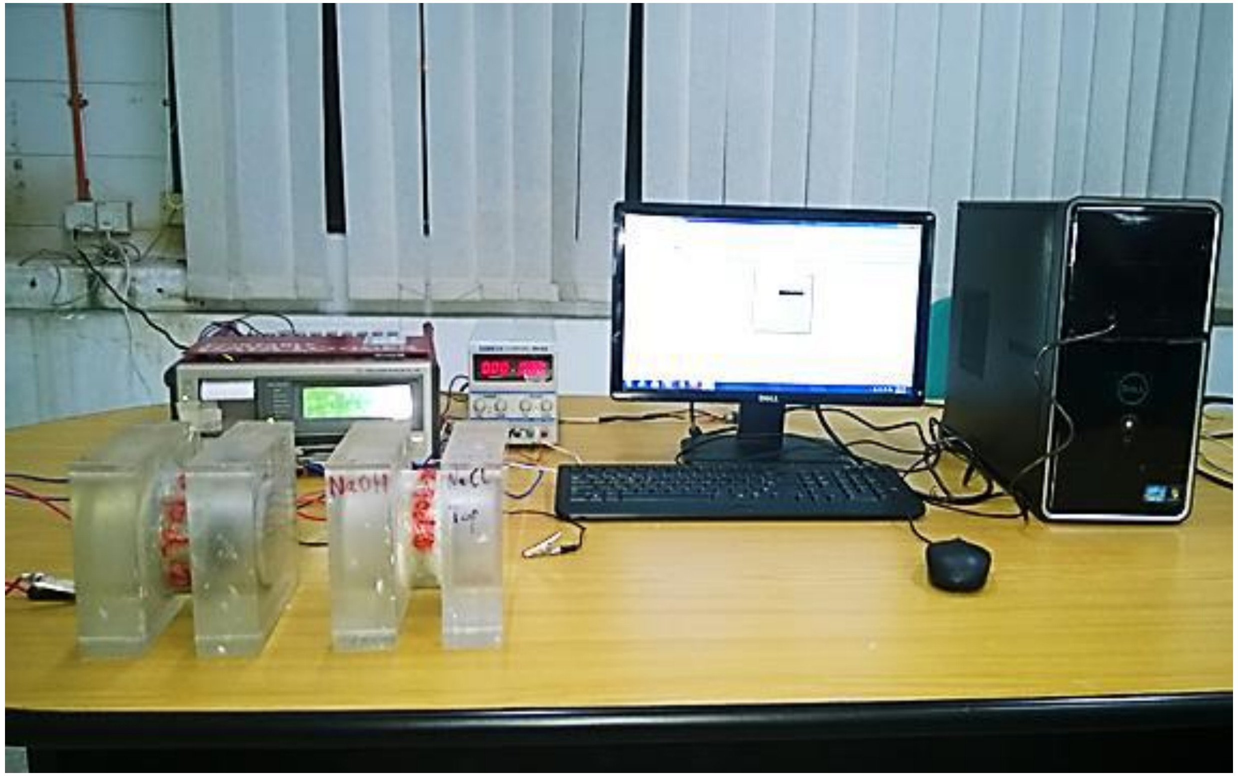


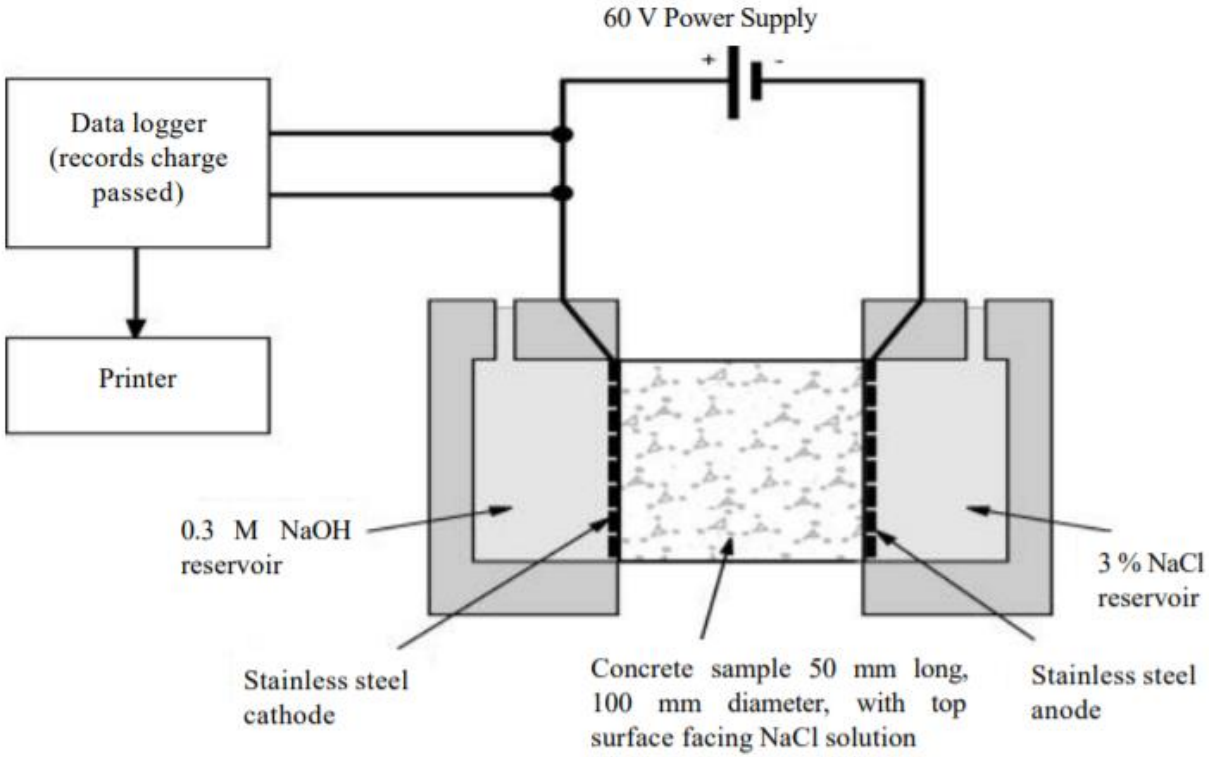
Procedure

Rapid Chloride Penetration Test (RCPT)

- Indication as concrete ability to resist chloride ion penetration.
- Accordance with ASTM C1202 (2012) to determine the chloride ions charge.
- Carried out on saturated surfaced diameter of 100 × 50 mm cylindrical.
- The cell that was connected to the positive terminal of the power supply was filled with 0.3 N sodium hydroxide (NaOH) solution.
- The cell that was connected to the negative terminal was filled with 3% sodium chloride (NaCl) solution.
- subjected to a 60 V applied DC voltage for 6 hours and the current reading was recorded every 30 minutes using data logger.

Rapid Chloride Penetration Test (RCPT)





RCPT Ratings

Charge Passed (coulombs)	Chloride Ion Penetrability	Typical concrete type **(Joshi and Chan, 2002)**
>4,000	High	High w/c ratio (>0.6) conventional OPC concrete
2,000 – 4,000	Moderate	Moderate w/c ratio (0.4-0.5) conventional OPC concrete
1,000 – 2,000	Low	Low w/c ratio (<0.4) conventional OPC concrete
100 – 1,000	Very Low	Latex-modified concrete, internally sealed concrete
<100	Negligible	Polymer-impregnated concrete, polymer concrete

ASTM C1202

Rapid Chloride Penetration Test (RCPT)

Advantages	Disadvantages
• Is relatively quick—can be used for quality control • Has simple and convenient setup and procedures • Provides results that are easy to interpret • Correlates well with 90-day chloride ponding test	• May not represent the true permeability (or potential permeability) for concrete that contains supplementary cementitious materials or chemical admixtures • May allow measurements before a steady state is achieved • Can cause physical and chemical changes in the specimen, resulting in unrealistic values • May not be suitable for concretes that contain conducting materials (such as steel or carbon fibers) • Has low inherent repeatability and reproducibility

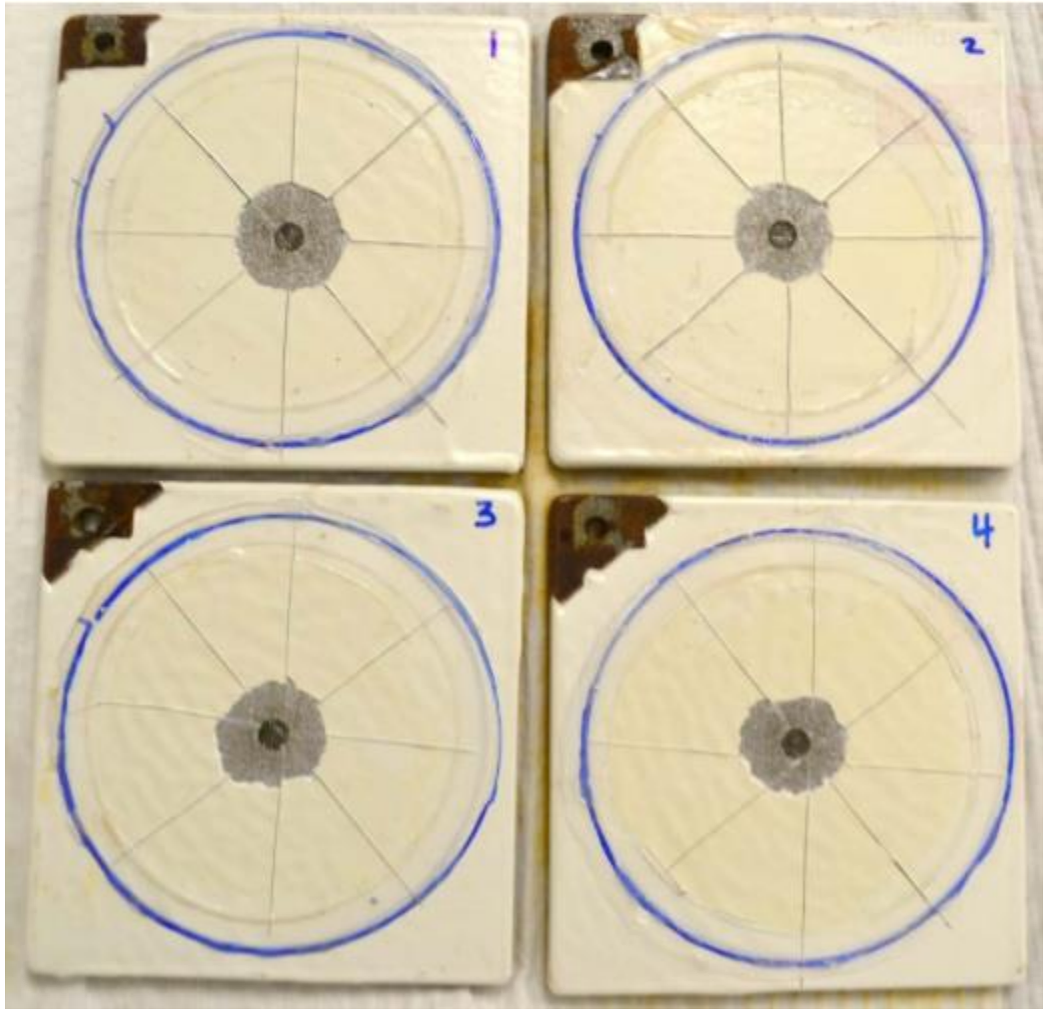
Cathodic Protection

- Cathodic protection is fundamental to preserving a pipeline's integrity.
- Cathodic protection is a method of corrosion control that is achieved by supplying an external direct current that neutralizes the natural corrosion current arising on the pipeline at coating defects.
- A simple method of protection connects the metal to be protected to a more easily corroded "sacrificial metal" to act as the anode.

Cathodic Protection

- Current required to protect a pipeline is dependent on the environment and the number and size of the coating defects.
- Clearly, in a particular environment, the greater the number and size of coating defects, the greater the amount of current required for protection.
- Coating plays an integral part in the functioning of a pipeline's cathodic protection system. Where a coating system has badly deteriorated, cathodic protection requirements and costs can increase exponentially.

Cathodic Disbondment Testing (CDT)



Procedure

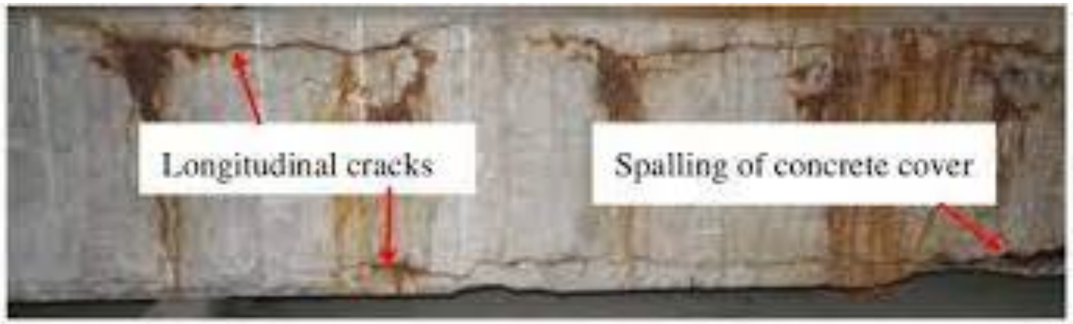
Testing for Reinforcement Corrosion

- Reinforcement corrosion may lead to structural weakening due to :

  -loss of steel cross-section (bars or strands);

  -cracking & spalling;

  -internal delamination (concrete fracture plane occurs at the level of the corroding steel mesh).



Testing for Reinforcement Corrosion

- To identify the risk of corrosion (not apparent at the surface);
- To identify the extent of corrosion (partially observable at the surface);
- To assess the integrity of a structure which may have experienced corrosion.

Theory of Corrosion

- Steel reinforcement bars are protected by alkaline environment (passivity) provided by the pore fluid in hardened concrete.
- Corrosion starts when passivation is broken down by carbonation or ingress of chlorides.
- Corrosion is either localized or generalized form (generalized form is most disruptive due to expansion of rusting steel.

Half-Cell Potential

- Half Cell corrosion mapping is an effective method for assessing the severity of corrosion activity in concrete structures.
- Most well-known procedure to identify the likelihood of active corrosion
- The test does not provide any information about the kinetics of corrosion activity.
- Easy and cost-effective procedure of the test makes it popular among engineers and structure inspectors.

Half-Cell Potential

- Involves measuring the potential of an embedded reinforcement bar relative to a reference half-cell placed on the concrete surface.
- The difference in potential between concrete surface and steel is a good indicator of current flow.
- The electrochemical process produces an electric current, which is measurable as an electric field on the surface of the concrete.
- Copper/Copper Sulphate or Silver/Silver Chloride cells are typically used (See TRRL Application Guide 9 (1991) for guidance)
- Several standard associations have standardized the test procedure including the ASTM C 876, UNI 10174 and RILEM TC 154.

Half-Cell Potential

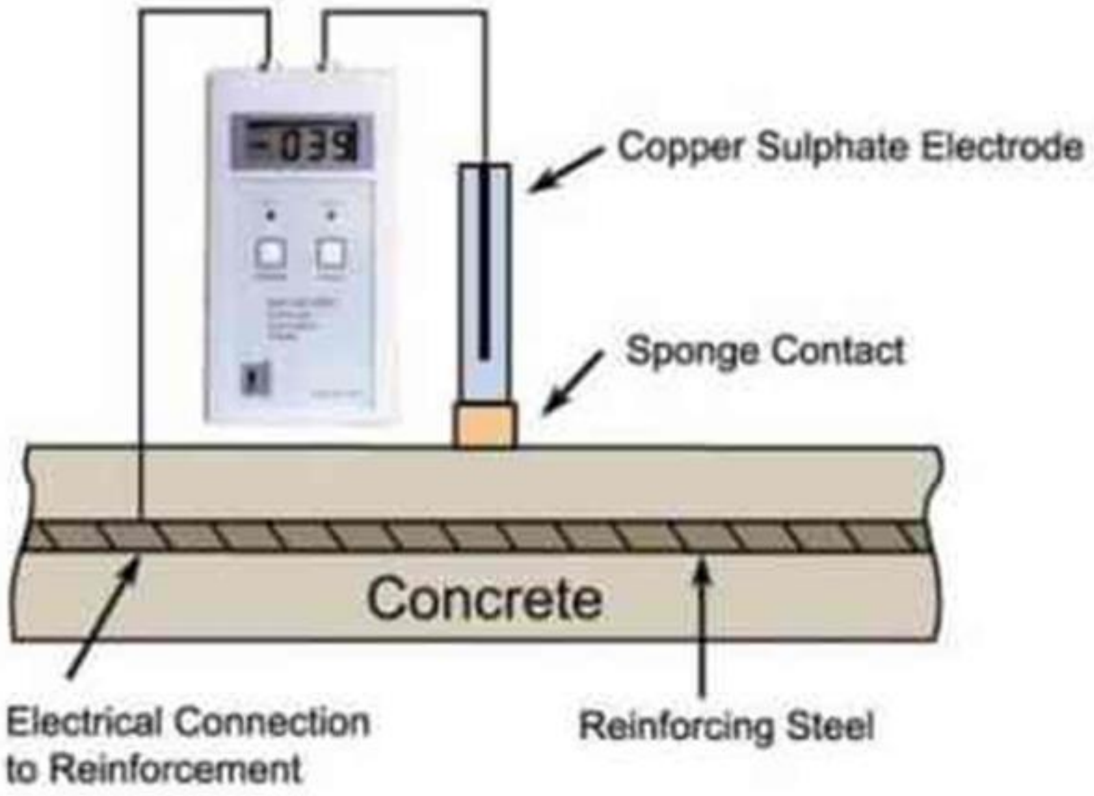
Potential Value	Possible Corrosion Rate
<= -0.20 V	90% probability of no corrosion
-0.20 to -0.35 V	Corrosion activity uncertain
> -0.35 V	more than 90% probability of corrosion

Value of Hall-cell Potential Test Versus the possible Rate of Corrosion of Steel bars in Concrete

Half-Cell Potential

- Simple equipment enables NDT survey to produce iso-potential contour maps of the surface of concrete member.
- Zones of varying degrees of corrosion risk may be identified from these ‘maps’.
- Half-cell method cannot indicate actual corrosion rate.
- Drilled hole may be needed to make electrical contact with the reinforcement bar.
- The positive terminal of the voltmeter is connected to exposed rebars and the negative terminal (common) to reference half-cell.

Half-Cell Potential

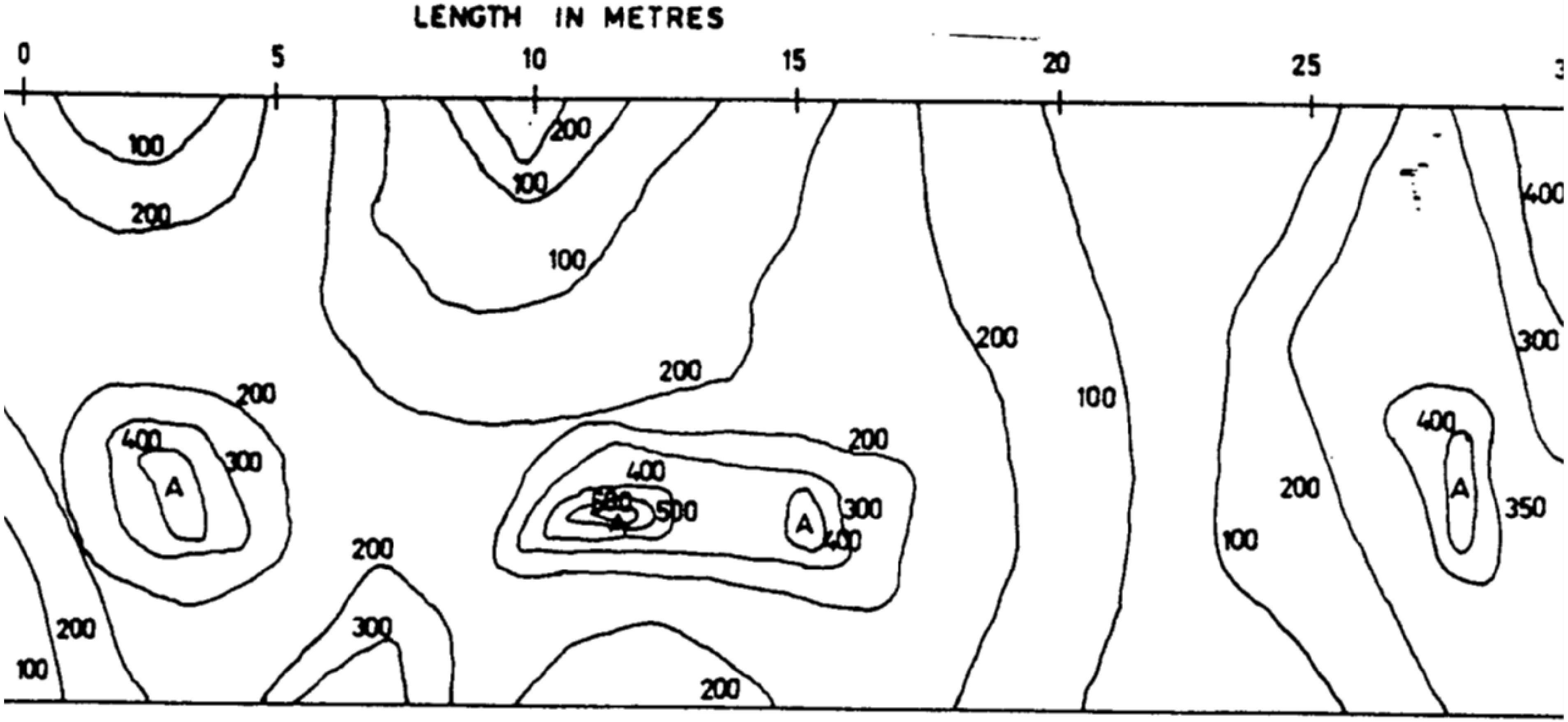


Procedure

1. Measurement Point
2. Rebar Connection / Connectivity Test
3. Electrical Connection to Voltmeter
4. Pre-wetting the surface
5. Perform Measurement

ASTM C876

Equipotential Contours



Influencing Parameters

- Electrical resistivity of concrete
- Density of concrete
  - (dense concrete versus porous concrete)
- Cover thickness
- Epoxy coatings
- Oxygen Availability
- Environmental conditions
  - (such as moisture and humidity)

"The higher the electrical resistivity is, the less accurate the half-cell potential measurements from the concrete surface will be."

"A decrease in oxygen concentration at the surface of the steel reinforcement will result in a more negative corrosion potential reading."

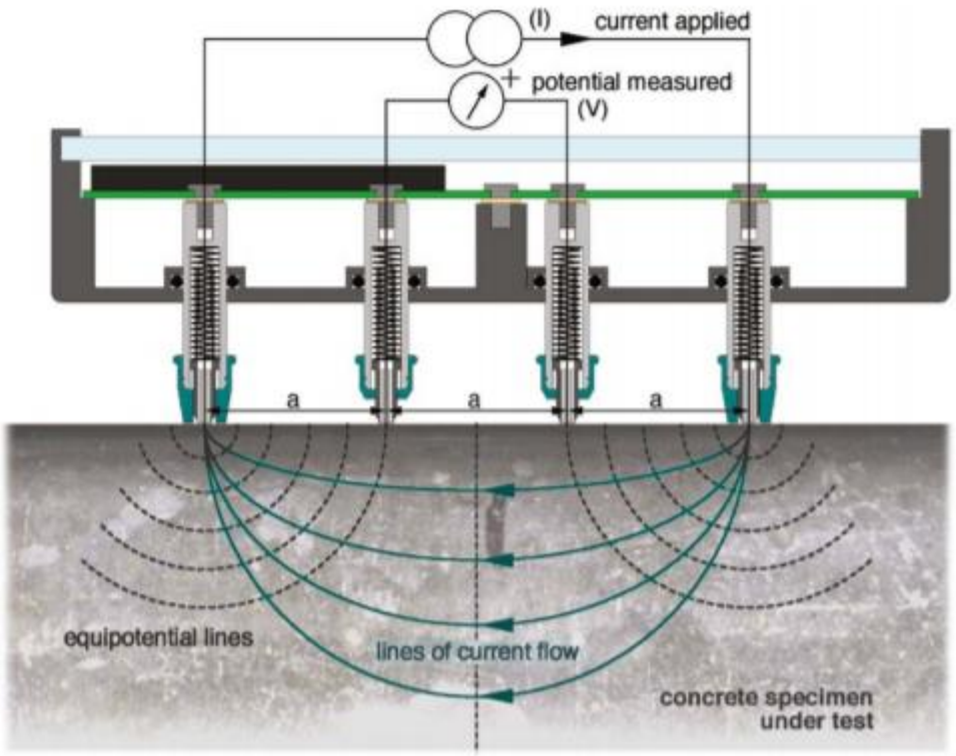
Resistivity Meter

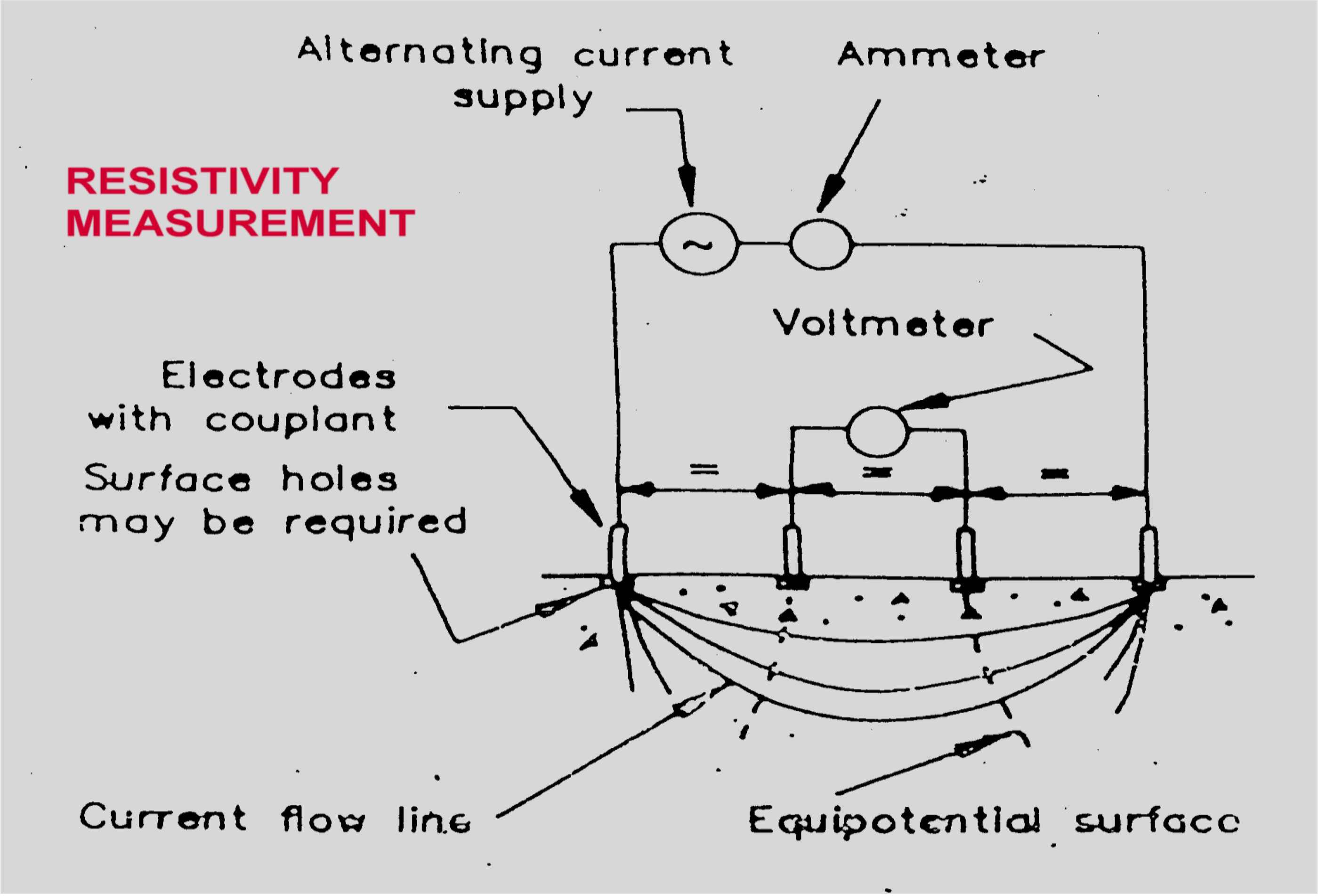
- The corrosion of steel in concrete is an electrochemical process that generates a flow of current.
- The resistivity of the concrete influences the flow of this current.
- The lower the electric resistance, the more easily corrosion current flows through the concrete and the greater is the probability of corrosion.
- The resistivity of concrete is a good indication of the probability of corrosion.
- Resistivity meter can be used to assess the probability of corrosion of steel reinforcement embedded in concrete.
- It is a very simple technique and can be adopted easily in the field.

Resistivity Meter

- Resistivity meter is very handy and portable equipment. The concrete resistivity is displayed on an LCD.
- Available with non-volatile memory and colored graphic display from which data can be transferred on PC.
- To measure the resistivity, metallic probes are placed over the concrete surface. A known current is passed on the outer probes and resulting potential drop between inner probes is measured.
- The resistance is computed by dividing the potential drop by the current.
- A conductive gel is used between probe and concrete surface to make effective contact.

Resistivity Measurement





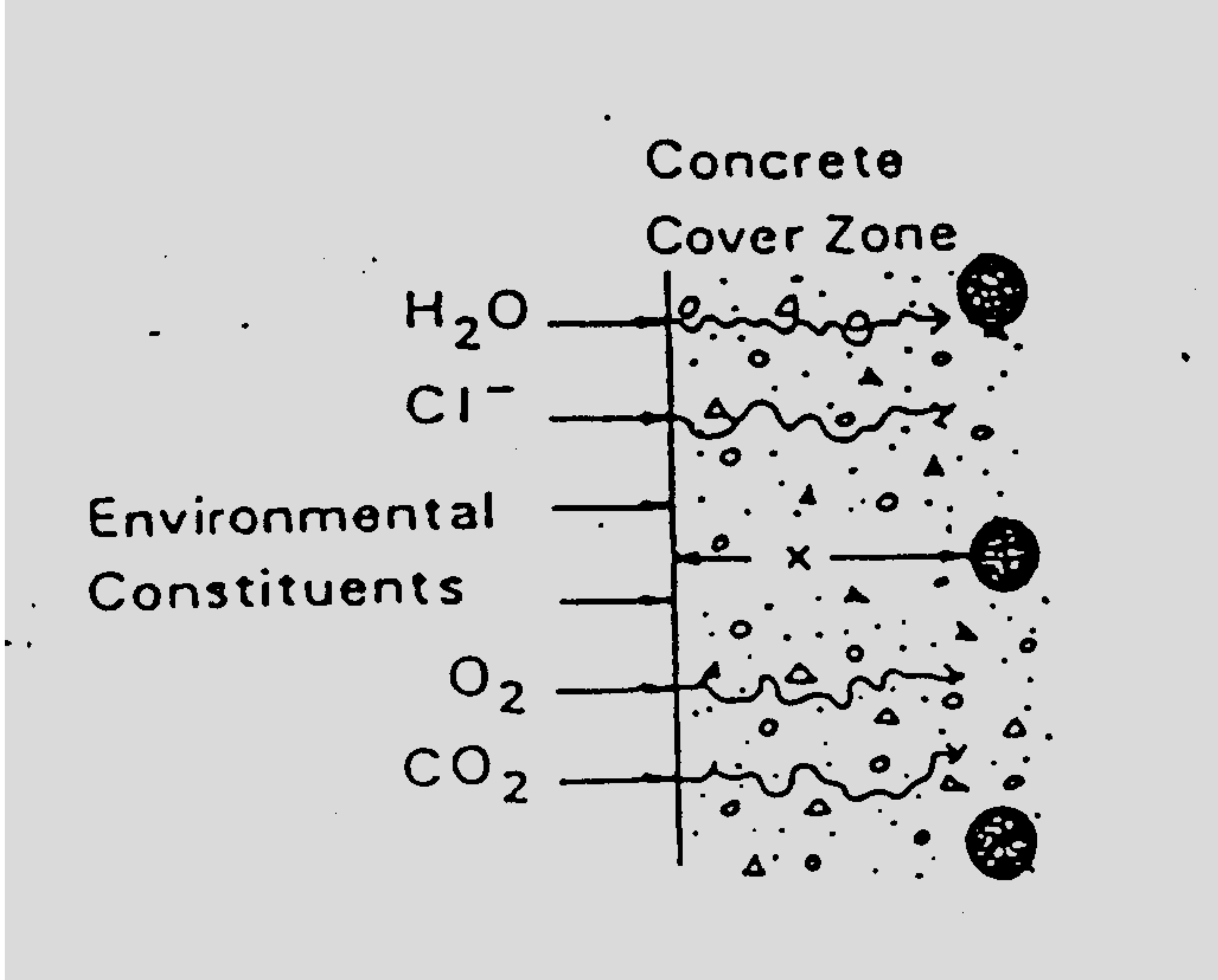
Resistivity Meter

Resistivity Meter

Concrete Resistivity (ohm/cm)	Rate of Corrosion
>20,000	Negligible
10,000 –20,000	Low
5,000 –10,000	High
< 5,000	Very High

Resistivity Level Versus Possible Corrosion Rate of Steel Reinforcements in Concrete

Carbonation & Chloride Attack



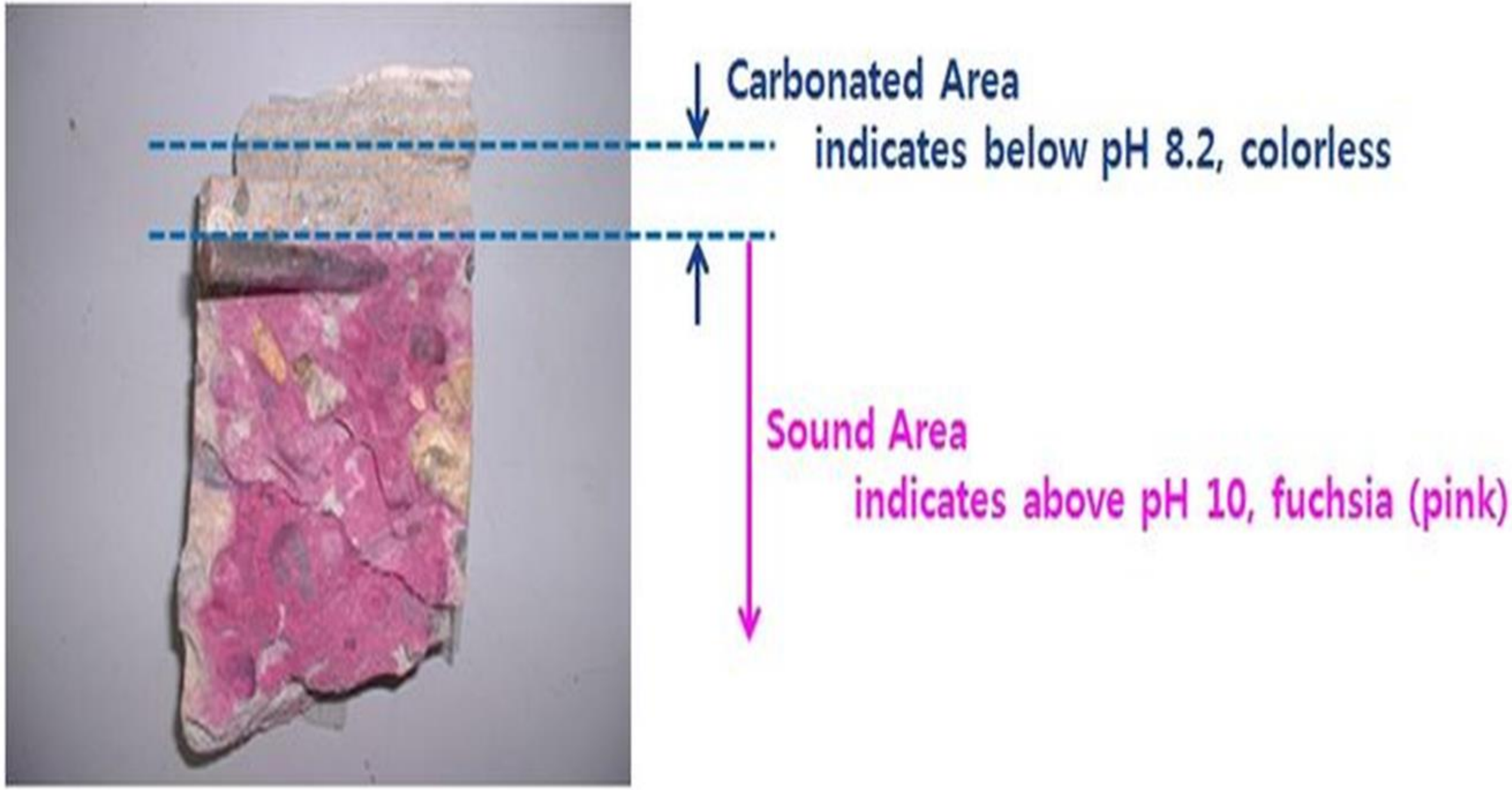
Carbonation

- Carbonation is the effect of CO_2 in the air on Portland Cement products, mainly $Ca(OH)_2$, in the presence of moisture.
- If concrete is of good quality (dense & impermeable), further ingress of CO_2 is prevented.
- In poor quality concrete, carbonation will not be halted at the surface but will proceed through the depth, resulting in lowering of pH from 11.5 to 9 or less.

Carbonation Depth

- The loss of alkalinity associated with carbonation of surface concrete may be detected by the use of phenolphthalein sprayed onto a freshly exposed or broken surface.
- A quick & simple approach which gives a visual indication of the position of the depassivation front relative to the steel.
- Test may also be conducted on core samples.
- Solution turns pink where ph > 9.

Carbonation Test



Chloride Attack

- Apart from being used in admixtures, chloride ions may be introduced into concrete by other means :
  - Diffusion into mature concrete;
  - Accidental inclusion as contaminants in aggregates;
  - Penetration by de-icing slats, industrial brines, marine spray, fog etc.

Chloride Ion Penetration

- May be identified by chemical analysis of powdered drillings obtained from various depths below the concrete surface.

- Simple site tests (Hach & Quantab) are useful in providing preliminary results to establish the need for more sophisticated laboratory methods.

- Results expressed in terms of % chloride ion by weight of cement (0.35% is critical). Initial results by weight of concrete may be OK except for borderline cases.

- Detailed chemical analysis provided by BS1881 Part 124 (1988) and Concrete Society TR 32(1989).

Portable Chloride Test Kit

Chloride Profile Grinder

Chloride Categorization

- Categorization applies to chlorides which were present in the original concrete mix.

a)'Low' –with chloride ion content of up to 0.4% by weight of cement

b)'Medium' –from 0.4% to 1%

c)'High' –above 1%

- Lower limits may apply if chloride has penetrated from outside the hardened concrete

BRE Digest 264 Guide for Chloride Categorization

Chloride Categorization

- When cement content values are not known, the chloride content is expressed in terms of weight of chloride by weight of concrete.

a)Up to 0.02% : level insignificant

b)Up to 0.05% : chlorides unlikely to have been added to the mix, low risk category.

c)0.05% -0.15% : medium risk category.

d)Above 0.15% : high risk category.

BRE Digest 264 Guide for Chloride Categorization

Sulphate Attack

The formation of ettringite (calcium aluminate trisulfate), resulting in an increase in solid volume, leading to expansion and cracking:

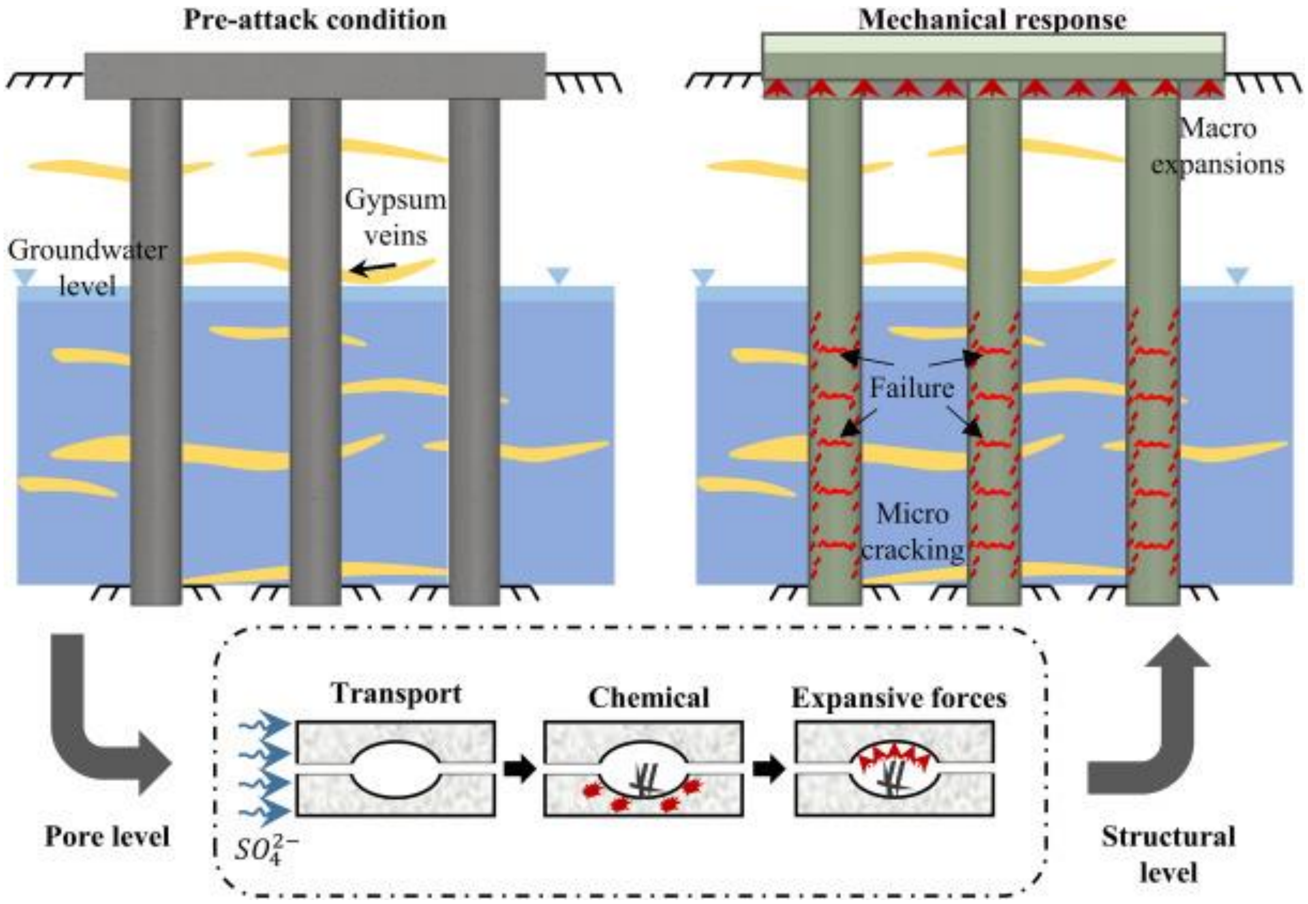
$$2(3CaO.Al_2O_3.12H_2O+3(Na_2SO_4.10H_2O)\Rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O+2Al(OH)_3+6NaOH+17H_2O$$

The formation of gypsum (calcium sulfate dihydrate), leading to softening and loss of concrete strength:

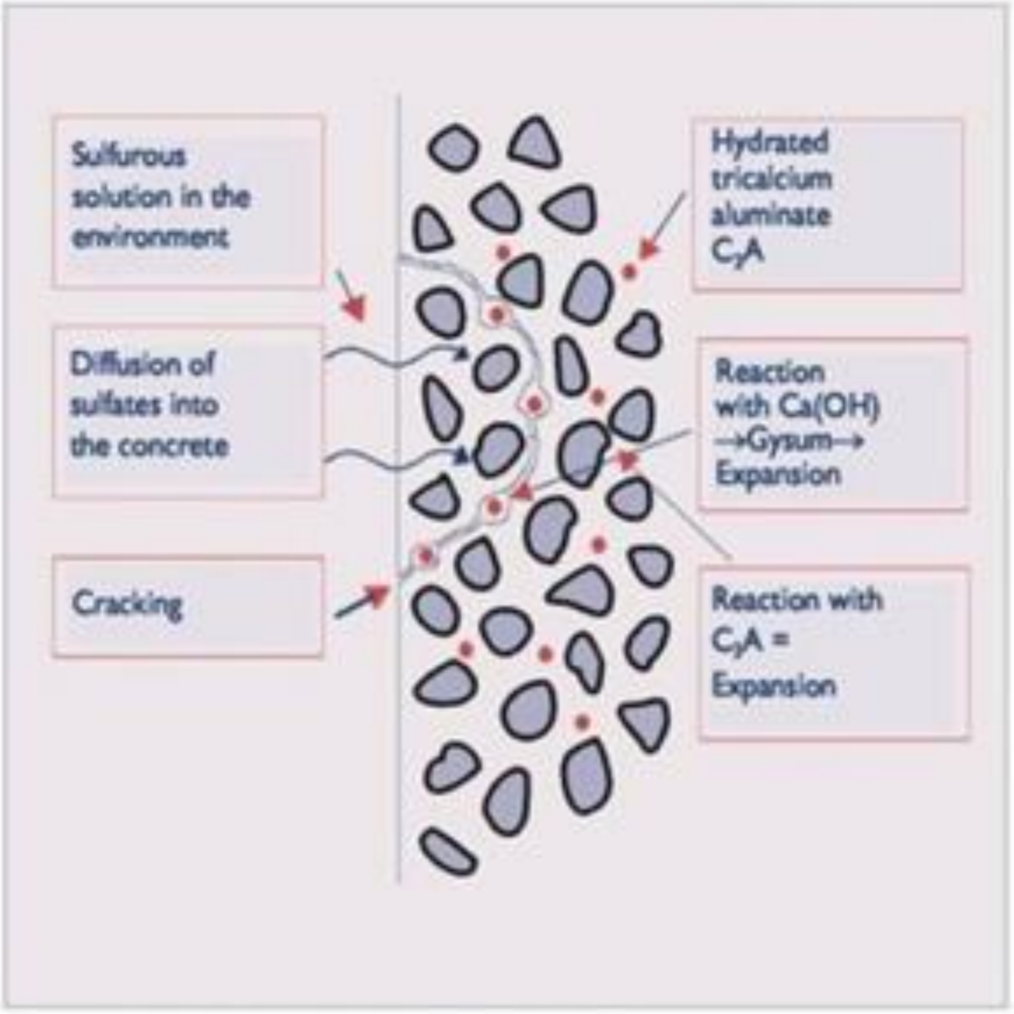
$$Ca(OH)_2+Na_2SO_4.10H_2O\Rightarrow CaSO_4.2H_2O+2NaOH+8H_2O$$

*Ettringite and gypsum formation lead to deterioration of concrete due to sulphate attack.

Mechanism

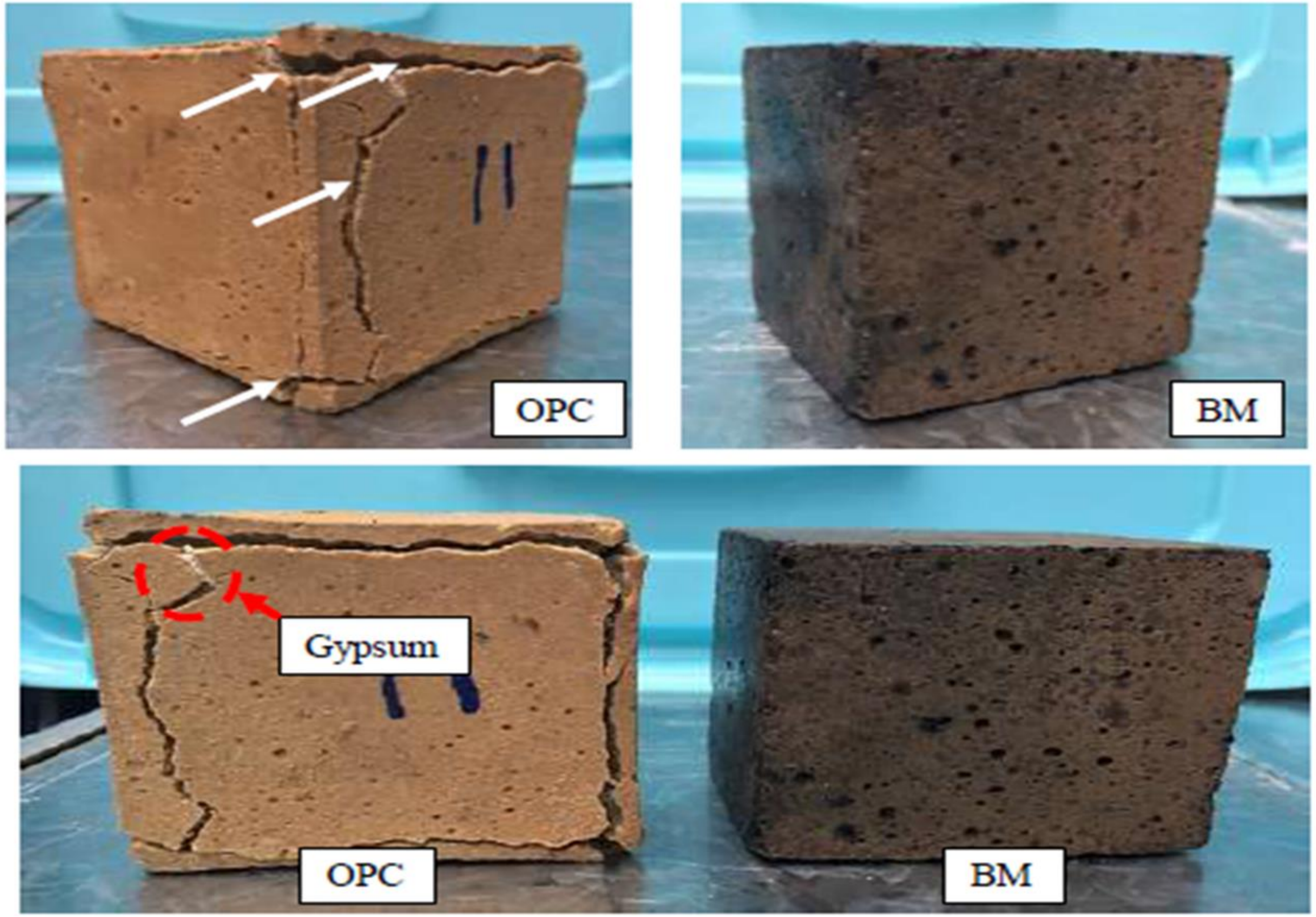


Pre-attack condition
Mechanical response
Gypsum veins
Groundwater level
Macro expansions
Failure
Micro cracking
Transport
Chemical
Expansive forces
Pore level
SO_4^{2-}
Structural level



Sulfurous solution in the environment
Diffusion of sulfates into the concrete
Cracking
Hydrated tricalcium aluminate C_3A
Reaction with Ca(OH) →Gysum→ Expansion
Reaction with C_3A = Expansion

Sulphate Attack



Concentration limit

Exposure	Concentration of Water-Soluble Sulphates in Soil (%)	Concentration of Water-Soluble Sulphates in Water (ppm)
Mild	< 0.1	< 150
Moderate	0.1 to 0.2	150 to 1500
Severe	0.2 to 2	1500 to 10000
Very Severe	> 2	> 10000

Thank You

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