Durability Assessment Techniques

MAB1033
Structural Assessment & Repair

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Introduction

- Deterioration of concrete structures may be due to physical & chemical effects.

- Durability assessment is associated with identifying the nature & extent of observed deterioration as a basis for assessing residual strength & potential durability.

- The aim is to assess the need for future maintenance & repair.

- Durability resistance is dominated by permeability of concrete to water & gases.

Moisture Measurement

- Quantitative assessments using radioactive, chemical, capacitance & dew-point methods.

- Comparative assessments may be made using thermography or radar methods.

Radioactive Methods for Moisture Measurements

- Equipment & test configuration similar to radiometry (direct & backscatter)

- Direct method is more reliable.

- Backscatter results relate to surface zone only few mm deep.

- Calibration not simple. Accuracy improves with increasing moisture.

Chemical-based or electronic methods for Moisture Measurements

- Chemical-based humidity indicators & dew-point sensors are inserted into surface-drilled holes.

- Dew-point meters are also electronically controlled & operate on cyclic chilled mirror principle. Accuracy $\pm$ 1% for relative humidity.

- Electronic meter capacitance probes inserted into holes, monitor changes in capacitance & conductance cause by moisture in air within the hole to give relative humidity.
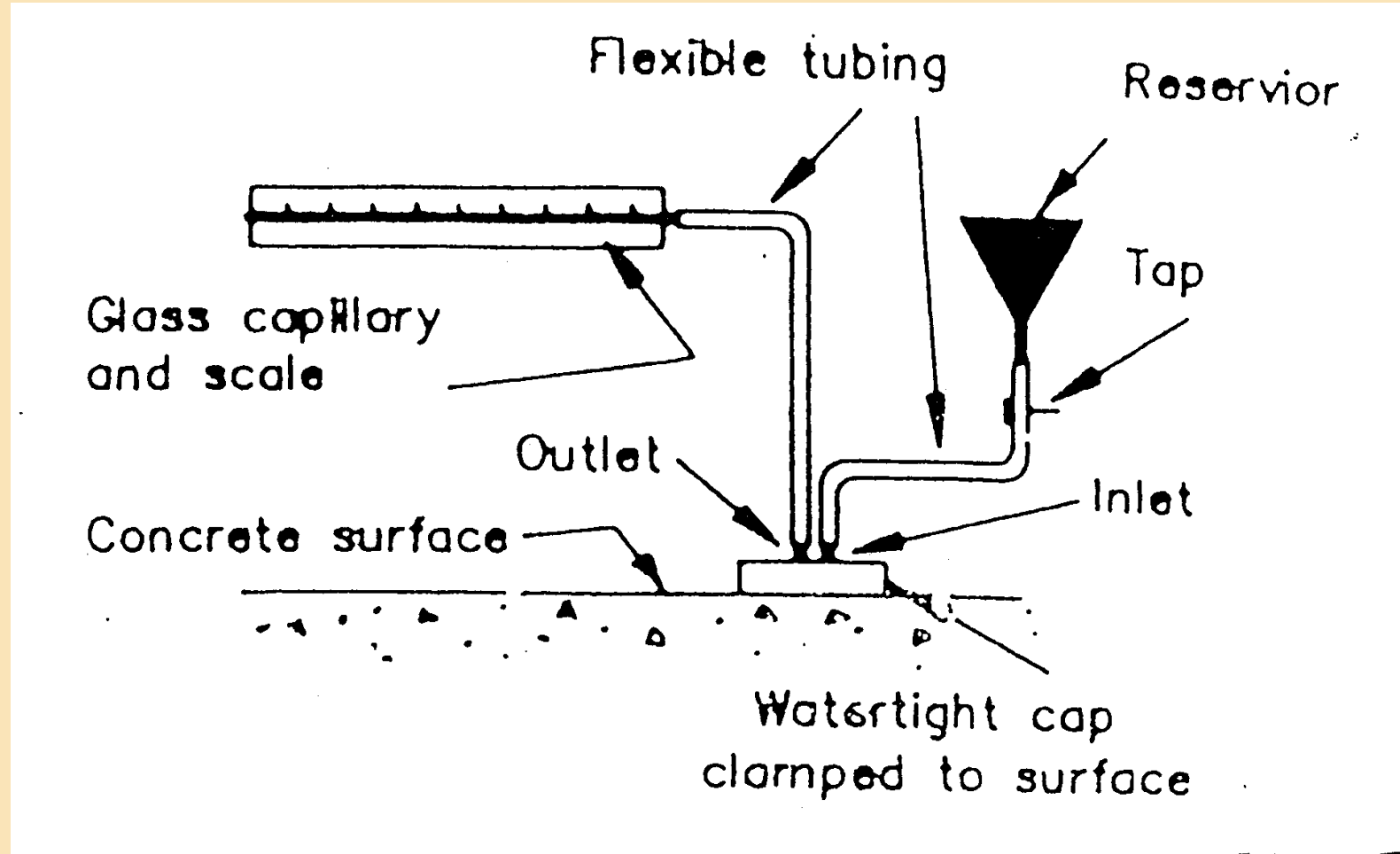
In-situ Permeability Tests

- Initial Surface Absorption Test is standardized in BS1881: Part 5.

- Other methods are described in Concrete Society TR31 (1988) : Clam Method, Poroscope (or Figg's) Method.

Initial Surface Absorption

- 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 5000mm2 & 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.

# ISAT Method

Water Permeability Test

Clam Method

- A pressurized version of the ISAT and may also be used to measure surface air permeability.

- A steel ring (50mm internal dia.) is bonded to concrete surface to isolate the test area.

- Test equipment comprises a hydraulic chamber with an internal pressure transducer located over the test area & connected to an electronic display panel.

- A system involving a piston with micrometer head, priming valve, syringe & bleed valve is used to control the tests.

- In water test : the volume entering concrete surface at low or high pressure is measured over a period of up to 20 minutes.

- In air test : pressure up to 1.5bar is created & the decay of pressure recorded over a 20 minute period.

Figg's Method (Poroscope)

- May also be used for water & air permeability.
- A drilled hole 10mm dia. & 40mm deep is sealed with a silicon rubber plug through which a hypodermic needle is passed into the void.
- In water test: water is forced by syringe through a needle into the void & connected to a horizontal capillary set at a head of 100mm. Time for absorption of 0.01ml following isolation from the syringe is measured.
- In air test : a vacuum of 55kPa below atmospheric is created in the void by hand pump & time for a 5kPa rise to occur is measured.

The Figg's Method

In-Situ Permeability Test (Figg's Method)
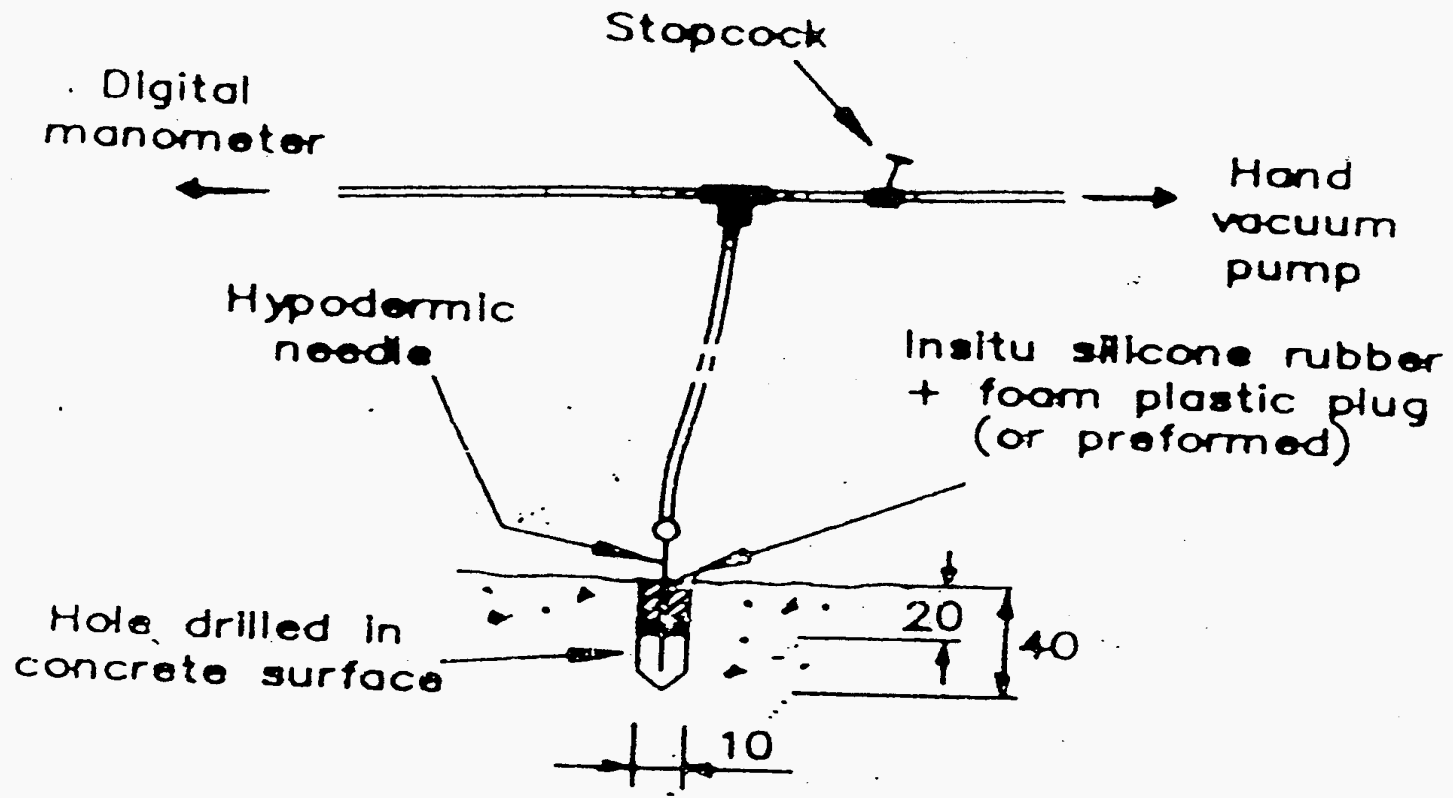
Gas Penetrability Test
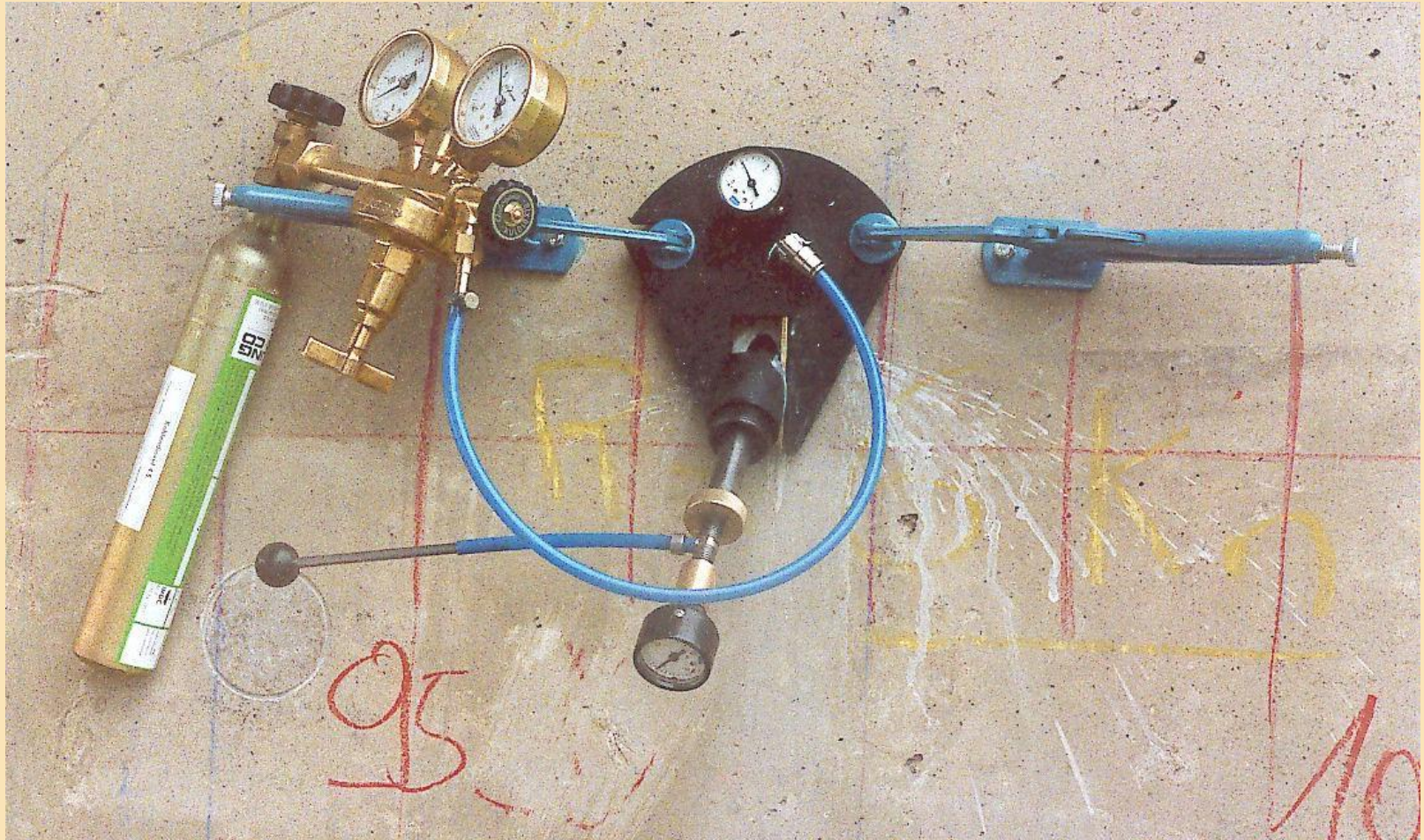
Testing for Reinforcement Corrosion

- 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.
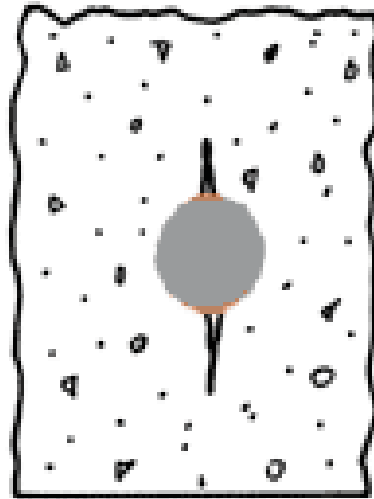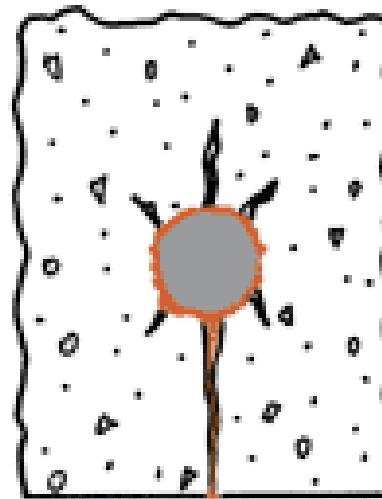
Corrosion Mechanism
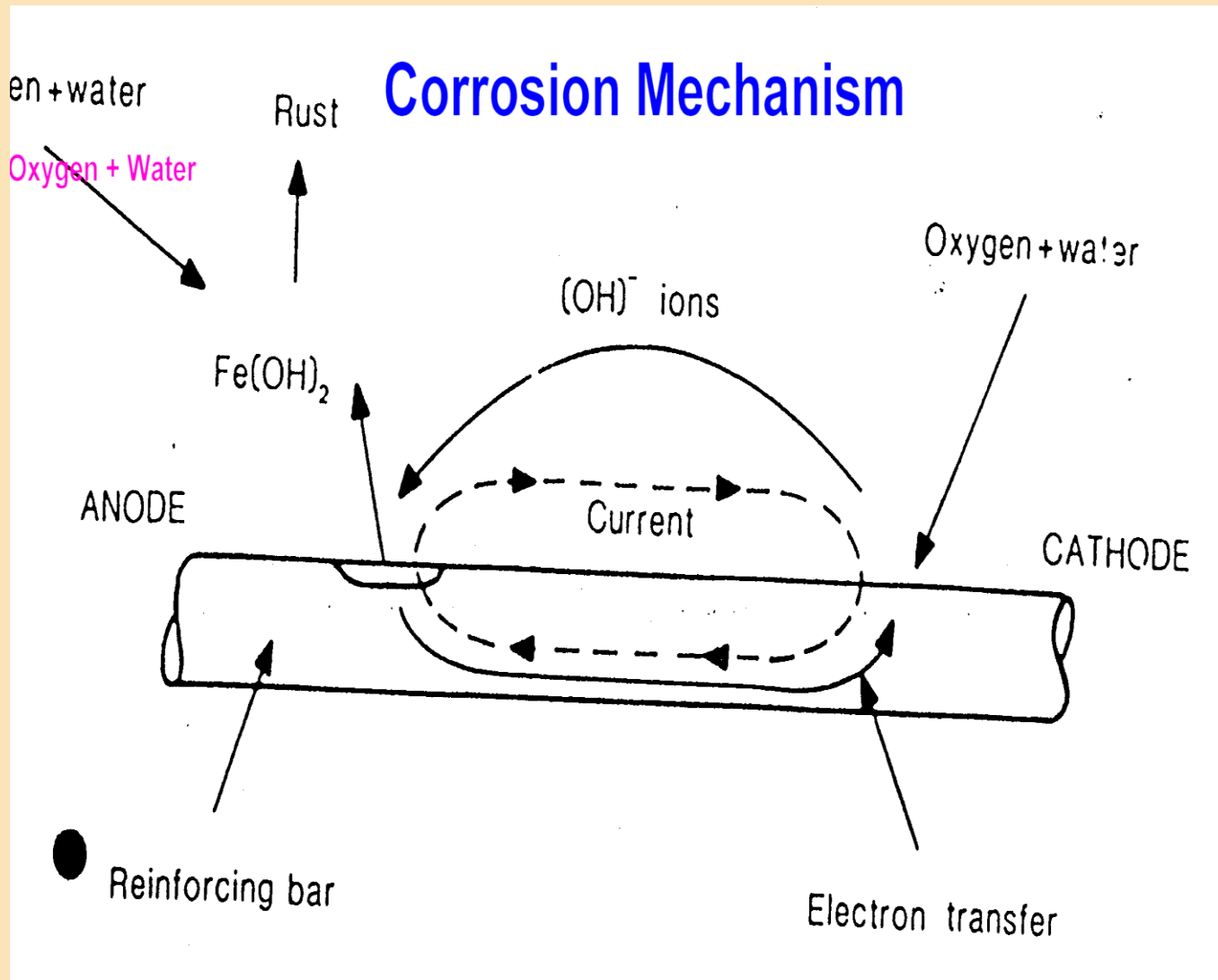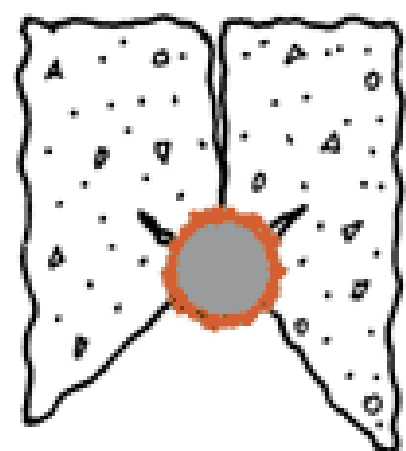
Corrosion Mechanism
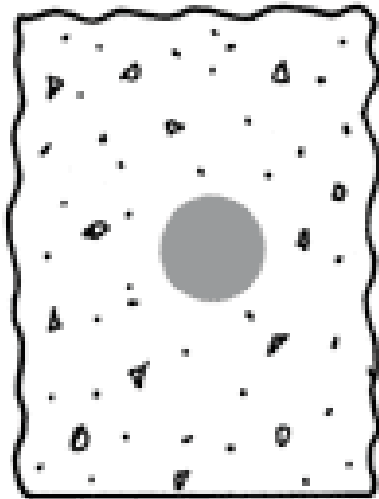

Before Corrosion

Build-up of Corrosion Products

Further Corrosion, Surface Cracks, Stains

Eventual Spalling, Corroded Bar Exposed

The corrosion cycle of uncoated steel rebar begins with the rust expanding on the surface of the bar and causing cracking near the steel/concrete interface. As time marches on, the corrosion products build up and cause more extensive cracking until the concrete breaks away from the bar, eventually causing spalling.

Corrosion Mechanism & Damage
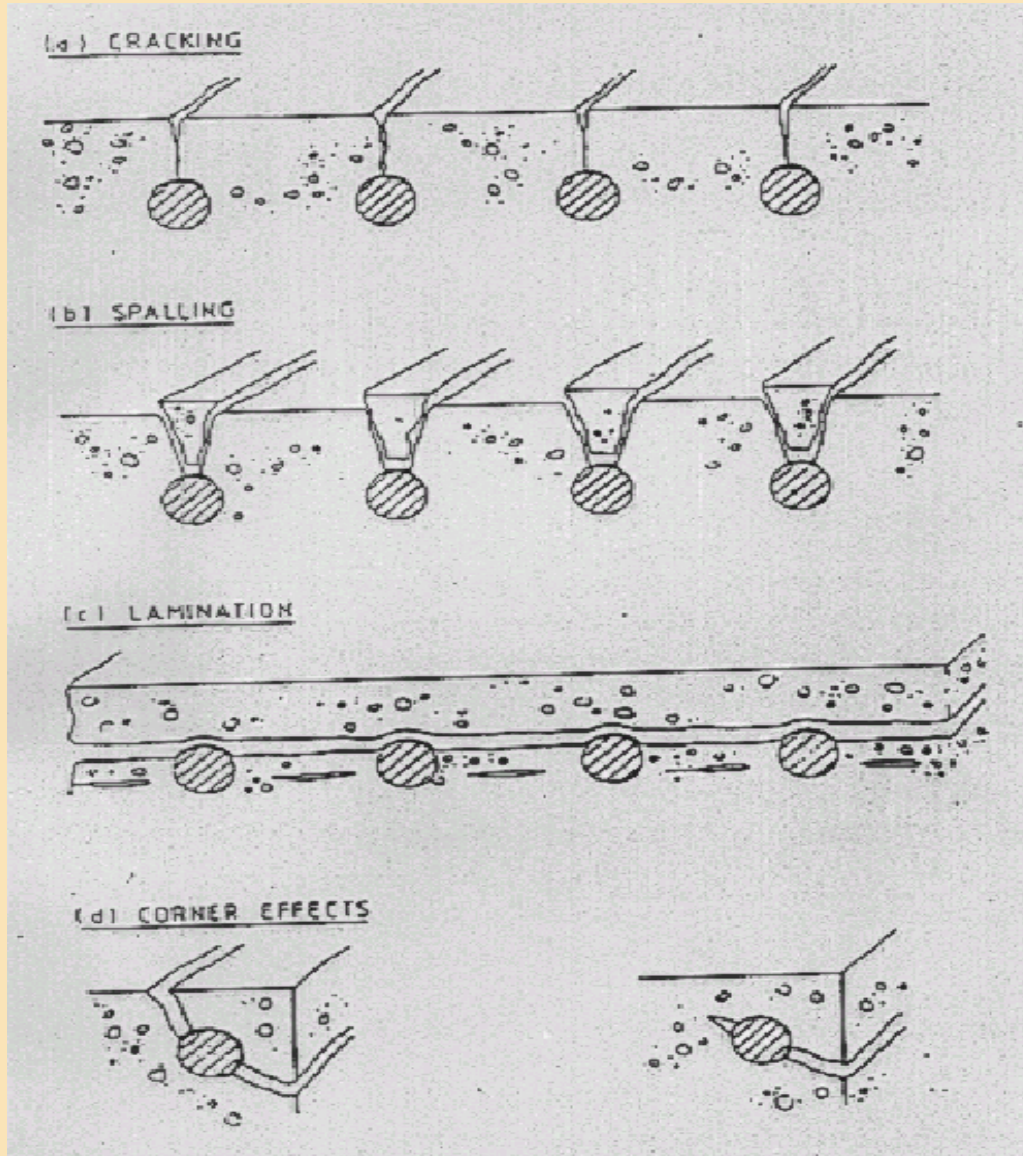
Corrosion Damage

Factors of Corrosion in Concrete

- The degree of depassivation of the steel;
- The setting up of corrosion macrocells by differential absorption of oxygen & chlorides in variable quality concrete;
- The lowering of the resistivity of the concrete by water & chlorides – down to 5000 ohm.cm or less;
- The availability of oxygen to fuel the corrosion process.

These factors show that the **quality of concrete** has a major influence on the corrosion behaviour of the steel, since it controls the rate at which the corrosion agents (oxygen & chlorides) reach the steel.
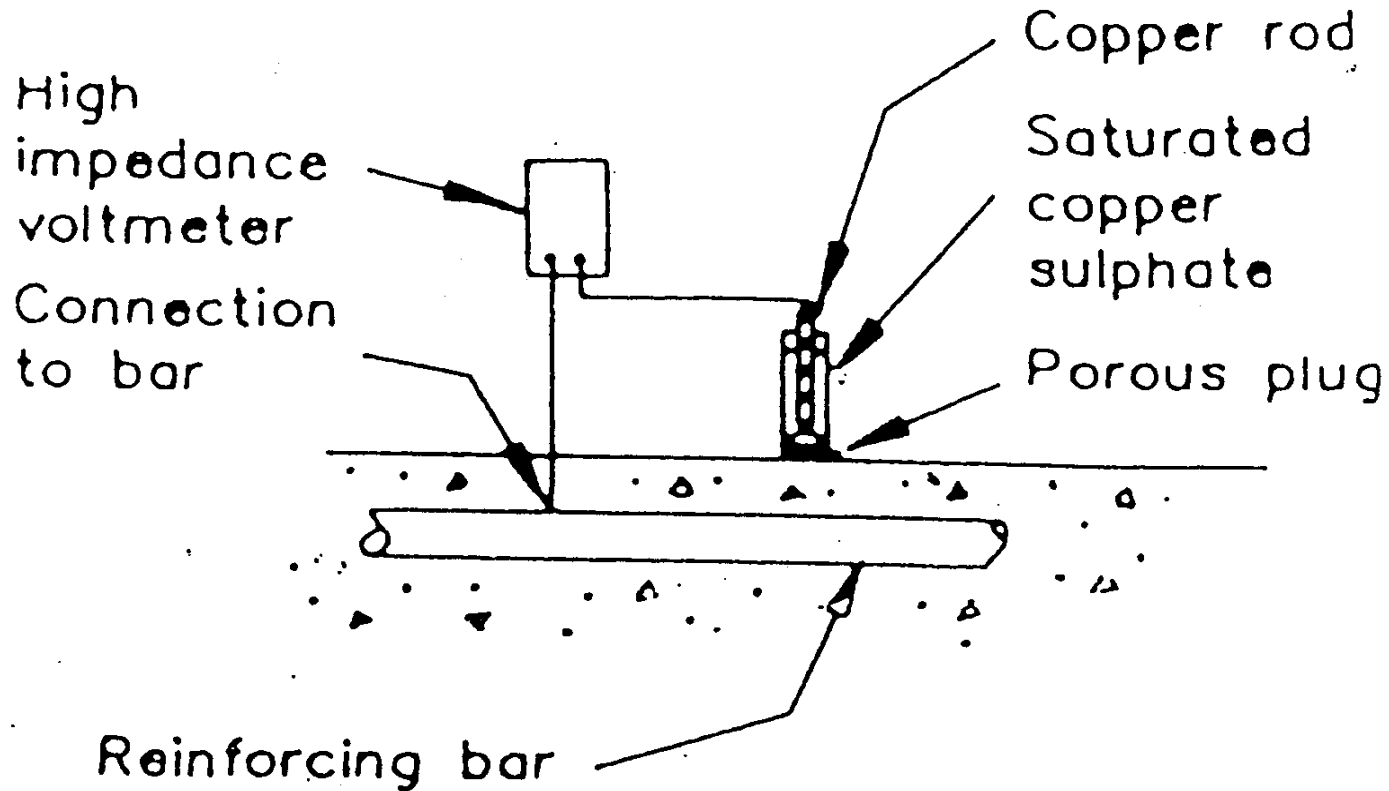
Principles of Corrosion Testing

- Steel corrosion is an electrochemical process : involving the establishment of corroding & passive sites on the metal, leading to the development of regions of differing electrical potential & current flow within the concrete.

- Measurement of the potentials & magnitude of corrosion current flow may enable assessment of existing & future corrosion behaviour to be made.

- Two principal tests to predict corrosion risk : Half-cell Potential & Resistivity measurements.

Half-Cell Potential

- Involves measuring the potential of an embedded reinforcement bar relative to a reference half-cell placed on the concrete surface.

- The concrete functions as an electrolyte and the risk of corrosion of the reinforcement in the test region may be empirically related to the measured potential difference.

- Copper/Copper Sulphate or Silver/Silver Chloride cells are typically used (See TRRL Application Guide 9 (1991) for guidance)

Half-cell Potential

Half Cell Potential Measurement

High impedance voltmeter

Connection to bar

Copper rod

Saturated copper sulphate

Porous plug

Reinforcing bar

Half-Cell Potential (contd.)

- 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.

- Commercially available equipment includes 'multi-cell' and 'wheel' devices with automatic data logging & graphical output.
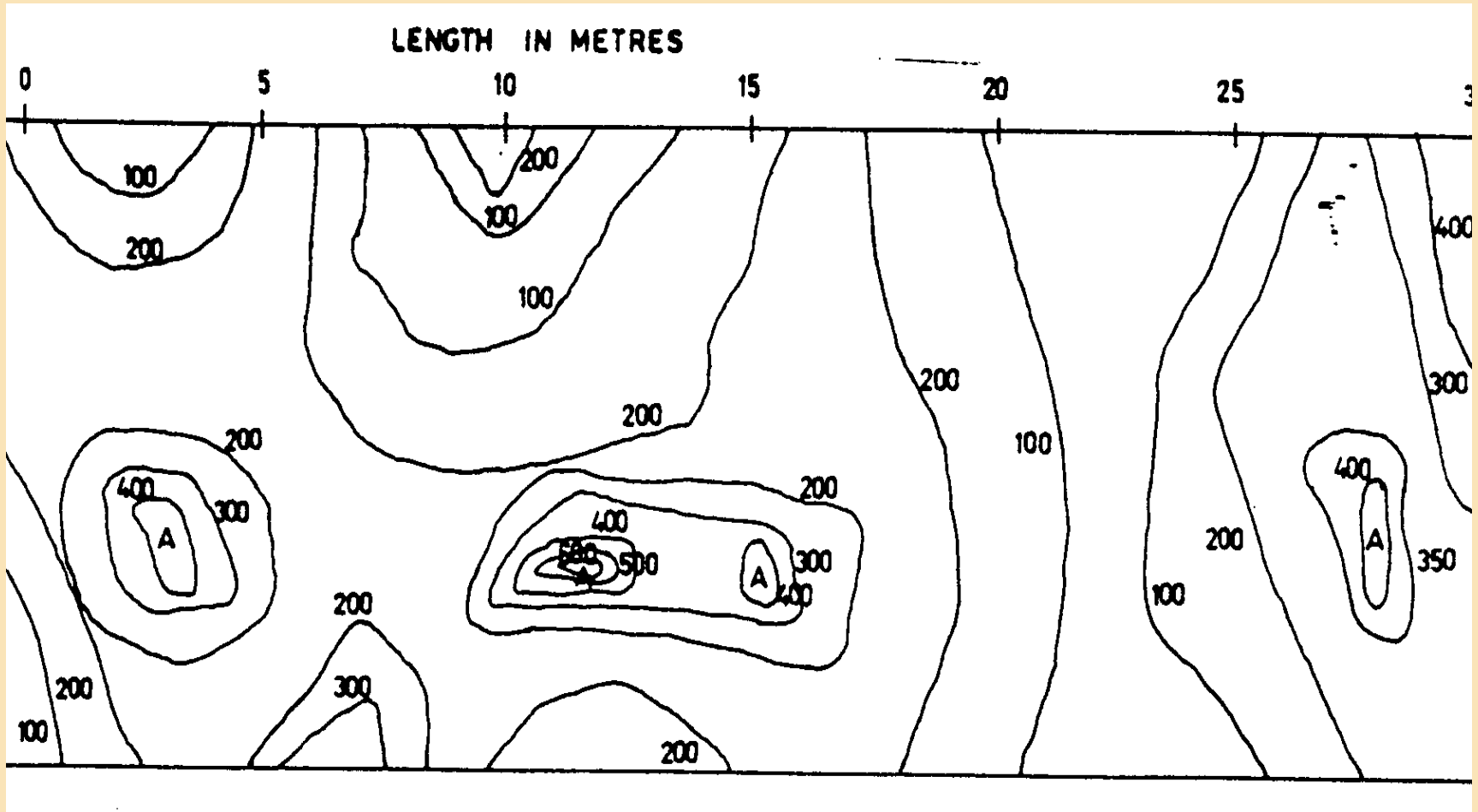
Corrosion Potential Measurement

Rapid Corrosion Survey
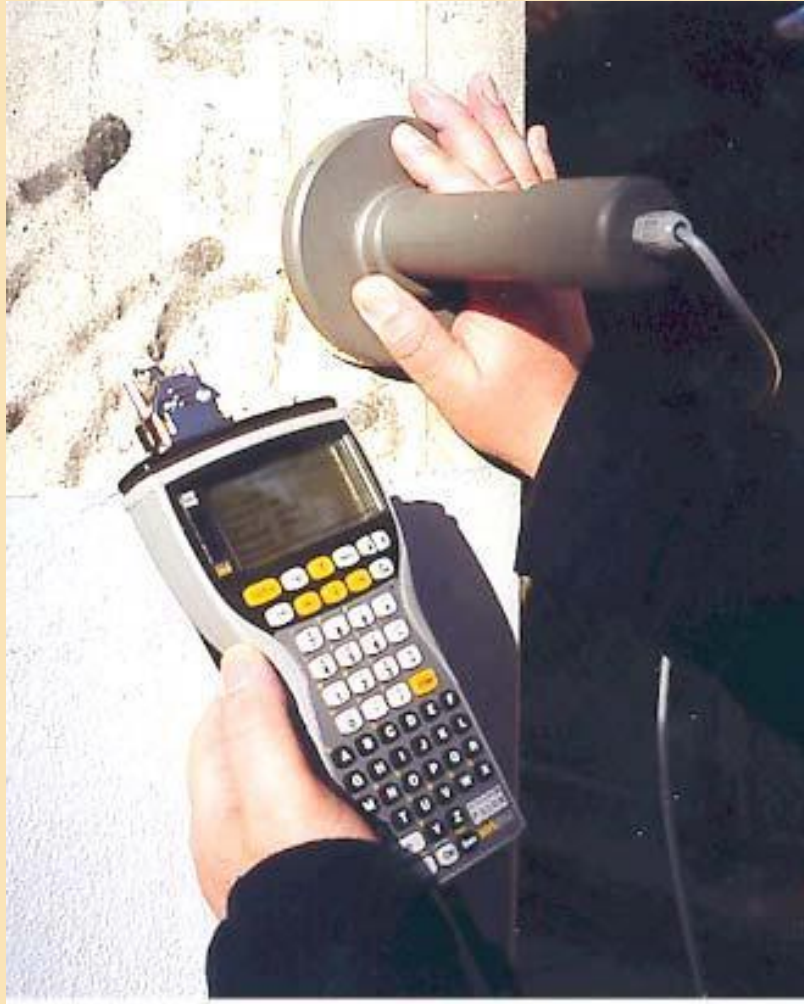
# Equipotential Contours

Corrosion Potential Assessment Criteria

Potential Measurement (millivolts)	% Chance of reinforcement being corrosively active
< - 350	95%
-200 to -350	50%
> -200	5%

Resistivity Measurement

- Measurements are made using a Wenner four probe technique in which four electrodes are placed in a straight line on, or just below the concrete surface at equal spacing.

- An alternating current is passed through the outer electrodes whilst the voltage drop between the inner electrodes is measured and resistivity calculated.

- The resistivity can be related to corrosion hazard of embedded bar & the likelihood of corrosion may be predicted in situations in which half-cell potential measurements show that corrosion is possible.

- Commercially available equipment include automatic data logging & spring-loaded automatic couplant dispensers for surface use.

Resistivity Measurement
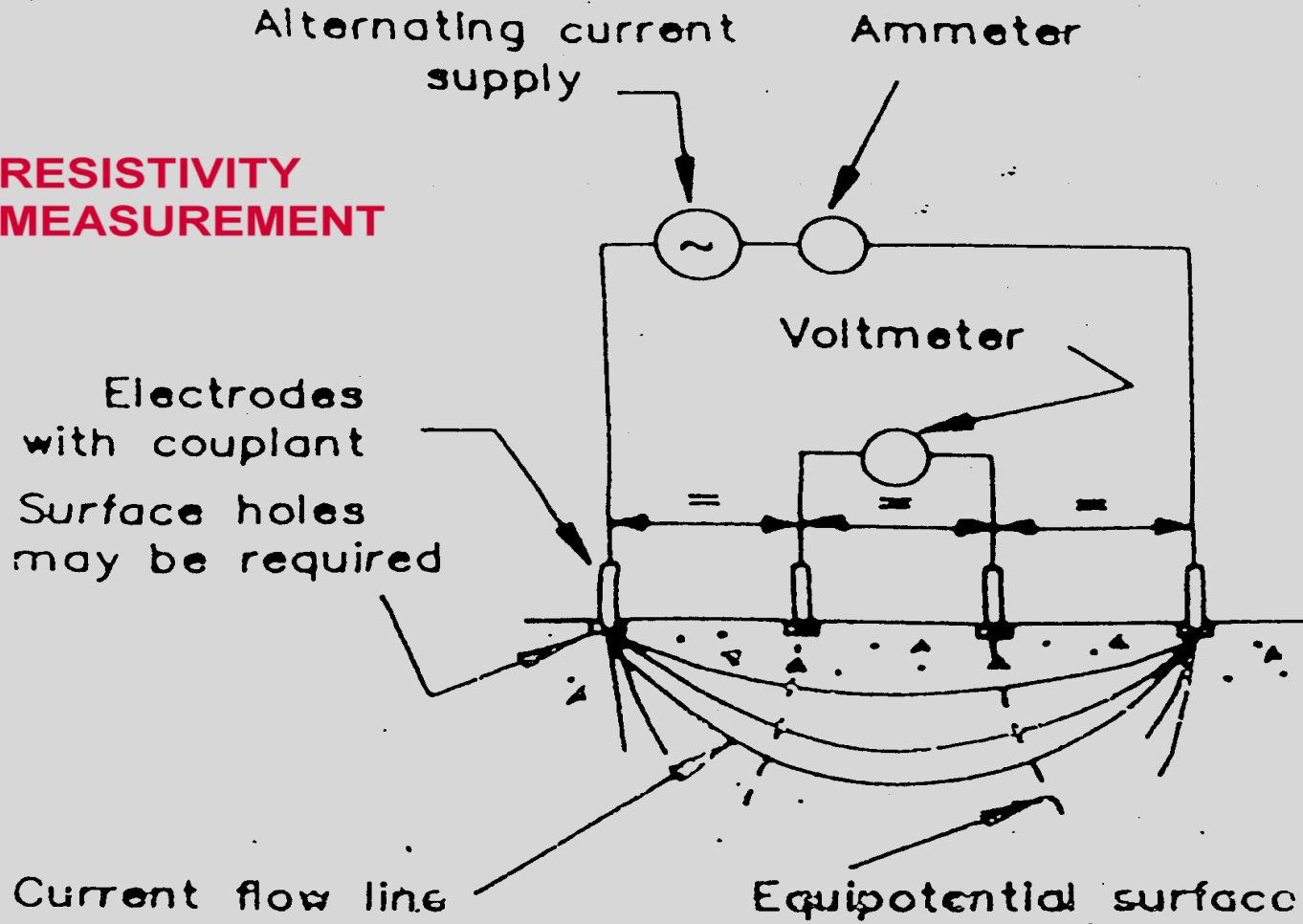
Concrete Resistivity Test

# Resistivity & Corrosion Vulnerability

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

Linear Polarisation Resistance (LPR)

- Used to predict corrosion rate.

- A small pertubative voltage is applied to eth corroding steel bar & the resulting current measured after a short time period for stabilisation.

- The measurement gives an instantaneous estimate of corrosion rate but cannot identify the degree of corrosion that has actually occurred.

- Equipment is relatively expensive.

Linear Polarisation Resistance
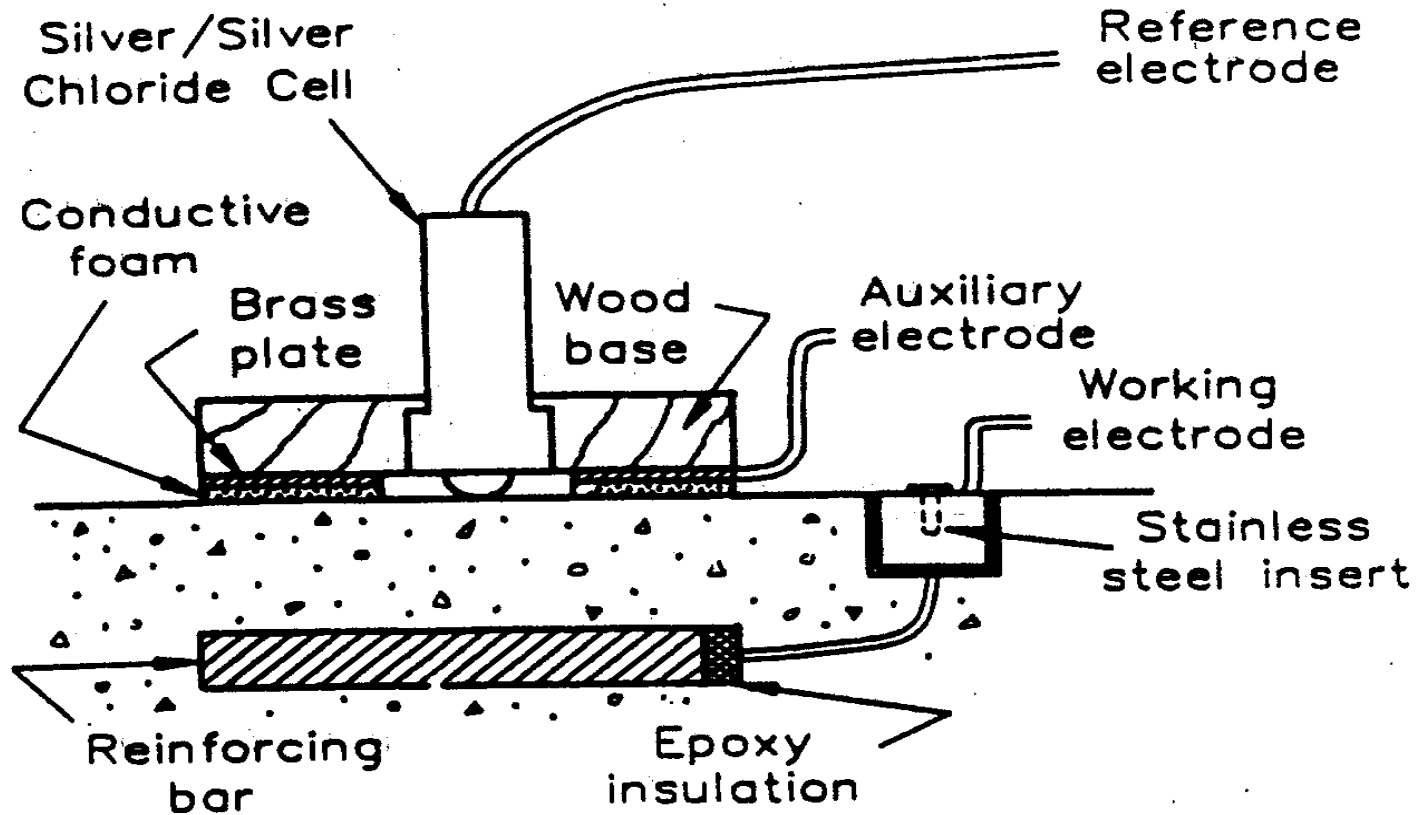
Covermeter Measurement

- Physical checking of the thickness of concrete cover using covermeter device within $\pm$ 5mm.

- Bar diameters may be estimated.

- Bars can be detected up to 300mm depth (reliable cover estimates may only be made for single bars up to 100mm).

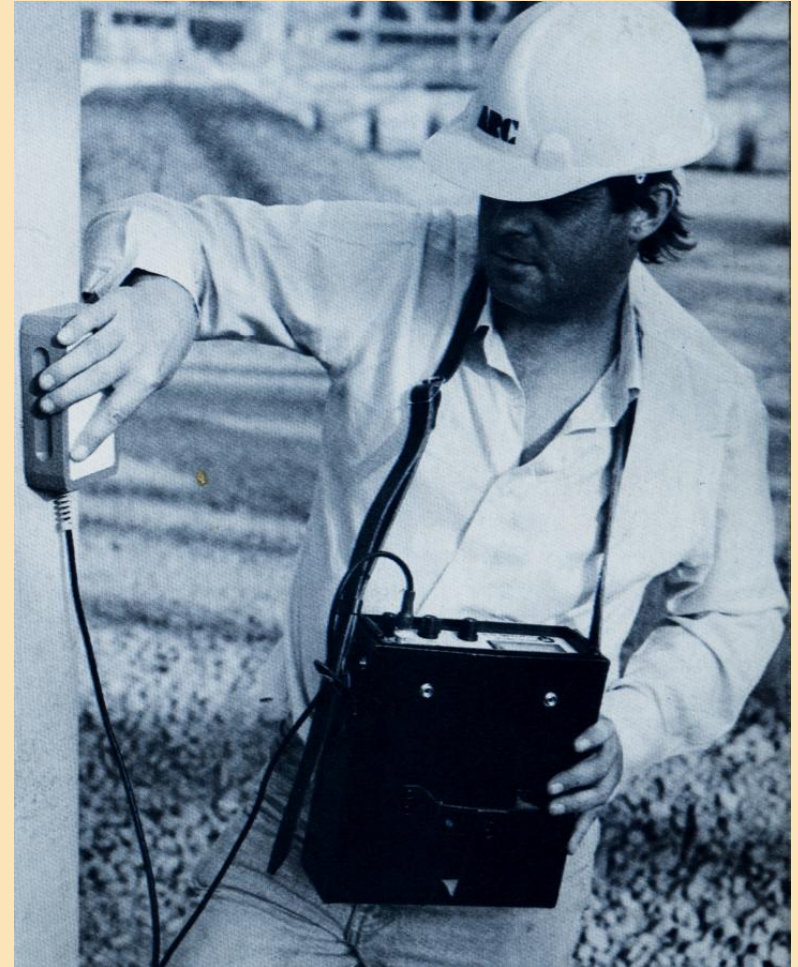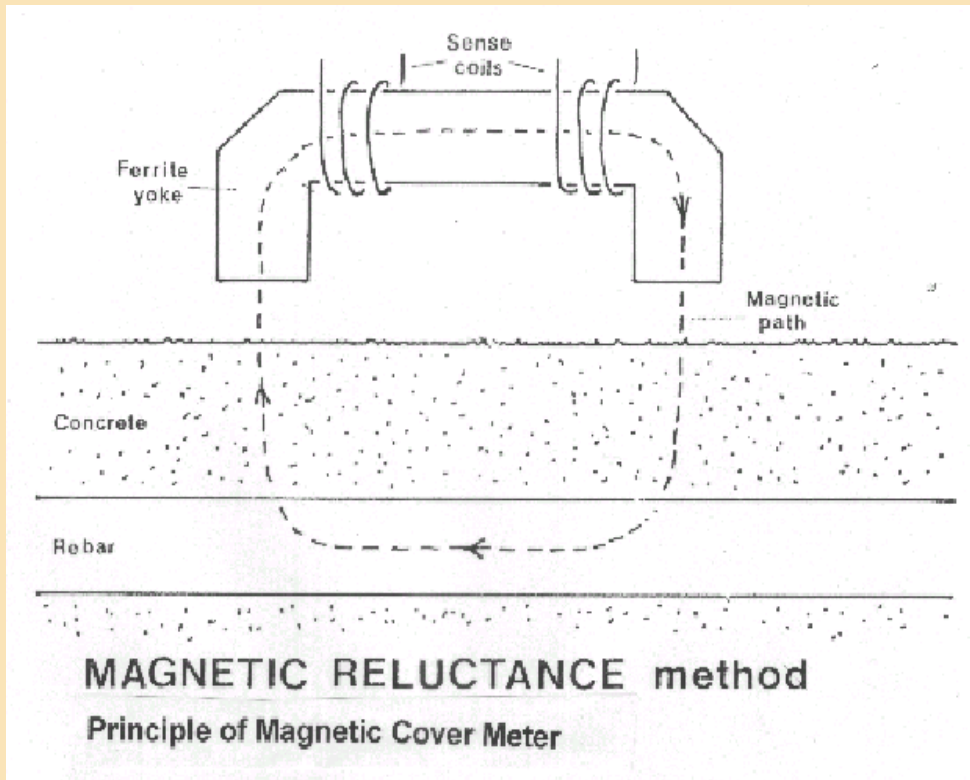- Always check for specific site conditions by reference to exposed bars or by drilling.

Covermeter

The Covermeter

Marking the location of reinforcement bar

Covermeter Measurement (contd.)

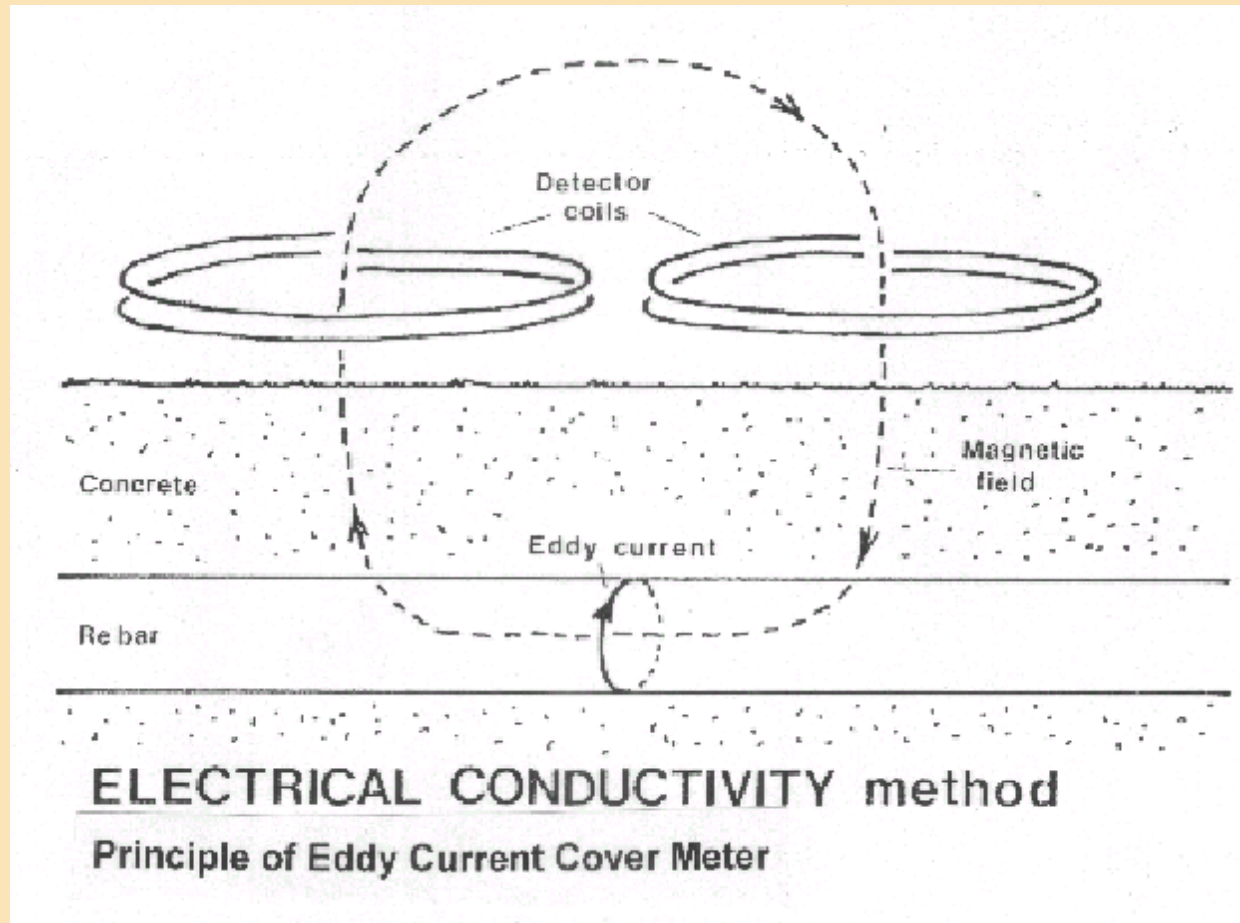- Measurements are based upon disturbance caused by the embedded metal to an electromagnetic field generated by a hand-held search head.

- The physical principles involved use either eddy current or magnetic induction effects.

- Readings by means of either analogue or digital display and may be with audible output.

- Alignment of bars obtained by rotating the search head on the concrete surface.

Magnetic Covermeter

Sense coils

Ferrite yoke

Magnetic path

Concrete

Rebar

MAGNETIC RELUCTANCE method

Principle of Magnetic Cover Meter

Eddy Current Covermeter

ELECTRICAL CONDUCTIVITY method
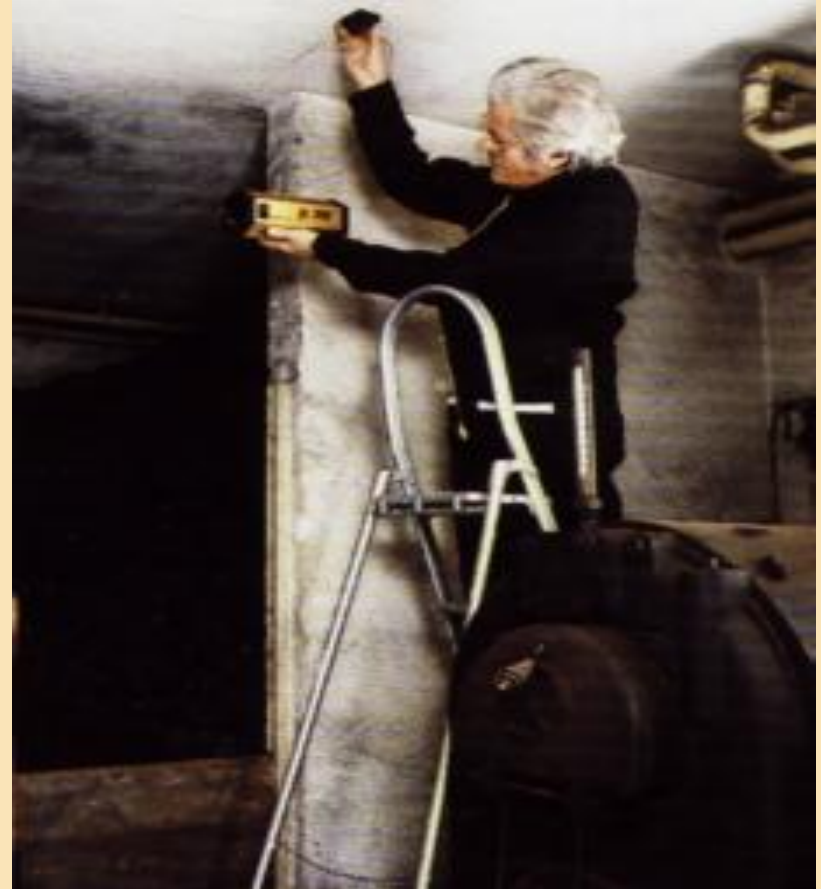
Principle of Eddy Current Cover Meter

Use of Covermeter

Locating the steel bars in a bridge column

Locating bars in slab soffit

Covermeter Measurement (contd.)

- Factors that influence equipment calibration are bar size & bar type.
- Factors causing erroneous readings :
  - multiple or closely spaced bars;
  - metallic debris;
  - tie wires (links);
  - aggregate type;
  - temperature changes;
  - stray magnetic fields.
- Equipment requirements & test procedures in BS 1881 Part 204.

Covermeter to locate reinforcement
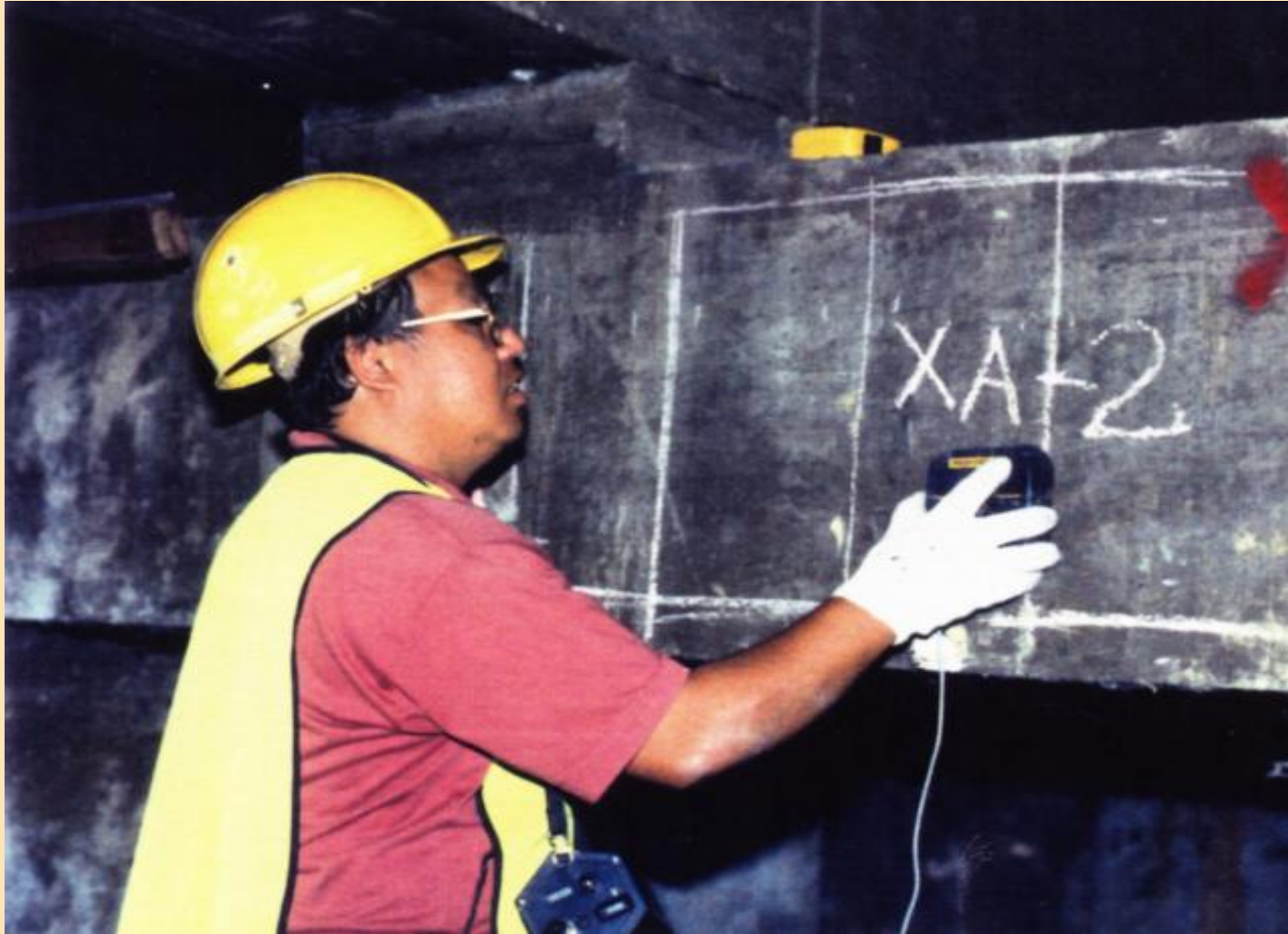
Covermeter at high places

Carbonation & Chloride Attack
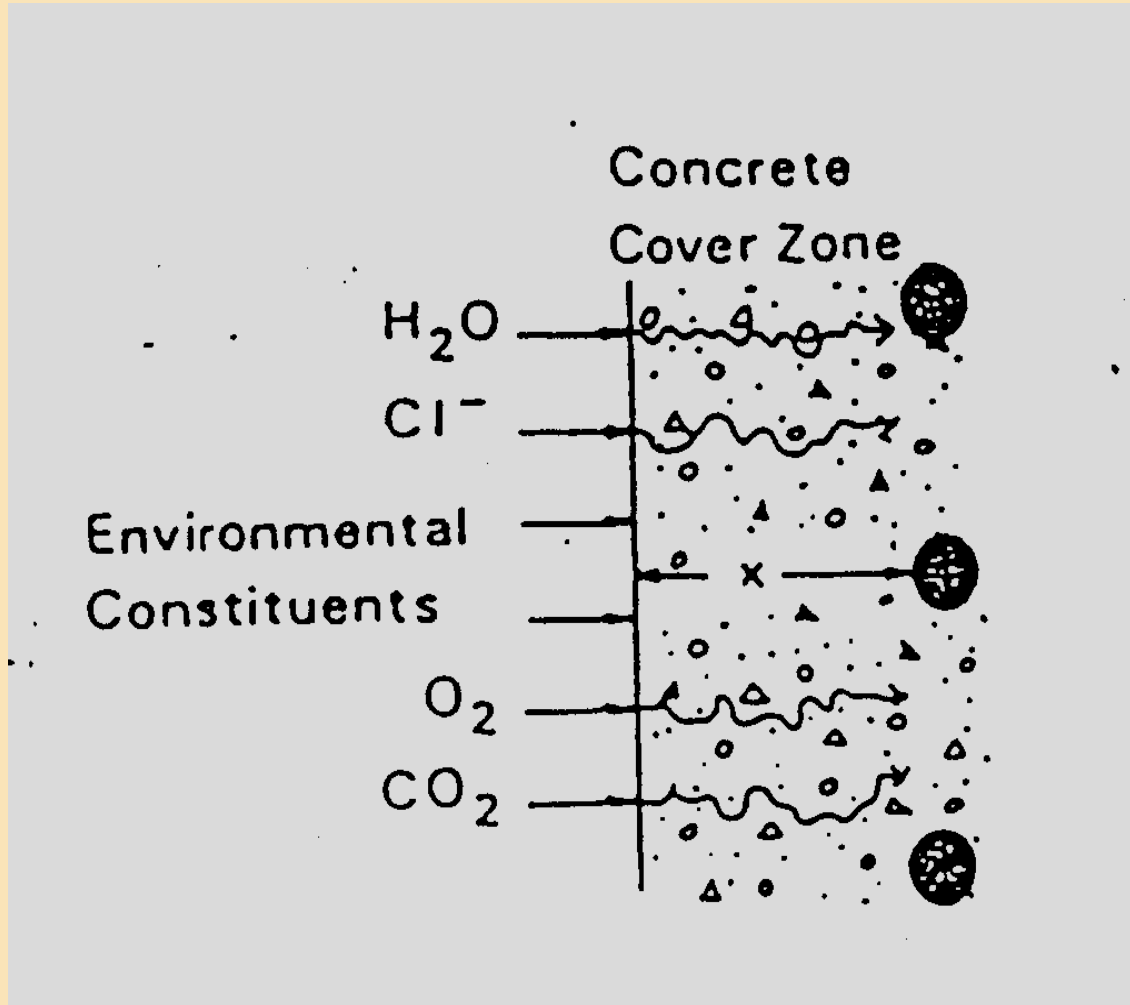
Carbonation

- 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 pheholphthalein 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 fro 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

BRE Digest 264 Guide for 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

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**

Testing for Material Deterioration

Deterioration of reinforced & prestressed concrete due to chemical & physical environmental effects upon the concrete includes:

a) **Sulphate attack**
b) **Akali-Aggregate reactions**
c) **Freeze-thaw damage**
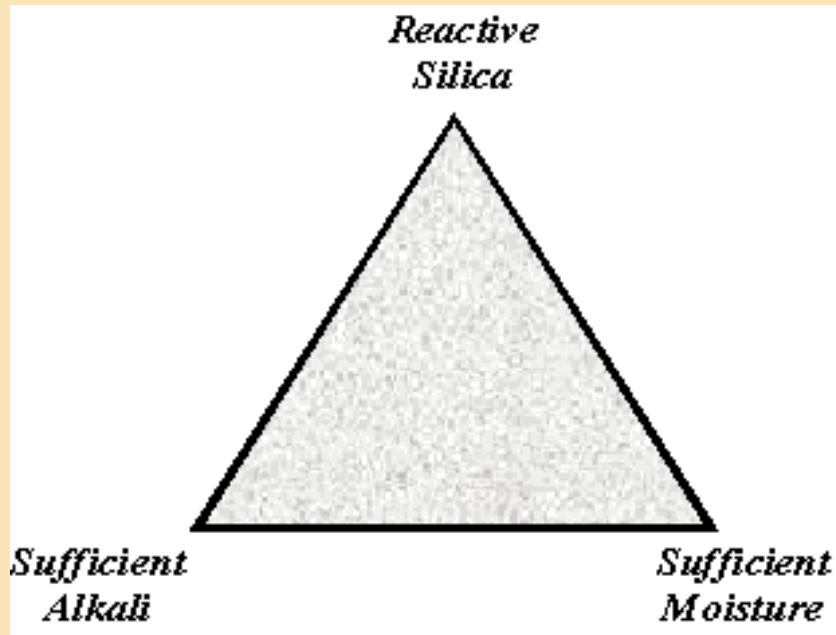d) **Fire damage**
e) **Abrasion**

Sulphate Attack

- External attack is usually characterised by irregular surface cracking within a few years followed by disintegration & erosion.

- The principal method of identification is to measure the sulphate content of a sample of concrete by chemical analysis. (see BS1881 Part 124 for details).

- Petrographic methods may also be used to reveal the presence of ettringite along cracks within the concrete. (expensive).

Alkali Aggregate Reaction (AAR)

- An expansive hygroscopic gel forms at the surface of the reactive aggregate particles when in contact with highly-alkaline pore fluid in Portland cement concrete, the forces may be high enough to crack the concrete.

- Also known as ASR (Alkali Silica Reaction)

- Identification is achieved by microscopic study of thin sections. Chemical analysis may be useful & in-situ moisture testing may be relevant to remedial strategy.
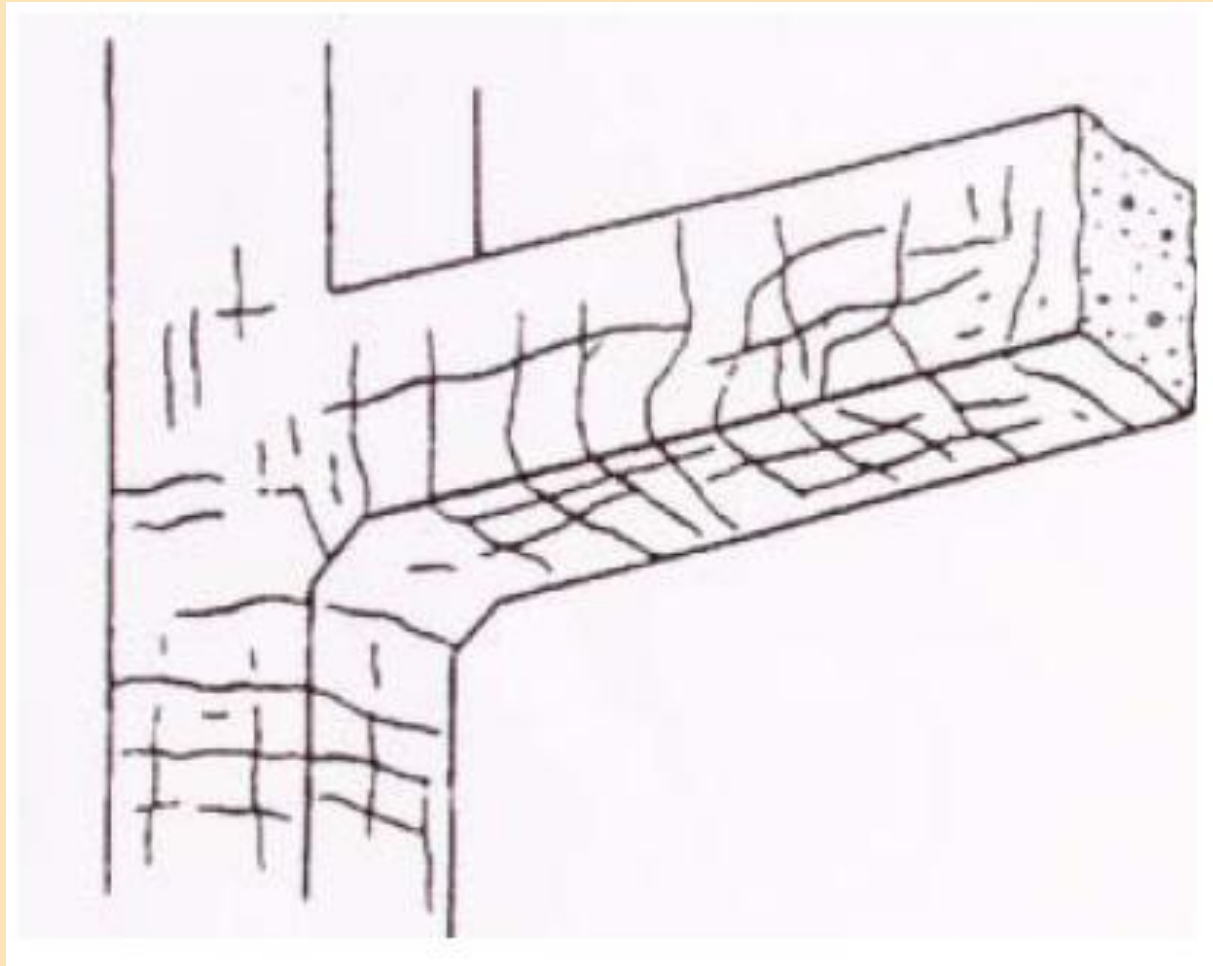
AAR or ASR Map Cracking

Fire Damage

- May range from localised spalling to major structural deterioration if long exposure caused temperature rise in reinforcement or prestressing steel.

- Visual assessment of cracking, spalling & colour change is useful.

- UPV may be useful for comparisons.

- Concrete Society TR 33 gives guidance.

Effect of Fire Damage (Sketch)

Abrasion

- Abrasion commonly caused by wheeled traffic.

- Other causes : wind blown sand, wave action etc.

- Abrasion resistance is related to surface hardness, rebound hammer measurements are relevant.

- For testing horizontal slabs, a rotating wheel device can be used to assess the wear caused in a specified period, which will permit abrasion resistance classification.

Main Causes of Durability Problem

In most cases, the causes of a particular problem can be traced to the following factors, singly or in combinations :

a) **Low cover steel**

b) **Permeable concrete**

c) **High chlorides**

Approaches that should be adopted to control the future deterioration of the concrete will depend on which of above causes (or combination of causes) applies.

Performance Model

- Prediction of future performance is a common aim of in-situ testing.

- Large number of contributing factors makes it difficult to predict the time at which an unacceptable performance level or lack of serviceability will be reached.

- General model for deterioration helps prediction.

Deterioration Model
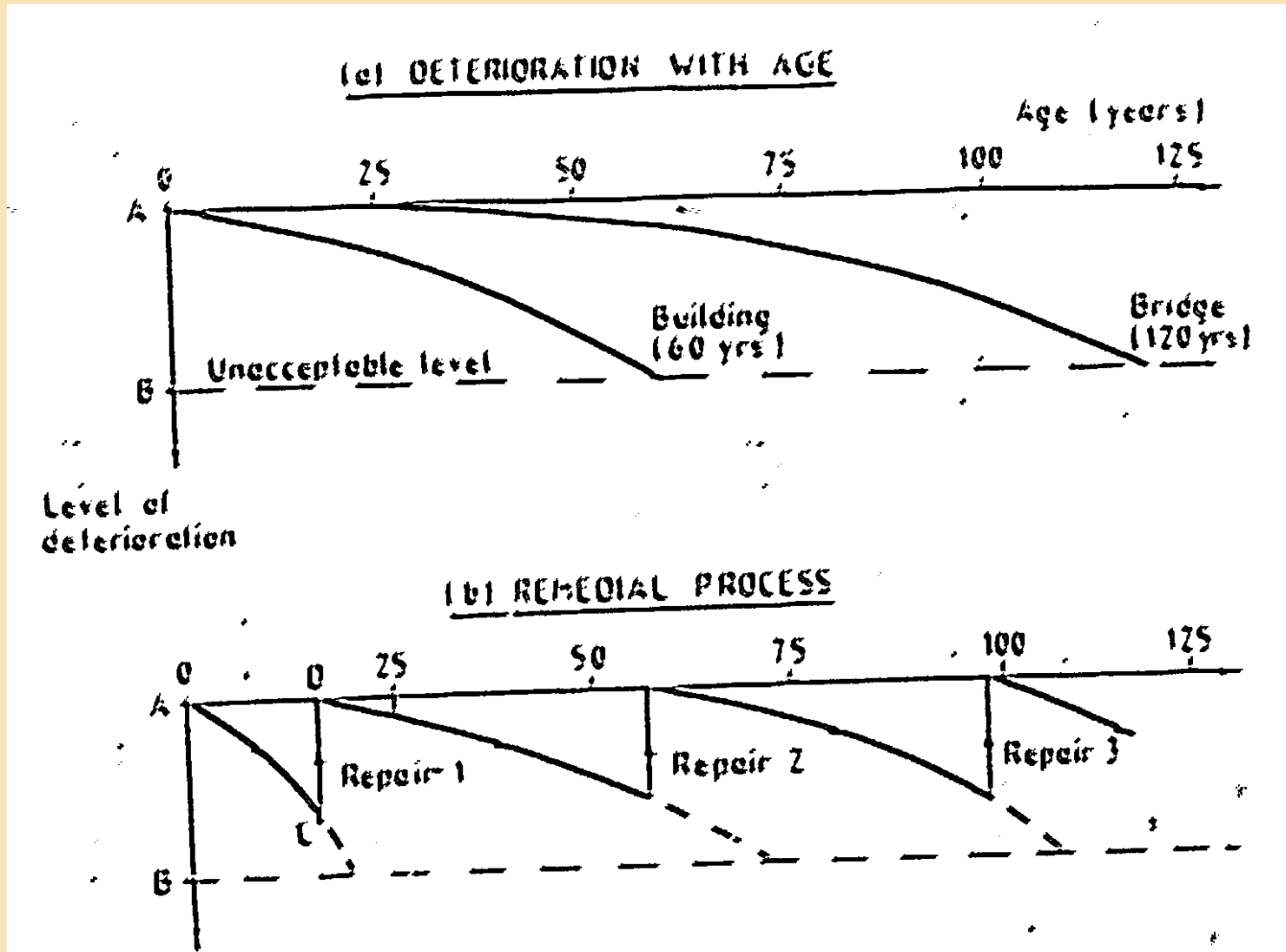
Example

The basement level of a 15-year old multi-storey car park is subjected to dampness condition especially during wet rainy seasons. The reinforced concrete columns in the basement area are showing signs of spalling indicating possible reinforcement corrosion. Following a site condition survey, a brief corrosion test regime is performed on selected columns, involving the covermeter survey, carbonation test and half-cell potential measurements, the results of which is summarized as shown in the Table.

Example (contd.)

Type of Test	Brief Results
Covermeter survey	Highest measured cover = 50mm Lowest measured cover = 9 mm Average measured cover = 40 mm
Carbonation test	Highest depth = 50mm (columns B2, B3, and B5) Other areas, depth = 25mm to 50mm
Half-cell potential measurement	Columns B2,B3, B5 & B8 recorded more negative than 350 mVolts. Two corrosion cells were detected within the region below 500mm (columns B2, B5). Top regions recorded potential less than 100 mVolts

Example (contd.)

- With the aid of suitable sketches, describe briefly how the half-cell potential measurement is to be carried out on the basement columns. (10 marks)

- Based on the above results alone, describe in your own words, possible statements to be mentioned to your client, on the following aspects :

    a) A brief opinion on the probable extent of corrosion occurring in the structure. (8 marks)

    b) Brief recommendations on the requirements for further investigation and any additional tests to be conducted. (7 marks)

    c) Brief suggestions on possible remedial measures to be proposed for the affected columns. (6 marks)