# Concrete Durability Requirements in Public Works Projects

**Speakers**


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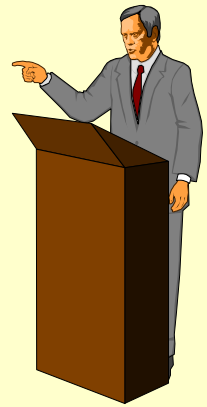


# Content

**Part 1 Durability of Reinforced Concrete Structures**

- **Introduction**
- **Factors Affecting Durability of RC Structures**
- **Deterioration of Structures**
- **Measures to Improve Durability**
- **Durability Tests**

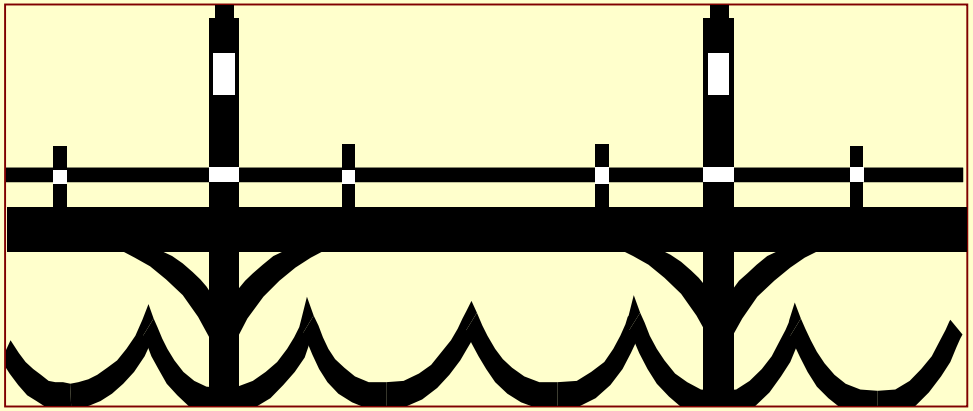
# Content

**Part 2 Requirements for Durability in Public Works Projects**

- **Cementitious Content**
- **W/C Ratio**
- **Workability**
- **Concrete Temperature Control**
- **Durability Requirements of Concrete**
- **Concrete Coating and Surface Treatment**

# Part 1

# Introduction



# Durability

**Prof. A.M. Neville, “Properties of Concrete”**

It is essential that concrete should withstand the conditions for which it has been designed, without deterioration, over a period of years. Such concrete is said to be durable.

# Durability

**BS8110 – Structural use of concrete**

A durable concrete element is one that is designed and constructed to protect embedded metal from corrosion and to perform satisfactorily in the working environment for the life-time of the structure.

# Durability

**BS EN 1992-1-1:2004 Design of concrete structures. General rules and rule for buildings**

• The choice of adequately durable concrete for corrosion protection of reinforcement and protection of concrete attack, requires consideration of the composition of concrete. This may result in a higher compressive strength of the concrete than is required for structural design.

- Strength = Durability ?

# Design Life

**Port Works Manual, 1996 edition**

- The design life of a structure is taken to be its intended useful life, and will depend on the purpose for which it is required.

- Design life for all permanent marine structures should be 50 years.

# Service Life

**Structures Design Manual, HyD**

- In the design of highway structures, due consideration should be given to durability during the service life. Achievement of durability is primarily affected by design and detailing, material specifications and quality of construction.

- The specific durability requirements of a structure should be assessed during the design stage and measures for their achievement should be considered.

# Total Design Life Solution vs Maintenance & Repair Design Life Solution

- Commonly used 120 years design life

- Meaning of 120 years design life:
  1. Total design life solution (i.e. no major maintenance) or
  2. No replacement but continued maintenance

# Factors Affecting Durability of RC Structures

## External Factors

- Temperature
- Humidity
- Chloride
- Chemicals including sulphate
- Climate factors like sunshine, freeze and thaws
- Oxygen and bacteria

# Summary of Hong Kong Climatic Data Over the Past 45 Years

| Description | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Mean (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Temperature (°C) | 15.8 | 15.9 | 18.5 | 22.2 | 25.9 | 27.8 | 28.8 | 28.4 | 27.6 | 25.2 | 21.4 | 17.6 | 23 |
| Range of Mean Daily Temp (°C) | 3.7 | 3.2 | 3.0 | 3.1 | 3.1 | 2.7 | 3.3 | 3.2 | 3.4 | 3.7 | 4.0 | 4.0 | 3.4 |
| Mean Relative Humidity (%) | 71 | 78 | 81 | 83 | 83 | 83 | 82 | 81 | 78 | 73 | 69 | 68 | 77 |

# Factors Affecting Durability of R.C. Structures

## Internal Factors

- Quality of Raw Materials
- Mix Design
- Alkali Aggregate Reaction
- Workmanship
- Curing

# Factors Affecting Durability of R.C. Structures

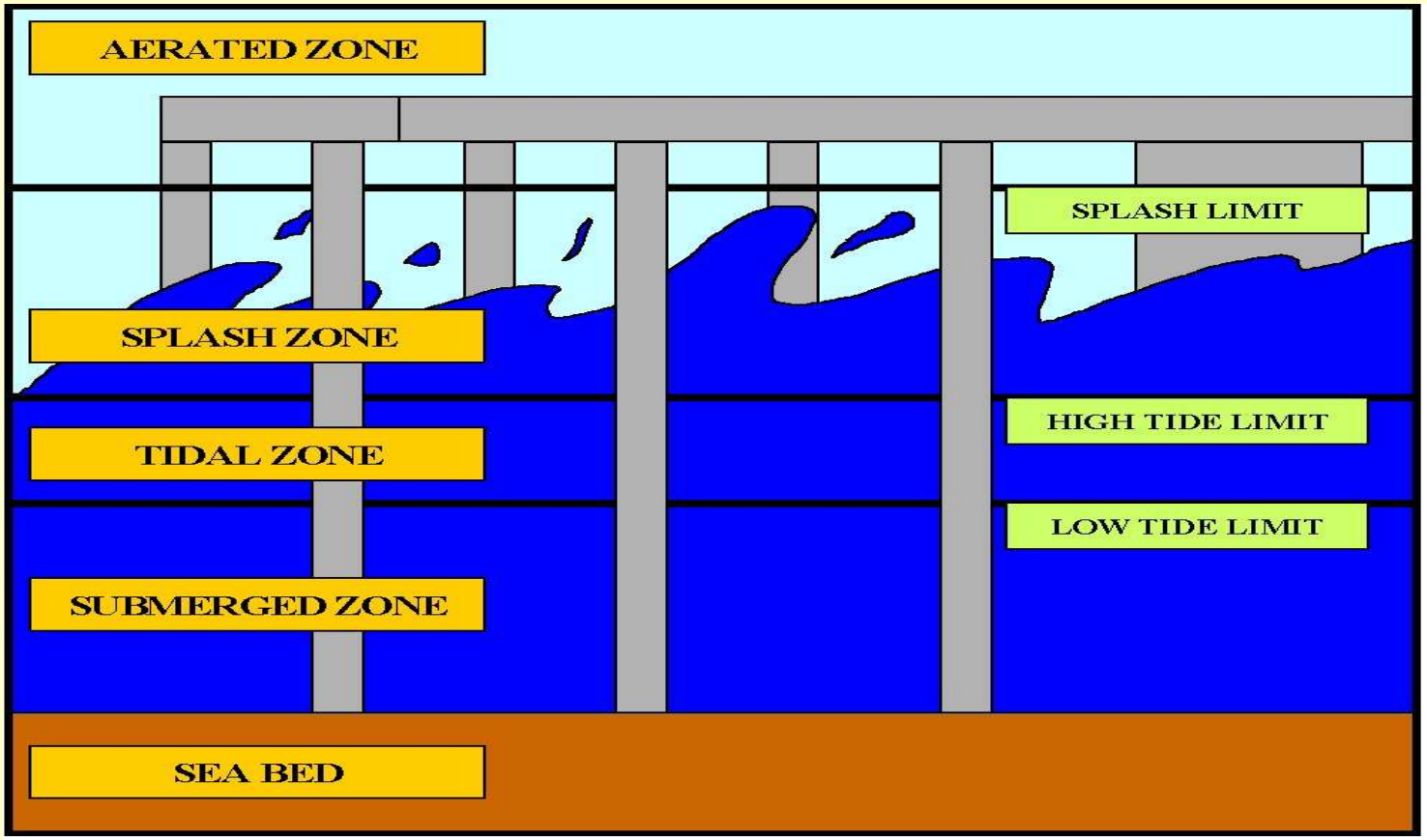
## Other Factors

- Structural cracks and damages due to inadequate structural design and detailing, or concrete shrinkage
- Use of chemicals and seawater for household maintenance
- Concrete coating

## Environments encountered

- Embedded below ground
- Submerged zone
- Tidal zone
- Splash zone
- Atmospheric zone

# Environments encountered




MARINE EXPOSURE CONDITIONS

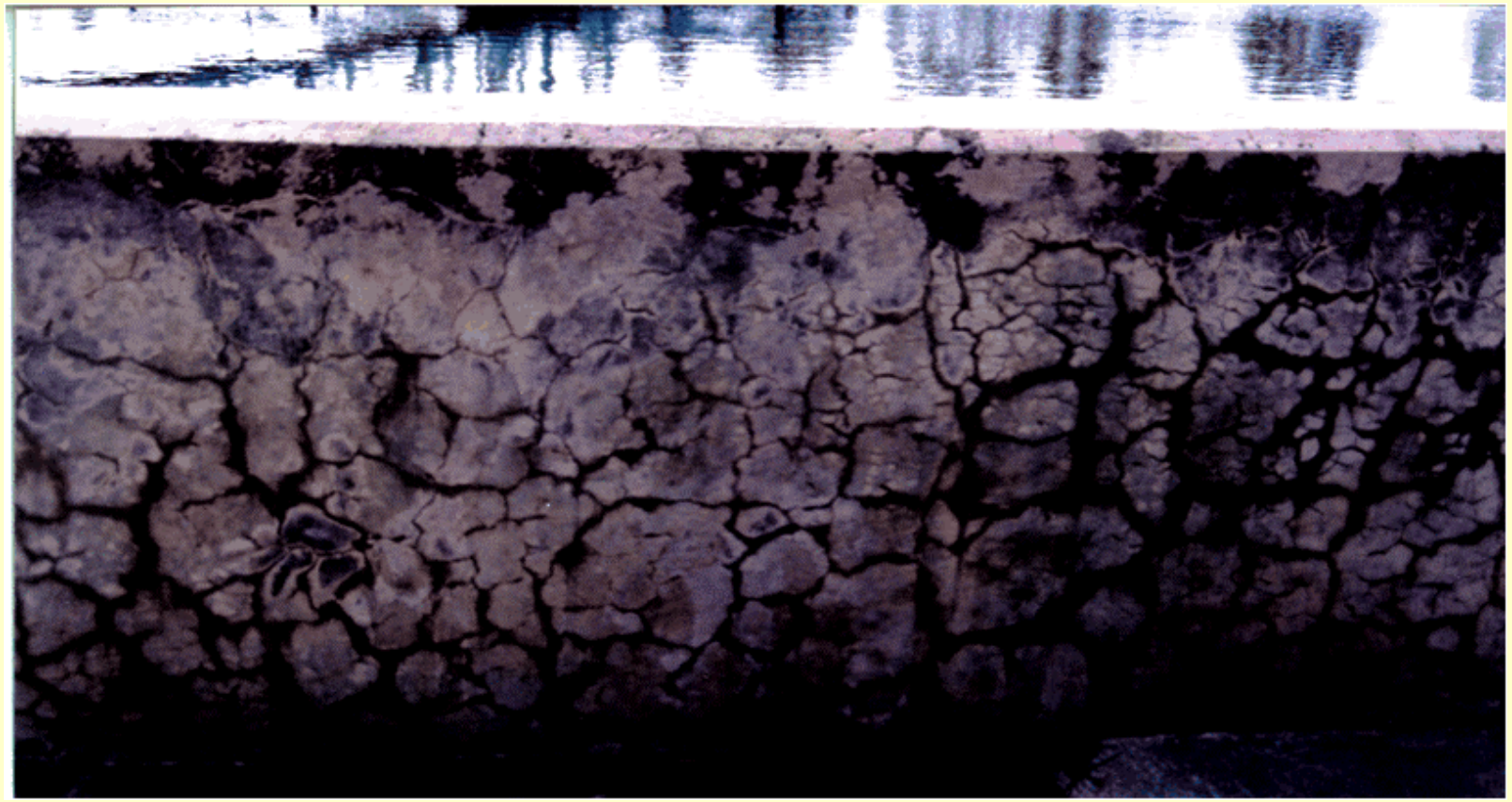
# Deterioration of Structures

# Deterioration of Structures

# Deterioration of Structures

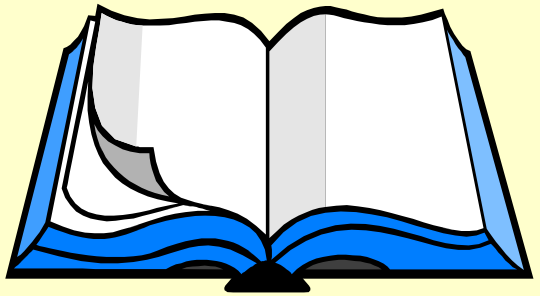
# Deterioration of Structures

# Deterioration due to AAR



## Measures to Improve Durability

- Reinforcement
- Measures to Impair Corrosion Process
- Improvements on Concrete Properties



# Measures to Improve Durability

## Reinforcement

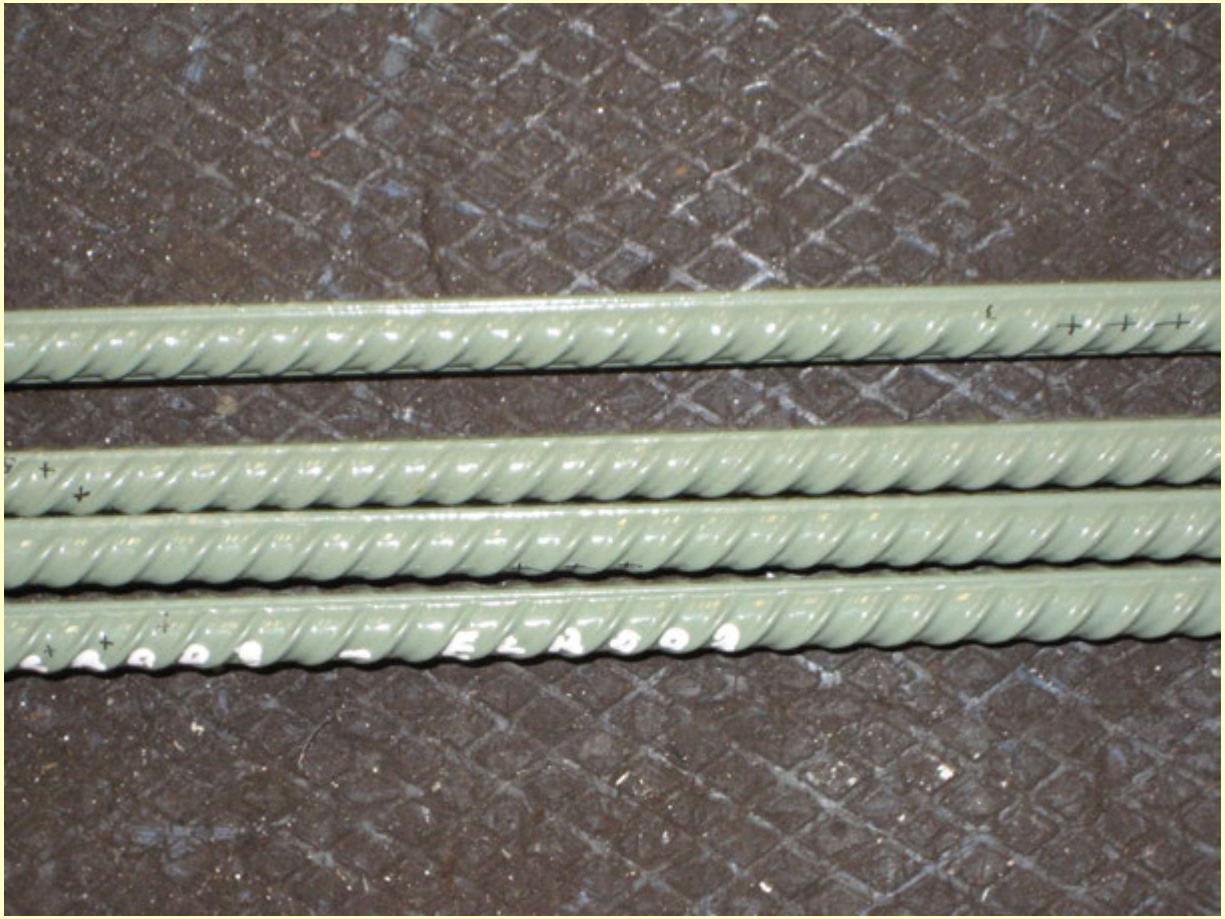
- Galvanized steel bars
- Epoxy coated reinforcement
- Stainless steel bars
- Carbon fiber reinforcement

# Measures to Improve Durability

## Reinforcement: Galvanized Steel Bars

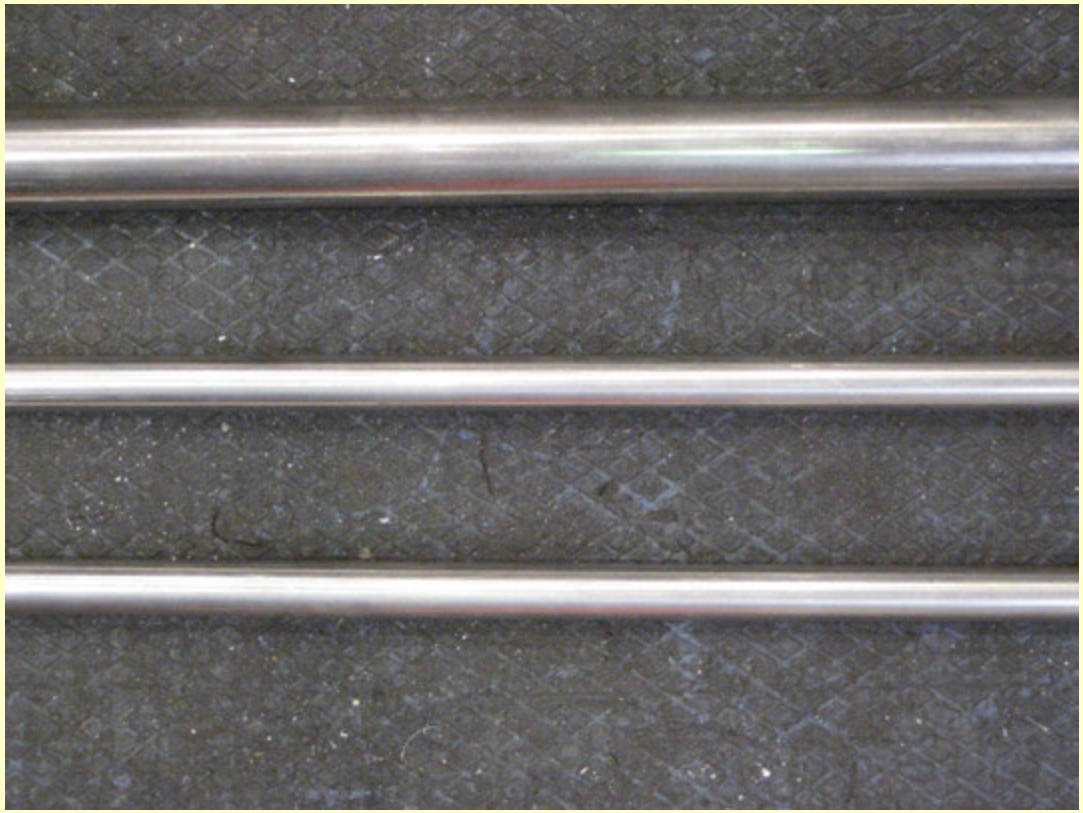
# Measures to Improve Durability

## Reinforcement: Epoxy Coated Reinforcement



# Measures to Improve Durability

## Reinforcement: Stainless Steel Bars



Source: International Molybdenum Association

# Measures to Improve Durability

## Reinforcement: Carbon Fiber Reinforcement

# Measures to Improve Durability

## Measures to Impair Corrosion Process

Increase concrete cover

- Marine concrete (GS Section 21):  Min. 75 mm

# Measures to Improve Durability

## Measures to Impair Corrosion Process

**Coating**

- Silane protection
- Epoxy coating

Silane protection

Applying the impregnation material on the Test Panel

# Measures to Improve Durability

## Measures to Impair Corrosion Process

### Coal Tar Epoxy

# Measures to Improve Durability

## Measures to Impair Corrosion Process

**Apply process such as impressed cathodic protection system**

Corrosion Process

Anode: $Fe \rightarrow Fe^{2+} + 2e^-$

Cathode: $0.5O_2 + H_2O + 2e^- \rightarrow 2OH^-$

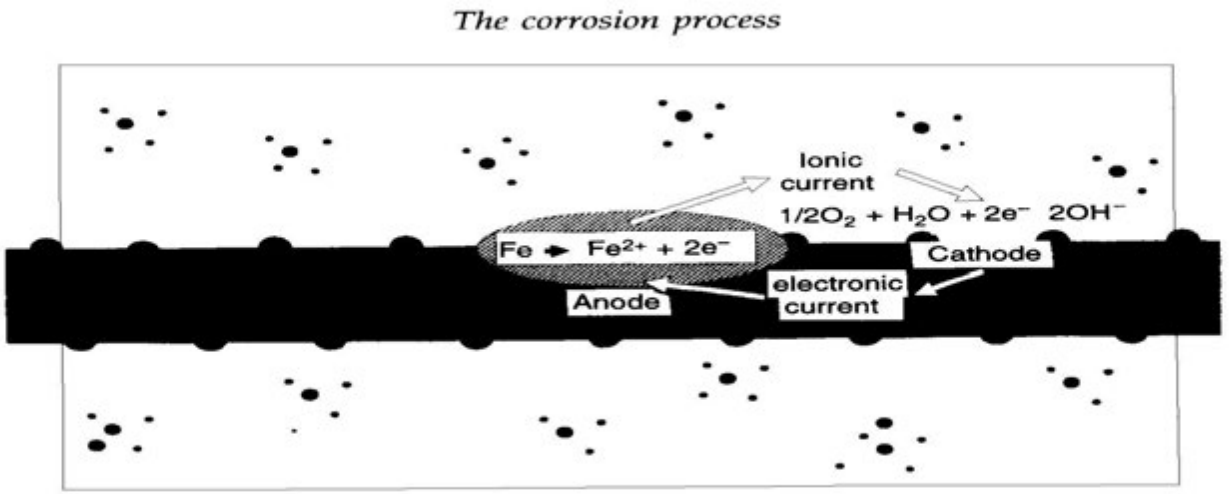



**Figure 2.1** The anodic and cathodic reactions.

# Durability Performance Tests

- **Bulk Diffusion Test**
- **Chloride Ion Penetration Test**

# Durability Performance Tests

## Bulk Diffusion Test



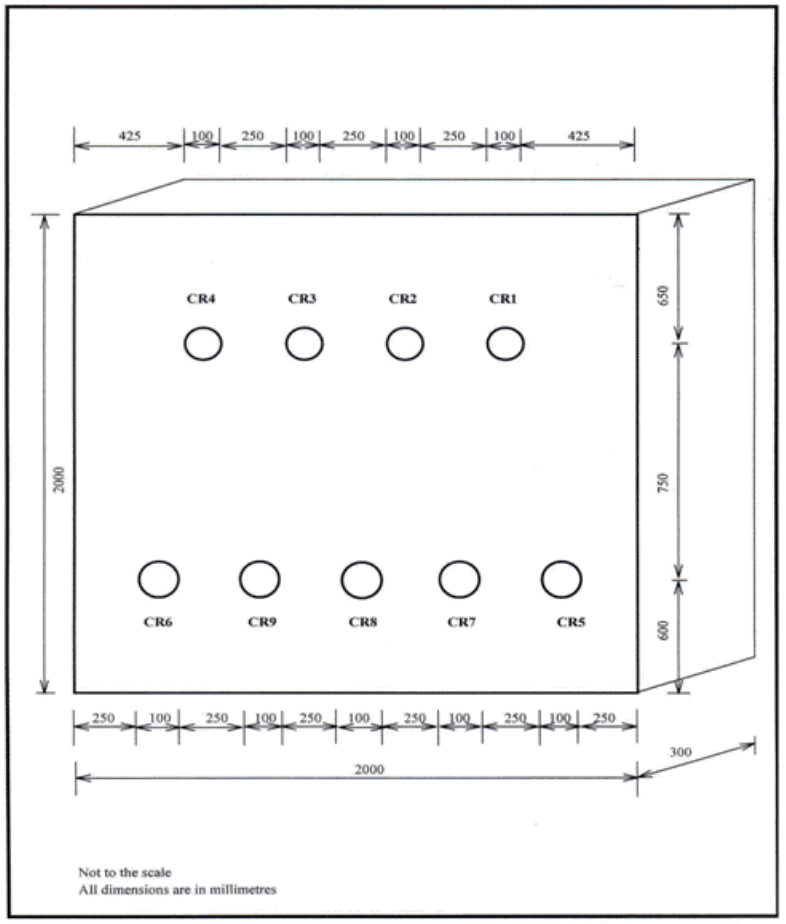


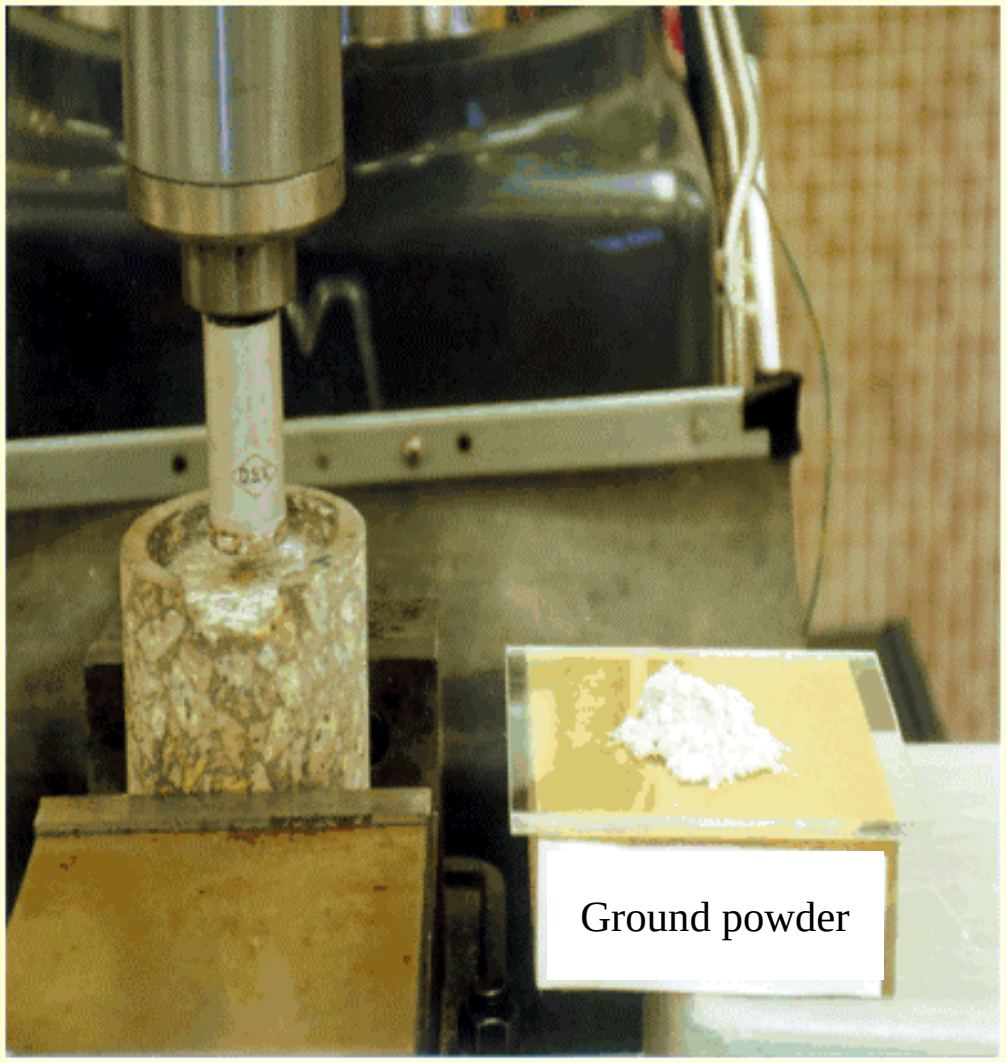

**Figure 2 - The Location of Cores on 2m x 2m x 0.3m Panel**

# Durability Performance Tests

## Bulk Diffusion Test

# Durability Performance Tests

## Bulk Diffusion Test



# Durability Performance Tests

## Results of Bulk Diffusion Test

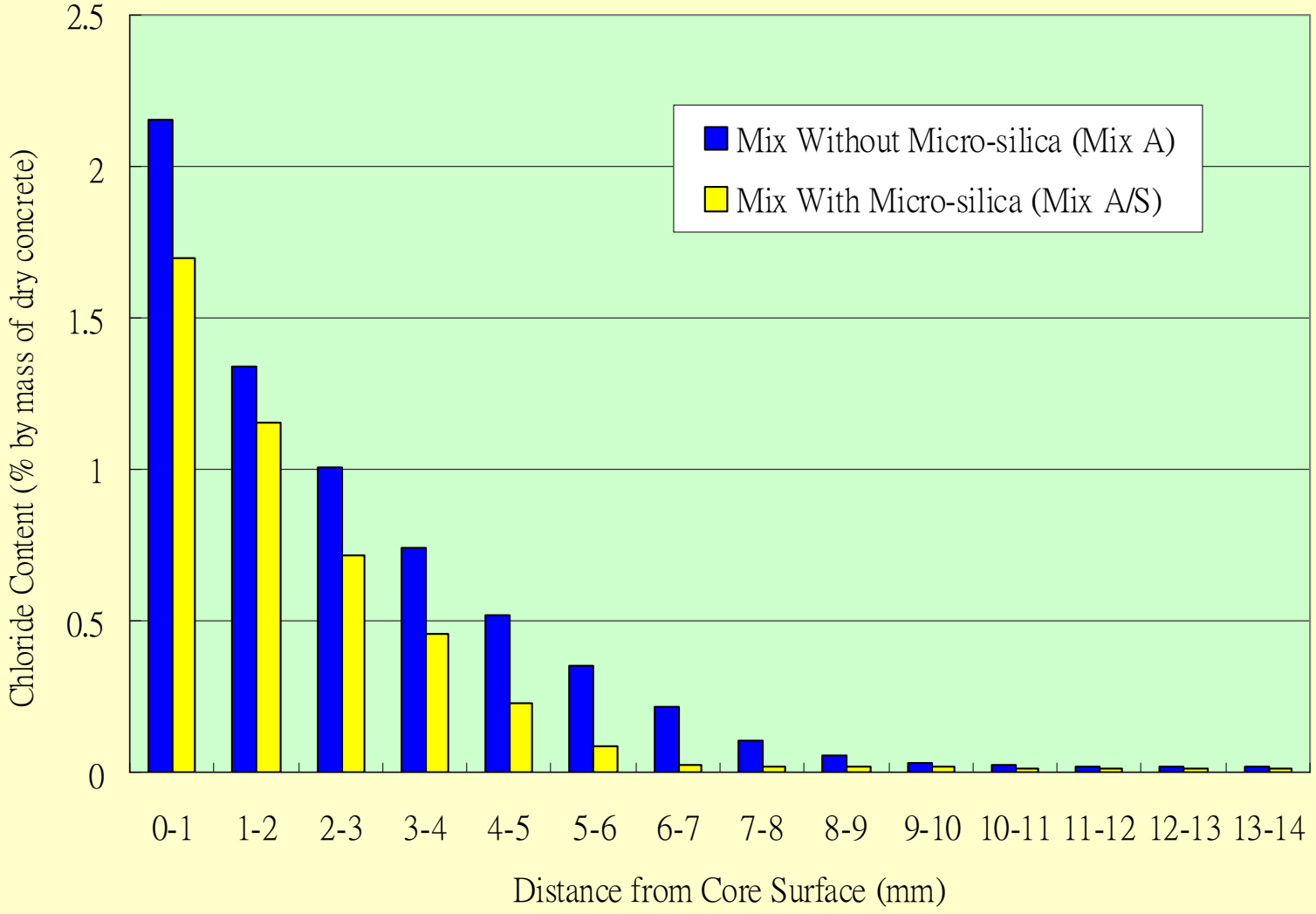
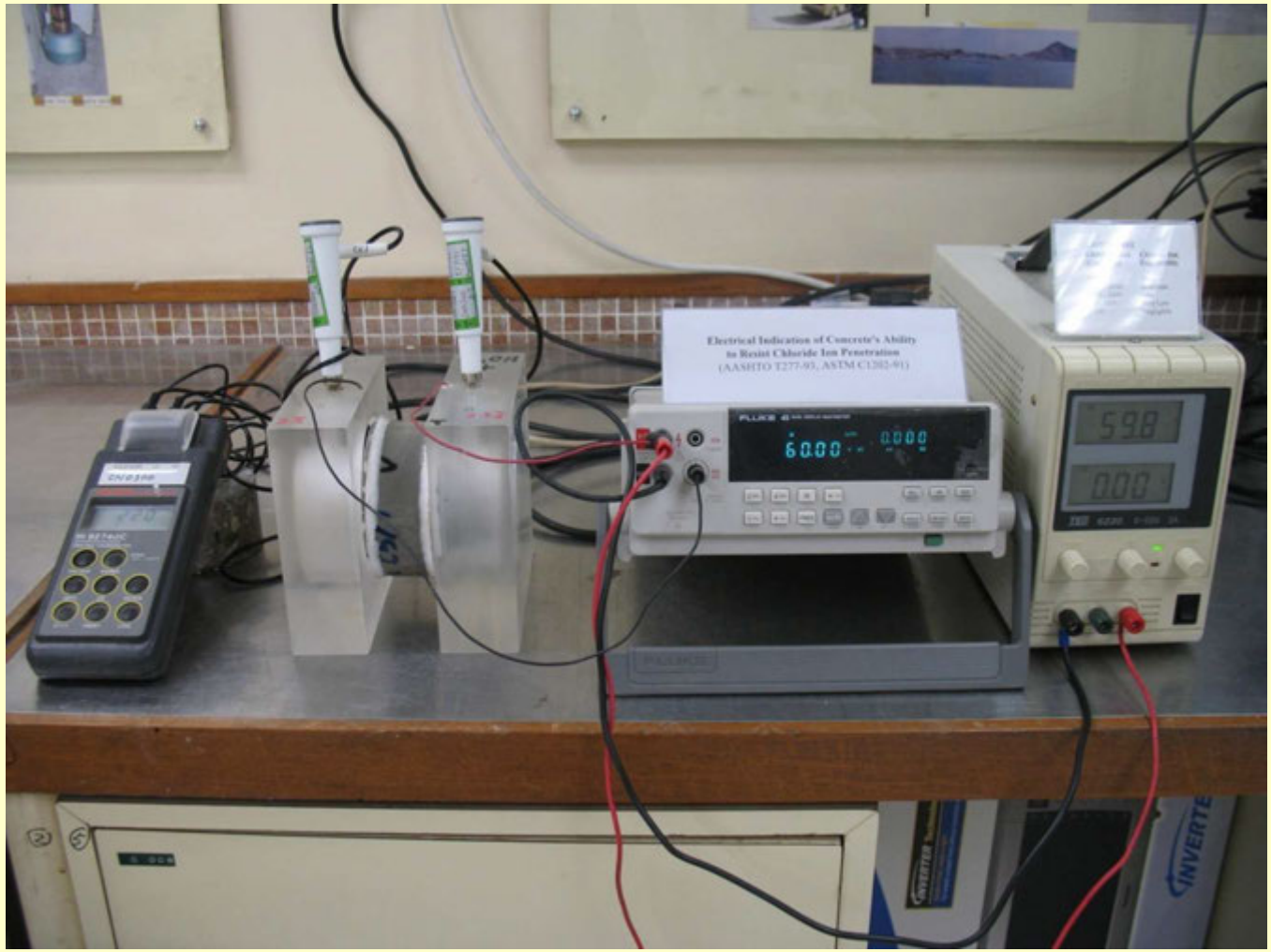



Fig 3 - Mean Choride Profiles of PFA Concretes at 84 Days

# Durability Performance Tests

## Chloride Ion Penetration Test




**CS1:2010 - Section 19 Determination of concrete's ability to resist chloride ion penetration**

# Durability Performance Tests

## Chloride Ion Penetration Test

| Charge Passed (Coulombs) | Chloride Ion Penetrability |
|---|---|
| >4000 | High |
| 2,000-4,000 | Moderate |
| 1,000-2,000 | Low |
| 100-1,000 | Very Low |
| <100 | Negligible |

# Part 2

# Requirements for Durability in Public Works Projects

- **Specification of concrete**

Aim:

To achieve state of art concrete quality with good durability performance

## Requirements for Concrete Durability in Public Works Projects

- **Cementitious Content**
- **W/C Ratio**
- **Workability**
- **Concrete Temperature Control**
- **Durability Requirements of Concrete**
- **Concrete Coating and Surface Treatment**

# Cementitious content

## Cementitious Materials

- Cement
- PFA or GGBS
- Microsilica

# Minimum Cementitious Content

## GS Section 16, (from Table 16.2 of GS):

| Grade strength (MPa) | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|
| Minimum cementitious content ($kg/m^3$) | 270 | 290 | 310 | 330 | 350 | 375 | 400 |

## Marine Concrete (GS Section 21)

- 380 $kg/m^3$

## Highways Project 1

- Grade 45: 350 $kg/m^3$ for all pile caps and 400 $kg/m^3$ for all bored piles
- Grade 60: 400 $kg/m^3$ for deck span, crossbeams and towers

## Highways Project 2

- Same as GS

## Drainage project

- Same as GS

# Maximum Cementitious Content

## GS Section 16

- For water retaining/water tight structures: 400 kg/m3 if use PC;
  450 kg/m3 if use PC and PFA
- Other structures: 550 kg/m3

## Marine Concrete (GS Section 21)

- 450 kg/m3

## Highways Project 1

- Grade 45: 450 kg/m3 for all pile caps and 500 kg/m3 for all bored piles
- Grade 60: 550 kg/m3

## Highways Project 2

- Same as GS

## Drainage Project

- Same as GS

## WSD Project

- The total cementitious content for salt water water-retaining structure shall not be less than 360kg/m3 and shall not exceed 430kg/m3.

# Cementitious Content: PFA, GGBS and Microsilica

| | GS Section 16 | Marine Concrete (GS Section 21) | HyD project 1 | HyD project 2 | DSD project | WSD Project |
|---|---|---|---|---|---|---|
| **Requirements** | Optional use of PFA & GGBS | Specified the use of CSF with either PFA or GGBS | Concrete grade 40 or above must contain wither PFA or GGBS. CSF may be used. | Concrete grade 40 must contain PFA. Grade 50 or 60 must contain CSF | Concrete grade 40 or above, PFA must be added. Grade 35 or below, either PFA or GGBS shall be added. | PFA must be used. |
| **PFA** | Normal concrete: not exceeding 35%<br><br>Pile cape/ substructure: at least 25% | 25 - 40% of total cementitious content | • 25 - 40% of the specified minimum cementitious content<br>• Min. 35% for Grade 60 concrete | 25 - 40% of the specified minimum cementitious content | 25-40% by mass of the cementitious content for concrete of Grade 40 and above for normal application | 25-40% by mass of the total cementitious content |
| **GGBS** | 35-75% for normal concrete (Proposed) | 60-75% of total cementitious content | • 60-80% of the specified minimum cementitious content<br>• Min. 60% for Grade 60 concrete | Not specified | • 60-75% by mass of cementitious content for normal application<br>• 60-90% by mass of cementitious content for low heat application | Not specified |
| **Microsilica** | Not specified | 5-10% of total cementitious content | Up to 8% of the specified minimum cementitious content | • Generally > 8%<br>• Min. 8% by weight of cementitious material for Grade 50 and 60 concrete | 5-10% by mass of the cementitious content | Not specified |

# Maximum water/cement ratio

| | | | | | | |
|---|---|---|---|---|---|---|
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# Workability

**GS Section 16**

- Minimum design slump shall be 75 mm

**Marine concrete (GS Section 21)**

- Same as GS Section 16

**HyD project 1**

- Same as GS Section 16

**HyD project 2**

- The workability of concrete is not specified but shall be proposed by the Contractor. Concrete workability of less than 75mm slump will not normally be acceptable.

**DSD project**

- Same as GS Section 16

**WSD project**

- Same as GS Section 16

# Concrete Temperature Control

**HyD project 1**

- Concrete grade 40 and above: placing temperature shall not exceed 30°C; grade 20 – 40, not exceed 32°C
- If section >= 500mm, placing temperature shall not exceed 25°C
- Peak temperature shall not exceed 70°C; if contain at least 25% PFA or 45% GGBS, then the peak temperature shall not exceed 80°C
- For large section, temperature differential (center to surface) shall not exceed 30°C. The max temperature difference between any points at 600mm apart shall not exceed 30°C.

**HyD project 2**

- Placing temperature shall not exceed 32°C
- Peak temperature shall not exceed 70°C
- Temperature gradient (center to surface) shall not exceed 20°C per m

**DSD project**

- Concrete grade 45 or above, the peak temperature shall not exceed 70°C. The maximum temperature difference (center to surface) shall not be greater than 20°C per m
- Concrete grade 40 or below, placing temperature shall not exceed 32°C

**WSD project**

- Placing temperature of concrete for water retaining structures shall not exceed 32°C

# Durability Requirements of Concrete

**GS Section 16 and Marine Concrete (GS Section 21)**

- None, except strength requirements

**HyD project 1**

- Grade 60 concrete: AASHTO T277-93, Mean value less than 1000 coulombs at 28 days

**HyD project 2**

- Same as GS Section 16

**DSD project**

- Water sorptivity test: not exceeding 0.07 mm/min
- AASHTO T277 at 28 days not exceeding 1000 coulombs

CS1:2010 - Section 19 Determination of concrete's ability to resist chloride ion penetration

# Other Durability Requirements

## Sulphate Soundness of Aggregates

- **GS Section 16**
  - Magnesium sulphate soundness weighted average loss shall not exceed 6%
- **Marine Concrete (GS Section 21)**
  - Same as Section 16
- **DSD project 1**
  - Maximum sodium sulphate soundness (ASTM C88) weighted average loss shall be 6%
- **DSD project**
  - Similar to DSD project 1

# Other Durability Requirements

## Alkali-silica Reaction (ASR)

- **PAH: Chapter 5, Appendix 5.9**
  - Additional requirements imposed referring to GEO Report No. 167
- **GS Section 16**
  - Inert to ASR unless a control framework installed
- **GS Section 21**
  - Same as Section 16
- **HyD project 1**
  - Similar to GS
- **HyD project 2**
  - Similar to GS and PAH
- **DSD project**
  - Similar to GS and PAH

## Concrete Coating and Surface Treatment

- **GS Section 16**
  - No particular requirement
- **GS Section 21 (marine concrete)**
  - PS to Model Specification for Protective Coatings for Concrete. Allowing the use of epoxy resin, acrylate, polyurethane resin and monomeric isobutyltriethoxysilane coatings.
- **HyD project 1**
  - Silane protection
- **HyD project 2**
  - No particular requirement
- **DSD project**
  - No particular requirement

# End of Presentation

Thank you!