Electrochemical Methods to Restore Concrete Structures

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Agenda

- Deterioration due to Corrosion
- Chloride Extraction (also called Desalination)
- Re-alkalisation
- Cathodic Protection (CP)
- Expelling Water (MPS System)

In Normal Reinforced Concrete Structures

- Complications/Problems due to:

Aggregates:

Soundness, deleterious substances, differential thermal and moisture movements, alkali-carbonate and alkali-silicate reactions

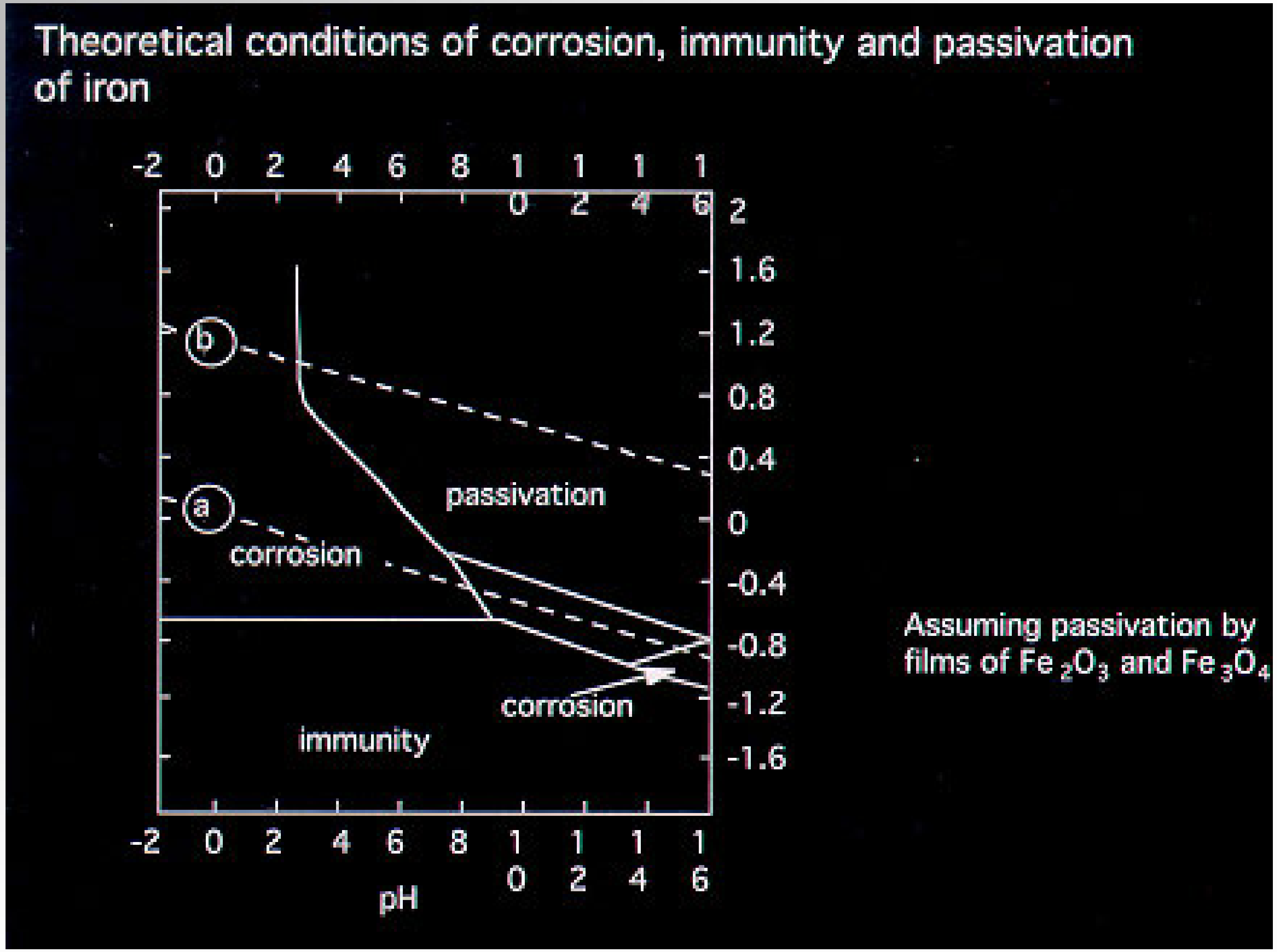
Steel:

Corrosion – a Major Problem

Deterioration due to Corrosion

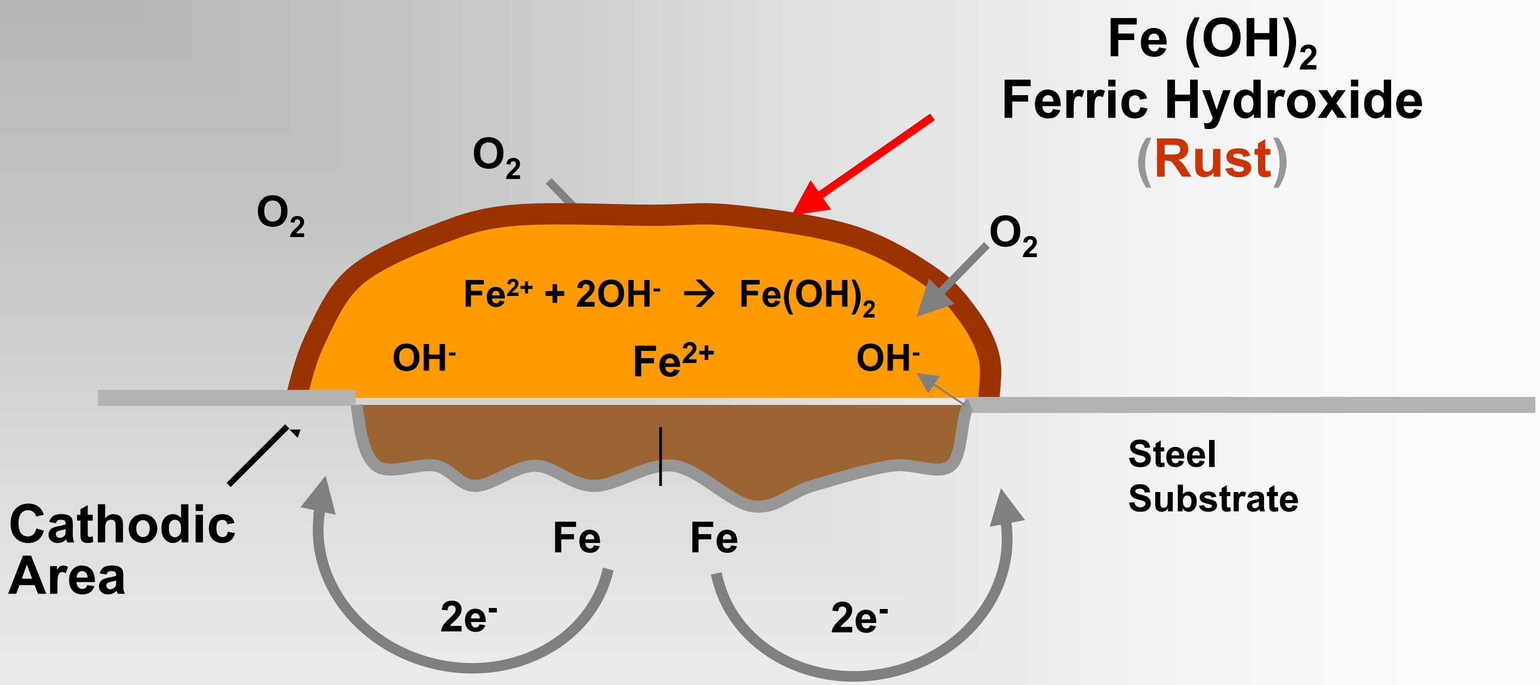
So why some corrode and others not ?

Pourbaix Diagram



Passivation stables between pH 10-12

Electrochemical Corrosion Cell



- **Anodic Reaction** $2Fe \rightarrow 2Fe^{2+} + 4e^-$
- **Cathodic Reaction** $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
- **Overall Reaction** $2Fe + 4OH^- \rightarrow 2Fe(OH)_2$

Defects Caused by Reinforcement Corrosion

- Corrosion product induced bursting force
- Cracking, spalling, delamination
- Prolonged period of deterioration will eventually cause structural failure

Passivation can be destroyed by:

- Reduction of pH, (i.e via carbonation)
- Chloride attack
- Voltage on the rebar of sufficient magnitude and duration (Stray Current)

Carbonation

- Carbonation of Concrete –

  A process where the dissolution of carbon dioxide (from the atmosphere) into the pore water in concrete to form carbonic acid, which neutralises the local high pH environment and causes the depassivation of steel

Chloride

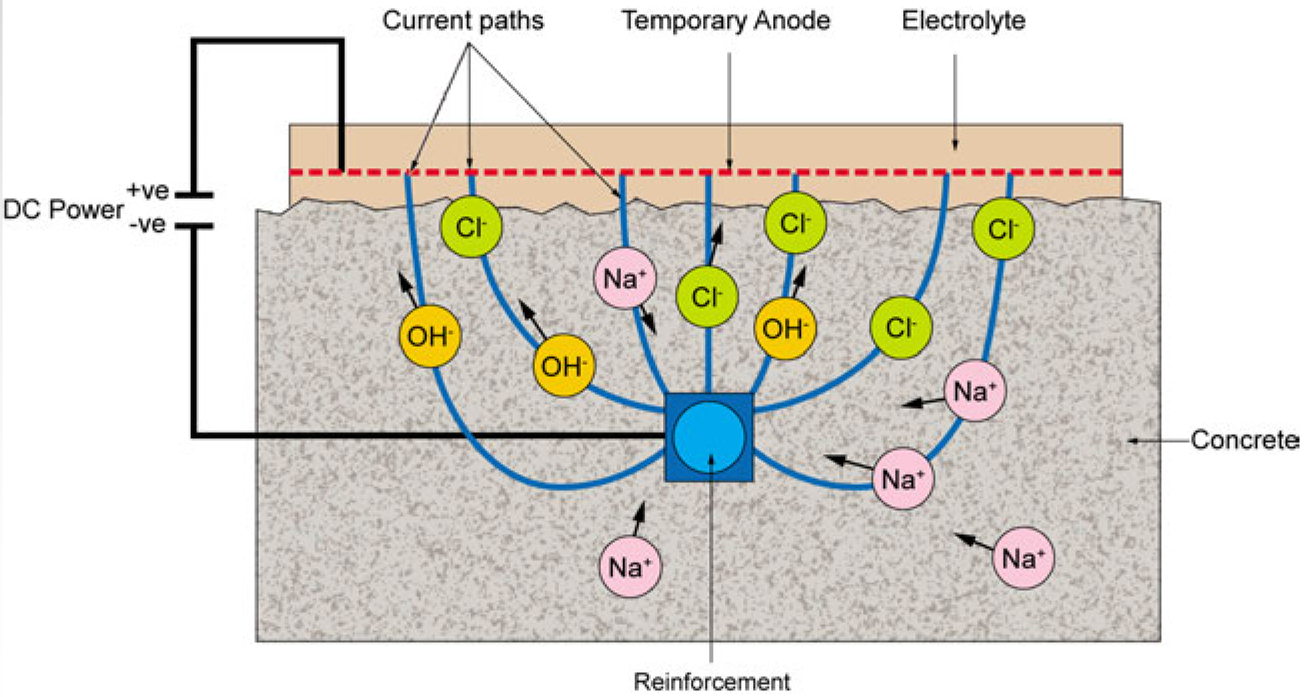
- Chloride may derive from external or internal sources
- Penetration of chloride depends on diffusion and absorption by capillary suction
- Can effectively breakdown the passive film covering steel reinforcement and initiate corrosion

What we need to do?

- Design stage:
  - Risk assessment / life expectance,
  - 4Cs: concrete, cover, compaction, curing.
  - Others: e.g. corrosion monitoring and protection, coatings
- During construction:
  - compaction, curing, cover
  - workmanship
- Maintenance:
  - Inspection, Monitoring
  - Repairs: conventional, desalination, re-alkalisation, cathodic protection, expelling water

Chloride Extraction

- Draw chloride ions from concrete
- Suitable for salt contaminated concrete
- Applying an electric field between rebar (cathode) and temporary anode (mesh and electrolyte)



Features

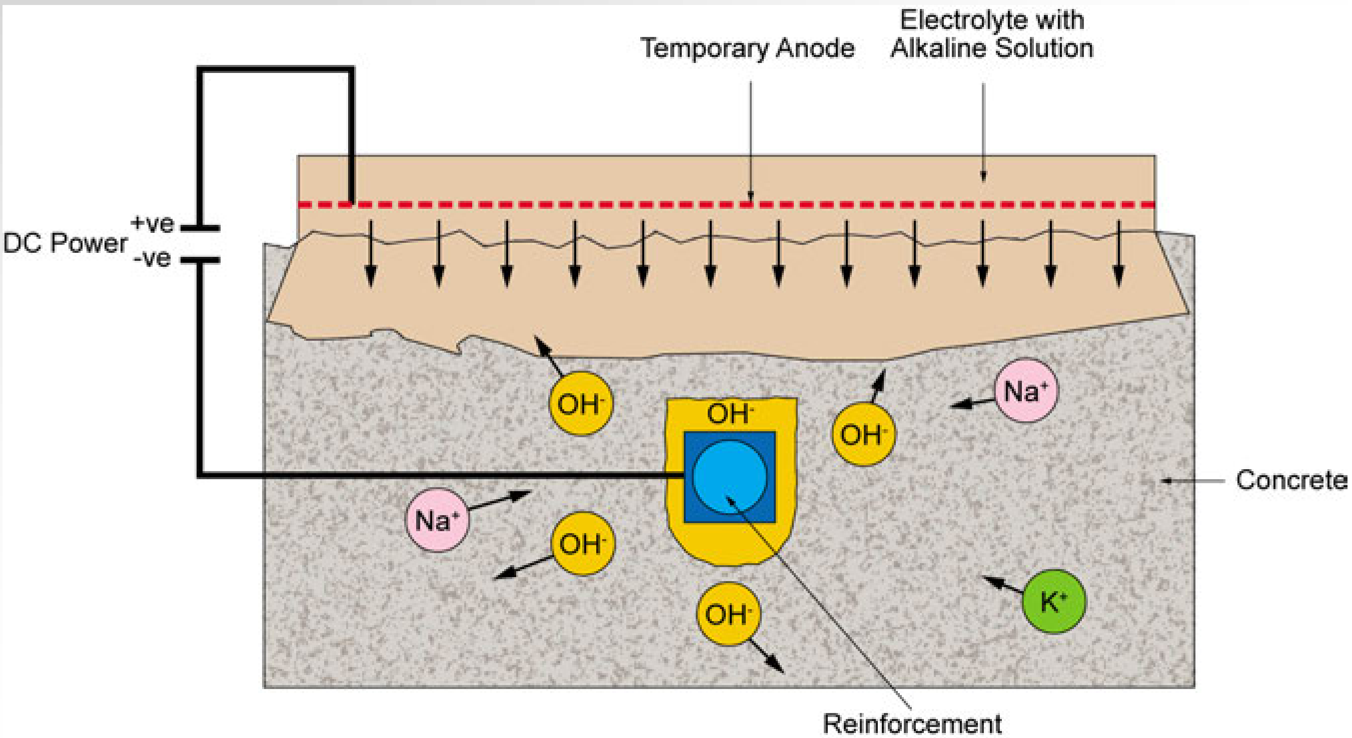
- Carry out together with concrete repair to provide electrolyte and restore appearance of structure
- Prolong service life by 5 to 10 years dependent
- Effective process yields 50% to 80% chloride removal

Examples of Chloride Extraction

- Island Eastern Corridor (trial)
- School (trial)
- Housing Projects

Re-alkalisation

- Reinstate protective alkalinity (pH 10-12) in concrete
- Suitable for carbonated concrete
- Applying an electric field between rebar (cathode) and temporary anode (mesh and alkaline solution)



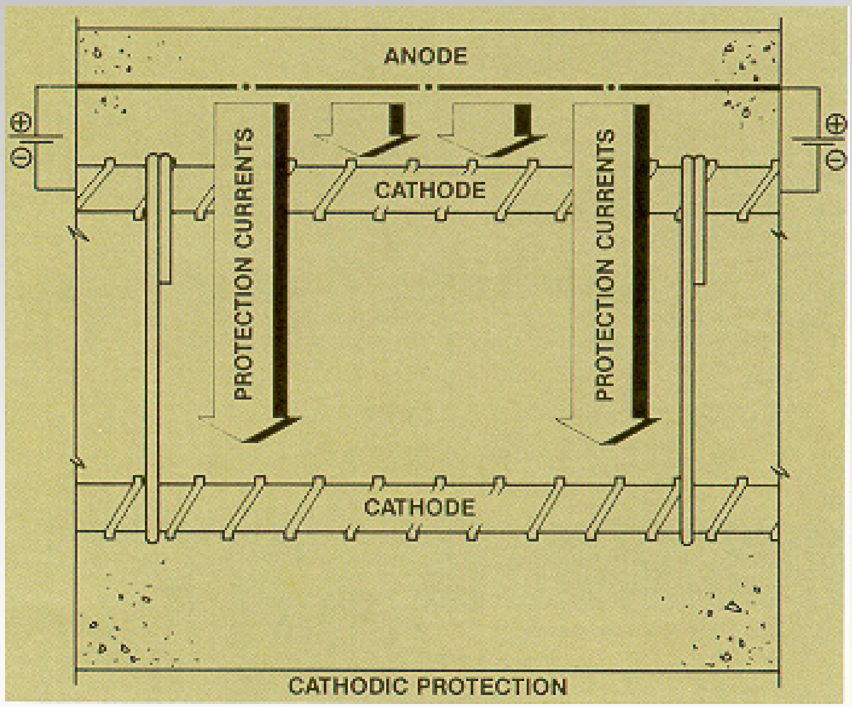
Features

- Carbonated but sound concrete can be retained (common for carbonated concrete)
- No major repair and thus less disturbance
- Prolong service life by 10 to 15 years

Examples of Re-Alkalisation in HK

- Lion Rock Tunnel (trial)
- Housing Projects

Cathodic Protection (CP)



- Reverse of cathodic corrosion
- Suitable for salt contaminated, carbonated and stray current affected concrete
- Impressed current passed to layers of reinforcement
- Require a source of direct current (DC) and an auxiliary electrode - Anode

Example - KCRC Bridge No. 5

- Installed in 1986
- Conductive coating anode
- Effectively operating for over 16 years

Example - Kwai Chung Terminal 2

- Flexible anode manufactured from conductive polymer
- Anode nailed to concrete surface
- Anode covered with render or spray concrete overlay

Example – Kwan Chung Terminal 4

- Used on beams at Kwai Chung T4 in 1992
- Titanium mesh anode nailed to concrete
- Spray render cementitious overlay
- Effectively operating for over 10 years

Example - MTRC Sea Channel Bridge

- CP specified, designed and installed at time of construction and tested after construction
- Corrosion monitoring of structure ongoing
- CP system will be energized when monitoring results show that it is necessary.

Case Study – Eastern Harbour Crossing (EHC)

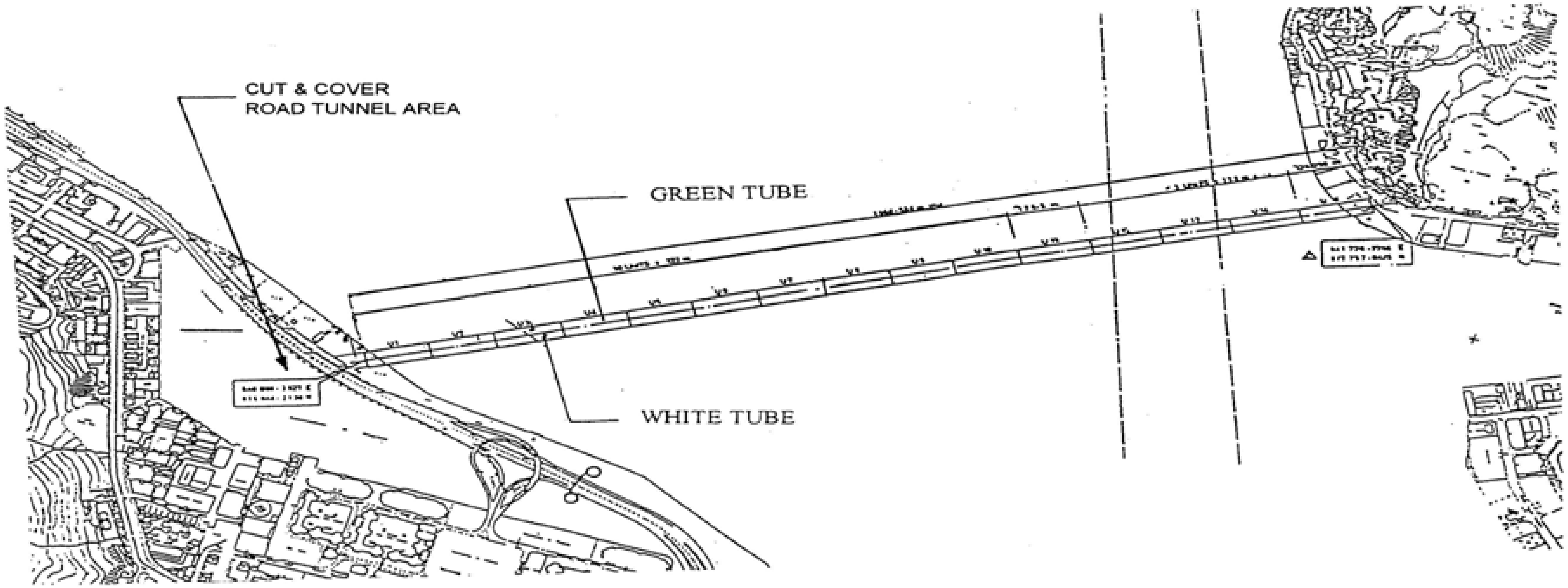


Figure 1.1 (a) Tunnel Plan View

Case Study – Eastern Harbour Crossing (EHC)

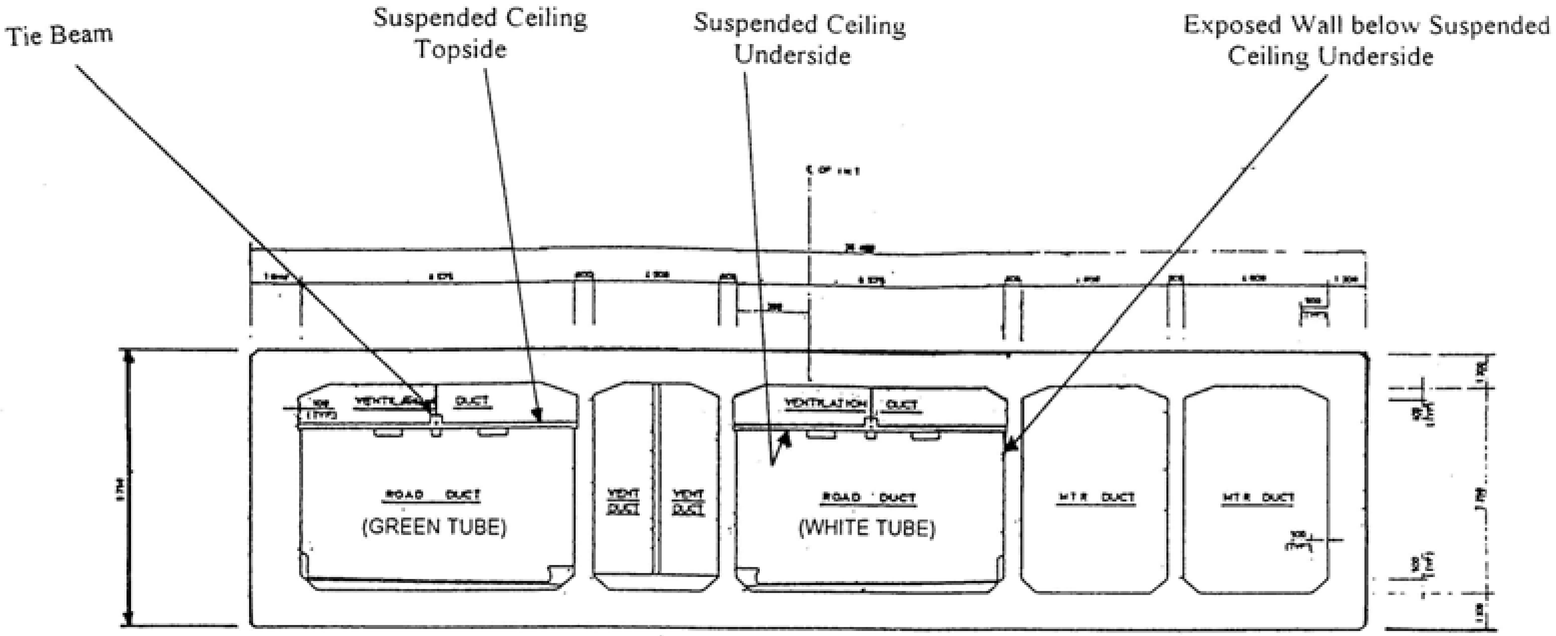


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Figure 1.1 (b) Tunnel Cross Section View

Investigation

- Working conditions
- Delamination survey
- Visual survey
- Chloride samples
- Potentials
- Resistivity
- Cover survey
- etc.

Design

- Using information on structure condition from investigation phase plus structural drawings
- Specify repairs required for delaminations and leaking cracks etc.
- Divide approx 1000m^2 of slab into 6 zones to be individually protected
- Specify reinforcement continuity (checked and implemented during repairs)
- Specify CP system requirements; TR unit, cabling, anode type and spacing, monitoring electrodes, power requirements, etc.

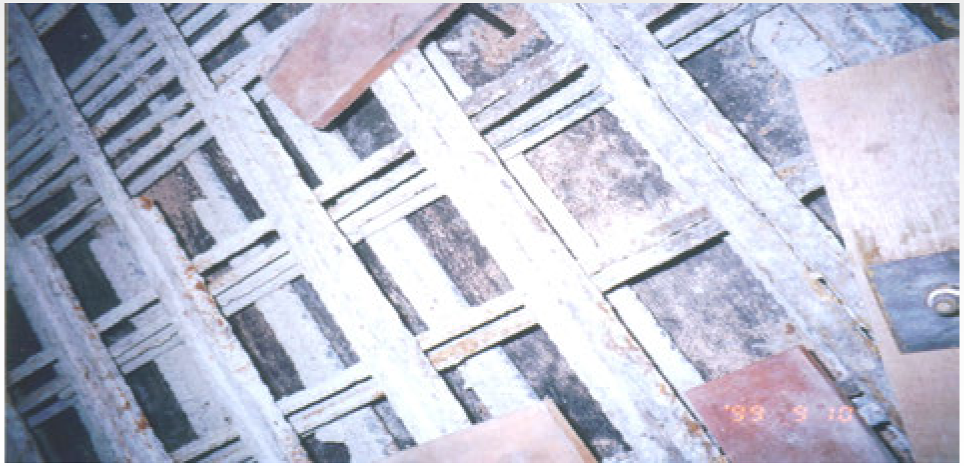
Polyurethane Crack Injection

- Leaking cracks sealed with flexible grout
- Allow for seasonal thermal movement
- Cross drill and inject at slab mid section
- Coring after injection for QC purposes

Patch Repairs




Slab Re-Casting



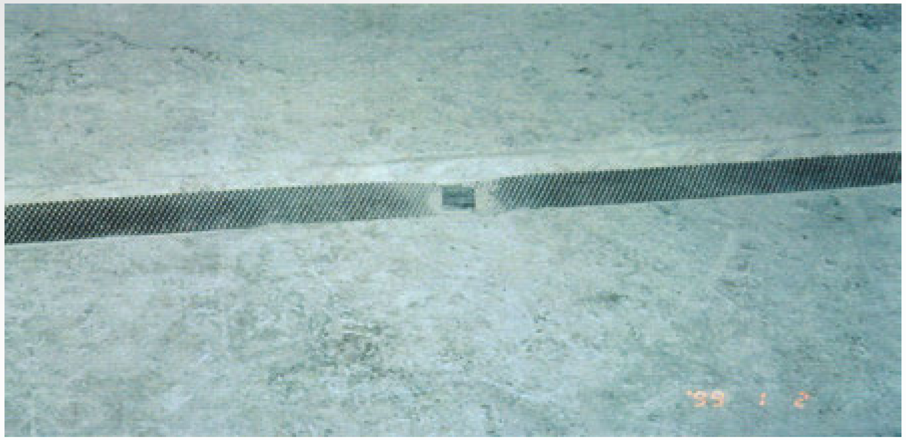
- Worst area of leakage
- Concrete cracked and delaminated above and below reinforcement
- Rebar cleaned, primed and new concrete placed

CP Installation - Anode

- Marking anode locations on slab top surface
- Anode laid out in accordance with design spacing
- Groove to be cut at anode locations

CP Installation - Anode

- Anode placed in groove
- Anode secured with plastic screw



CP Installation - Anode

- Anode strips welded together
- Anode welded to distribution bar
- Electrical continuity within discreet sections

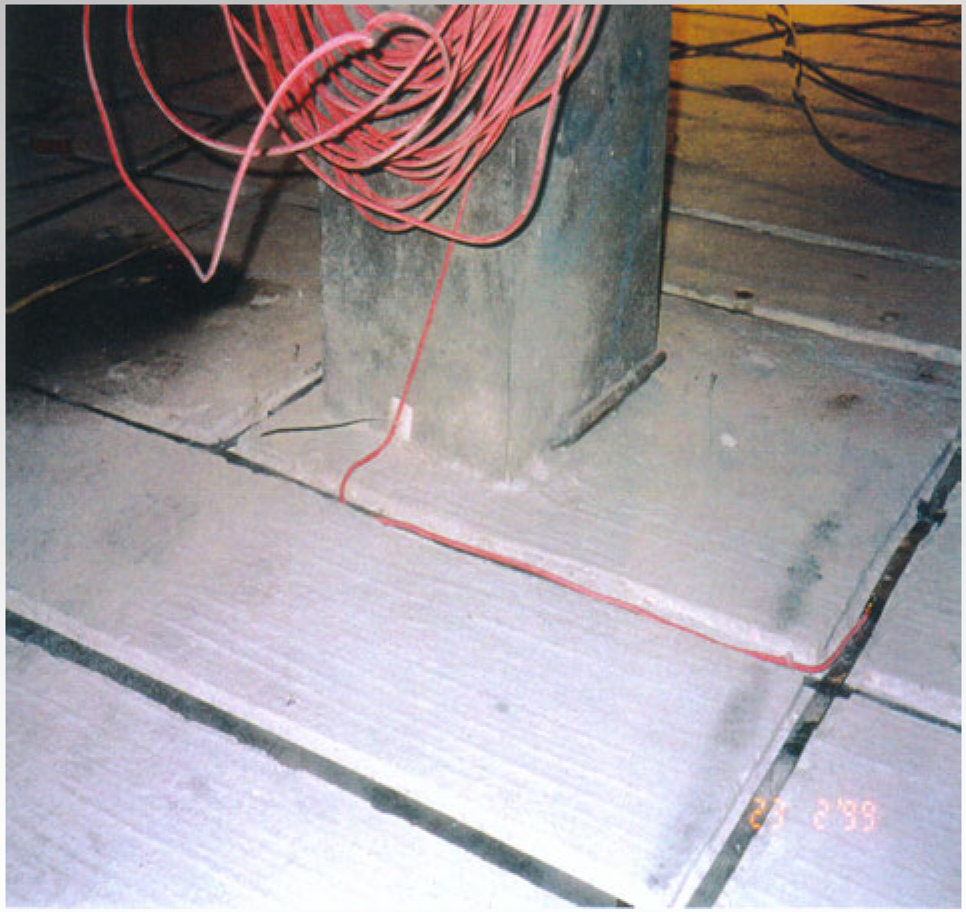
CP Installation – Ref. Electrodes

- Placed in pairs of silver/silver chloride electrodes
- At upper and lower layers of steel
- RE connection to reinforcement
- Negative return connection to upper reinforcement layer

CP Installation – Negative Return

- Two negative returns per zone
- Upper steel and lower steel
- Cable redundancy on upper steel connection
- Connection epoxy encased to prevent bimetalic corrosion

CP Installation – Anode Feed



- Positive connection from TR unit to anode
- Two connections to distribution bar per zone
- Connection redundancy
- Connection epoxy encased to prevent bimetalic corrosion

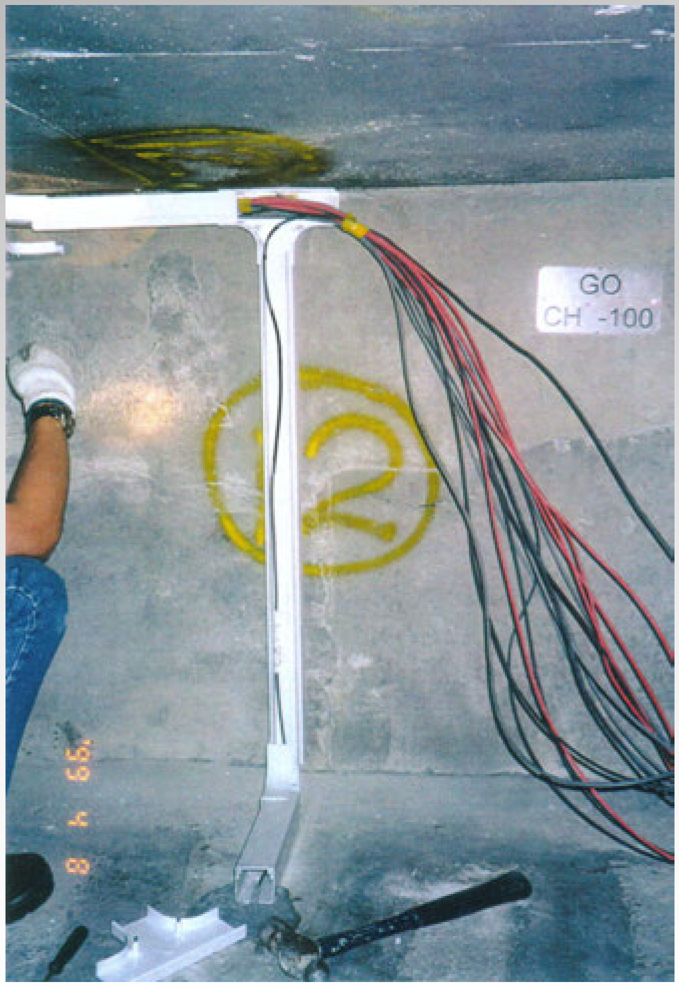
CP Installation – Anode Grouting

- Anode grouted to ensure full bond with concrete
- Proprietary flowable grout used for full anode encapsulation
- Reference electrodes and negative returns also grouted

CP Installation – Anode Grouting

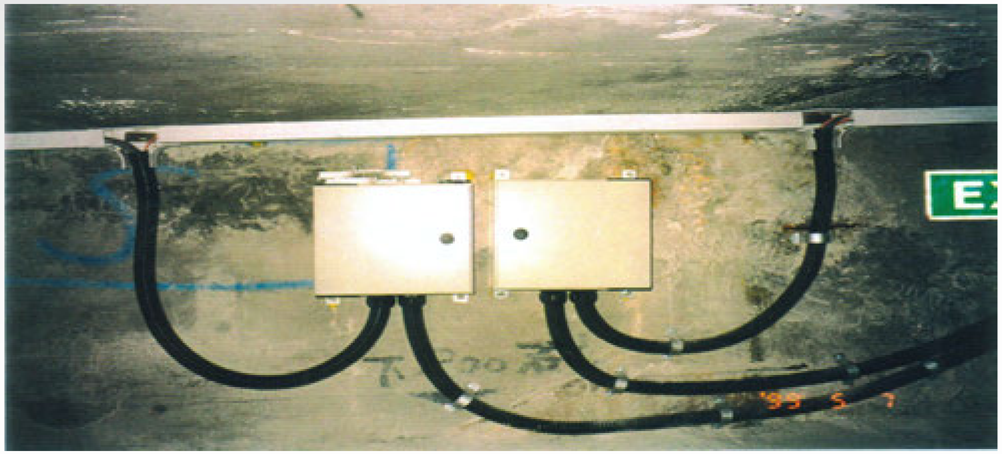
- Full anode encapsulation critical to system operation
- Core through grout and anode to visually inspect anode encapsulation and grout bond to concrete

CP Installation – Cabling

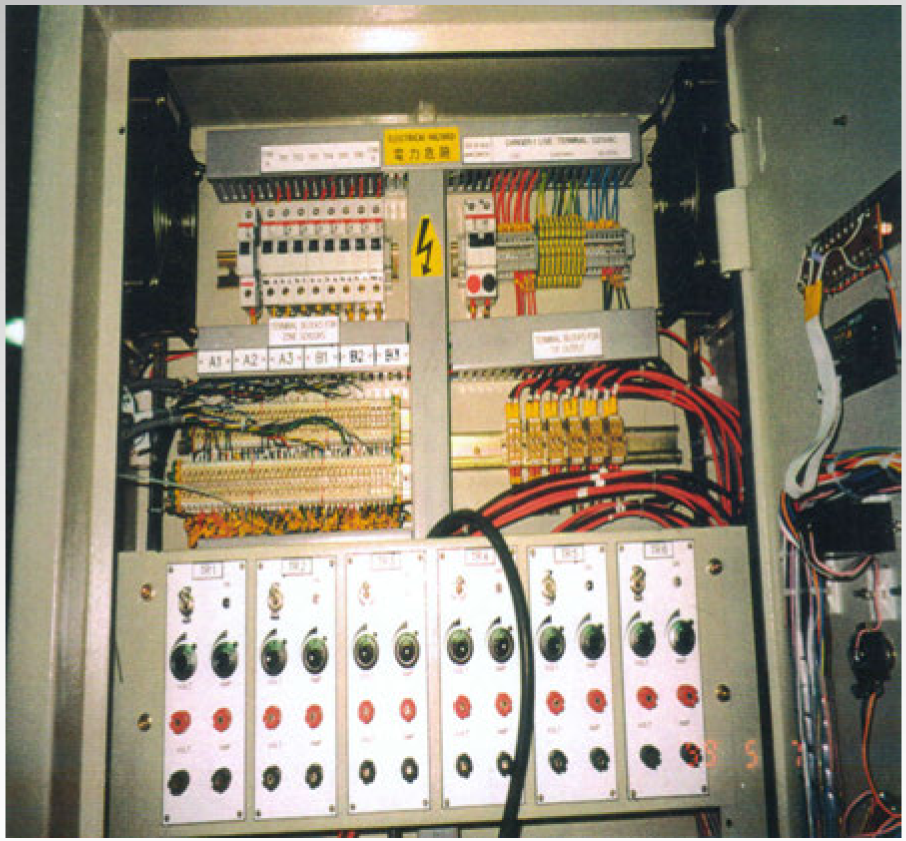


- Cables protected by conduit and run to junction boxes for each zone

- Cable in flexible conduit from junction boxes to TR unit



CP Commissioning



- Checking and energising the system
- Taking readings related to compliance criteria (instant off, potential decay)
- Assessing results
- Re-energising system and adjusting current to desired level

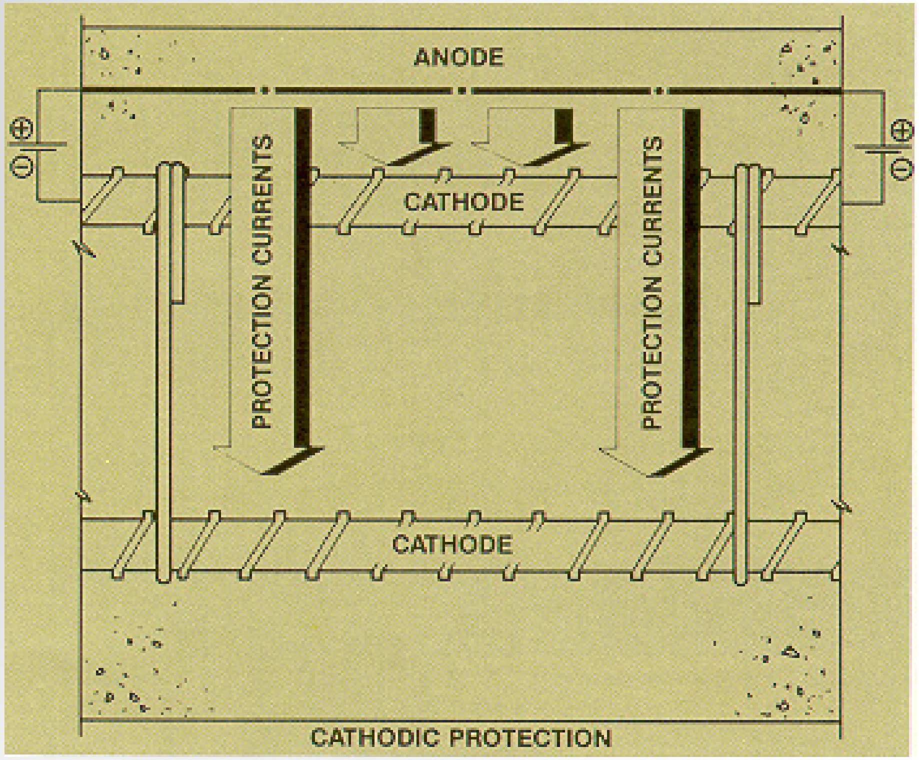
CP Operation and Monitoring

- System Monitoring
  - Monthly at first then becoming less frequent until annual after 4 or 5 years
  - General maintenance
  - Checking system operation
  - Potential decay
  - Adjusting current levels to provide optimum protection
- Operation without significant repair or replacement expected for a period exceeding 20 years

CP Provisions in New Structures

- Provide basic and necessary setup so as to facilitate the full installation and operation of future CP system
- Save initial capital costs
- Install at critical new structures in potentially hazard environments (e.g. tunnel, station and other structures exposed to drainage channel and aggressive soils)
- The need for energising of CP system is determined by assessing the data from the corrosion monitoring (CM) system

Components



- CP system design
- Re-bar continuity
- Negative returns
- Anode system design
- CP Monitoring System (CM System)

Examples of CP Provisions in Hong Kong

- Western Harbour Crossing immersed tube tunnels
- KCRC West Rail tunnels, stations, viaducts, box culverts, nullah structures and ancillary Structures
- KCRC East Rail Extensions viaducts

Devices

Reinforcement Continuity

- Objective: provide continuity of all reinforcement for future CP
- Device: continuity link reinforcement

Devices

Negative Returns

- Objective: provide the –ve connections
- Device: mild steel bar fixed to reinforcement

Devices

Reference Electrode

- Objective: to reflect the risk of steel corrosion and stray current influence
-
- Device: $Cu/CuSO_4$, Ag/AgCl reference electrode

Multi-depth Sensors

- Objective: monitor movement of chloride ions/carbonation front through concrete
- Device: pre-fabricated device consist of a series of coupled metal rods to be embedded in concrete cover

Devices

CM System in CP Provisions

- Objective: assess corrosion status and the need for implementation of a full CP System

- Device: reference electrodes and multi-depth sensors

- Monitoring at termination box

- Economical : < 1% of Total construction cost

Expelling Water by Electrochemical Method

-Multi-Pulse Sequencing (MPS) System

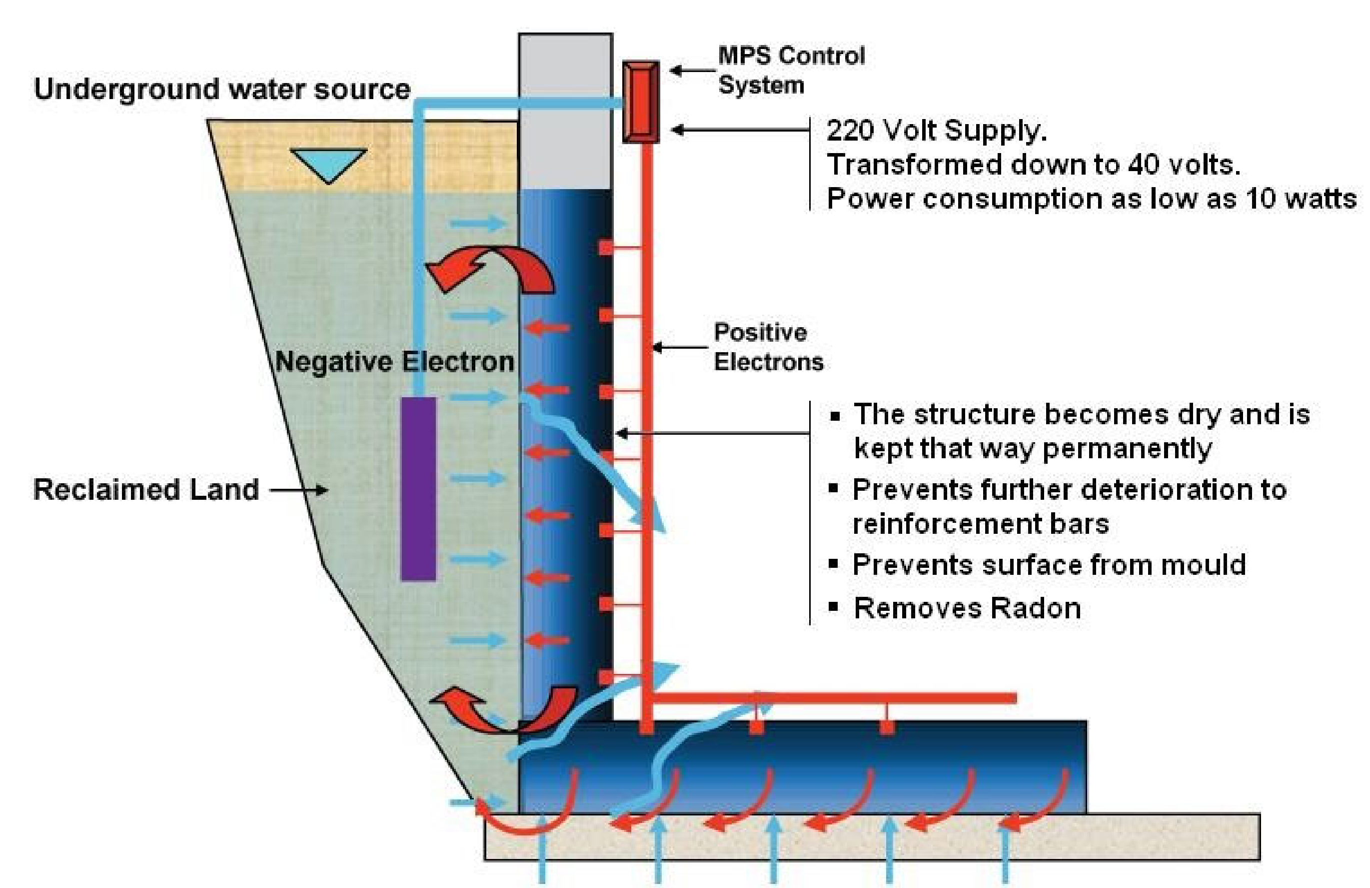
- Multi-function to prevent water ingress as well as slow down re-bar corrosion

Mechanism

- A highly advance form of electro-osmotic technology that uses low voltage and low current to ionise water and direct those liquid to a specific area
- The system will work under 60 bar of pressure
- Once drying is at the optimum level, the power usage will be less than the original required
- Normal drying time is around 4 to 8 weeks

Devices

- Anode
- Cathode in electrolyte (soil/water)
- MPS Control System Box
- Power Supply



MPS System at work

Before

After MPS System Installation

Electrical Cable Tunnel, Zhengzhou PR China

Before the Installation of MPS system

After the Installation of MPS system

MTRC Hong Kong Central Station Artwork Area

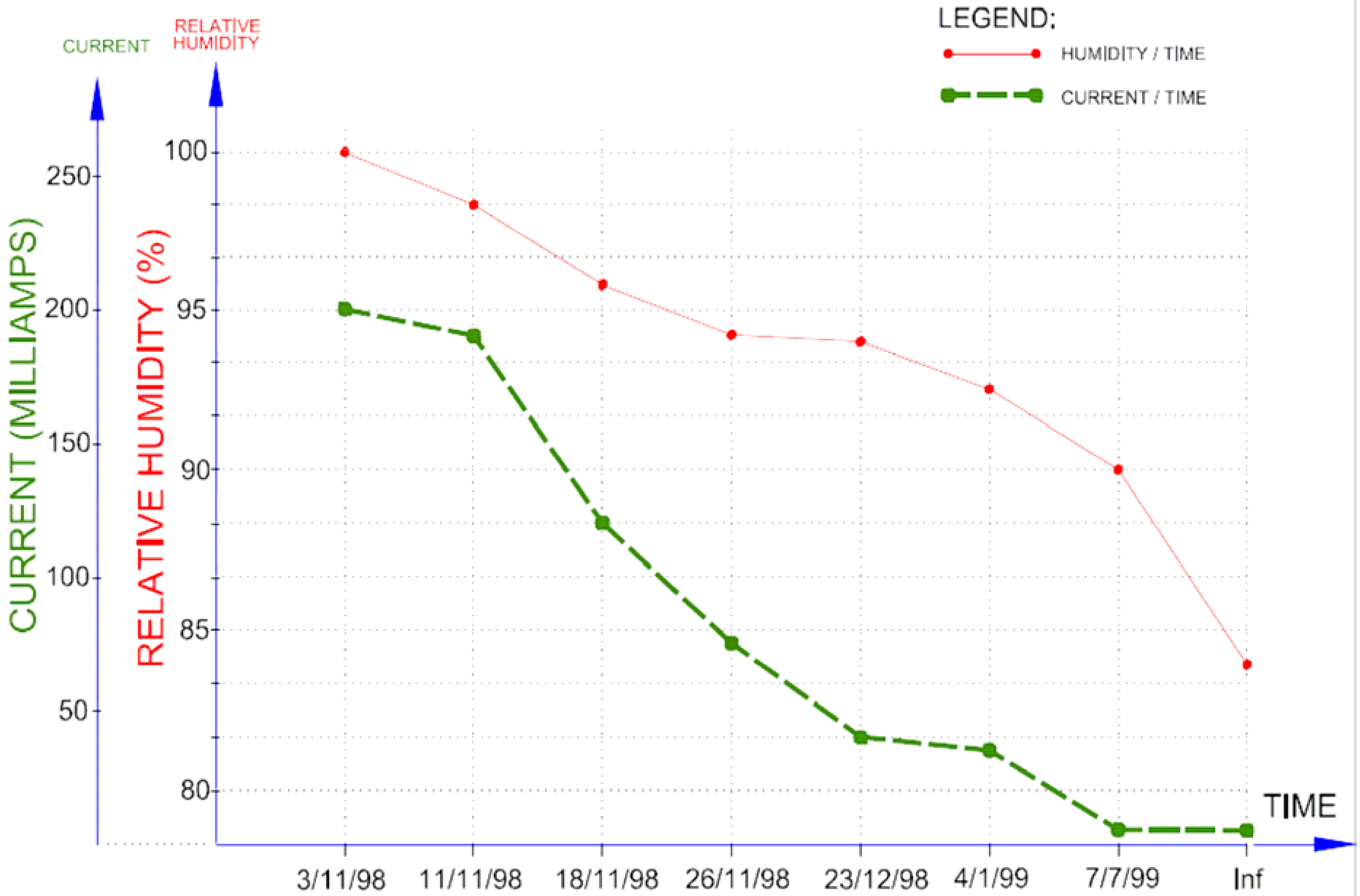
MPS System was installed at the Left side of the Artwork

No MPS installation at the Right side of the Artwork

Examples of MPS in Hong Kong

- Hong Kong International Finance Centre
- Hong Kong Central Station, Airport Express
- Hong Kong Hang Seng Bank Headquarters
- City Plaza Taikoo Shing Centre
- Hong Kong XinHua Agency

MPS MONITORING AT CITYPLAZA 4



Comparison

		Chloride Extraction	Re-Alkalinsation	CP	MPS
1	Application	Salt Contaminated	Carbonated	All	Water Leakage
2	Extended Service Life	Short	Medium	Long	Short to Medium
3	Capital Cost	Medium	Low	High	Low to Medium
4	Life Cycle Cost	High	Low	Medium	Low to Medium

Thank You