Concrete Specification and Maintenance Strategy for Marine Structures

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Part 1: Specifications for Marine Structures in HK

- Durability and Design Life of Marine Concrete Structures
- Factors affecting Durability of Marine Structures
- Conventional Specifications for Marine Concrete
- Durability Performance of Conventional Marine Concrete Structures
- Development of Marine Concrete Specification
- Durability Performance of Marine Concrete
- Recommendations to enhance durability performance

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.

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.



- 120 year design life
- For major structural elements, design life means without replacement

Factors Affecting Durability of Marine Structures

Internal Factors

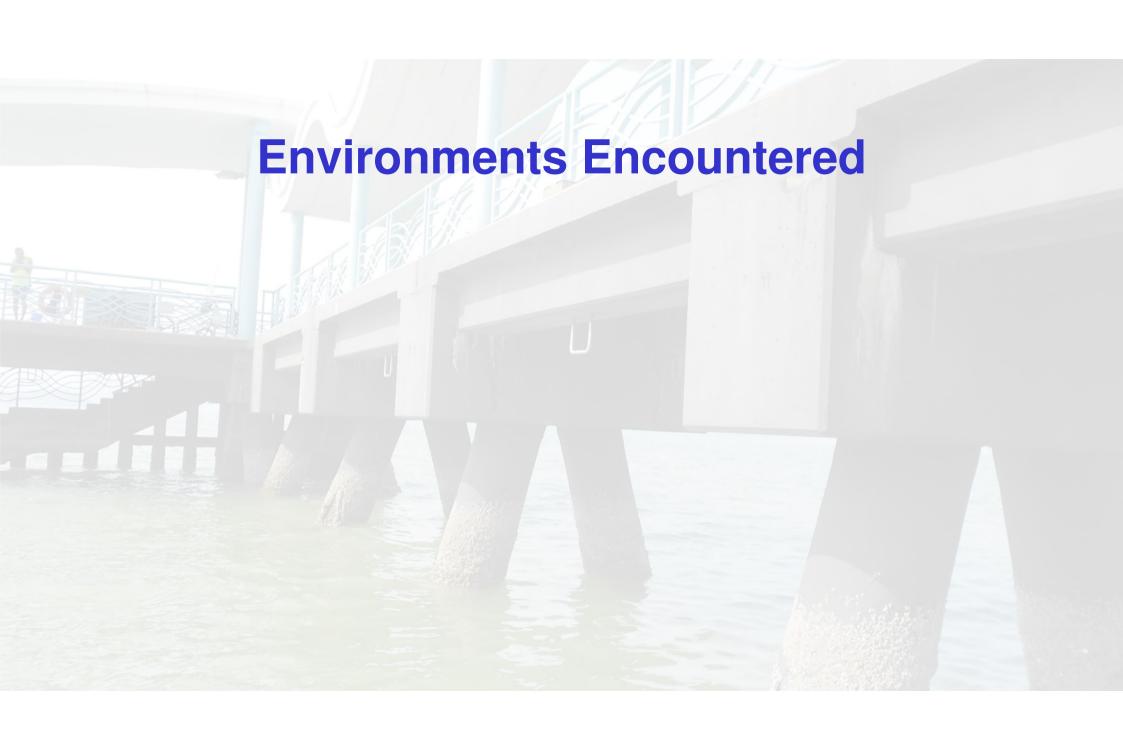
- Properties of Concrete
 - Quality of Raw Materials
 - Strength of Aggregate
 - Mix Composition
 - Workmanship
 - Curing

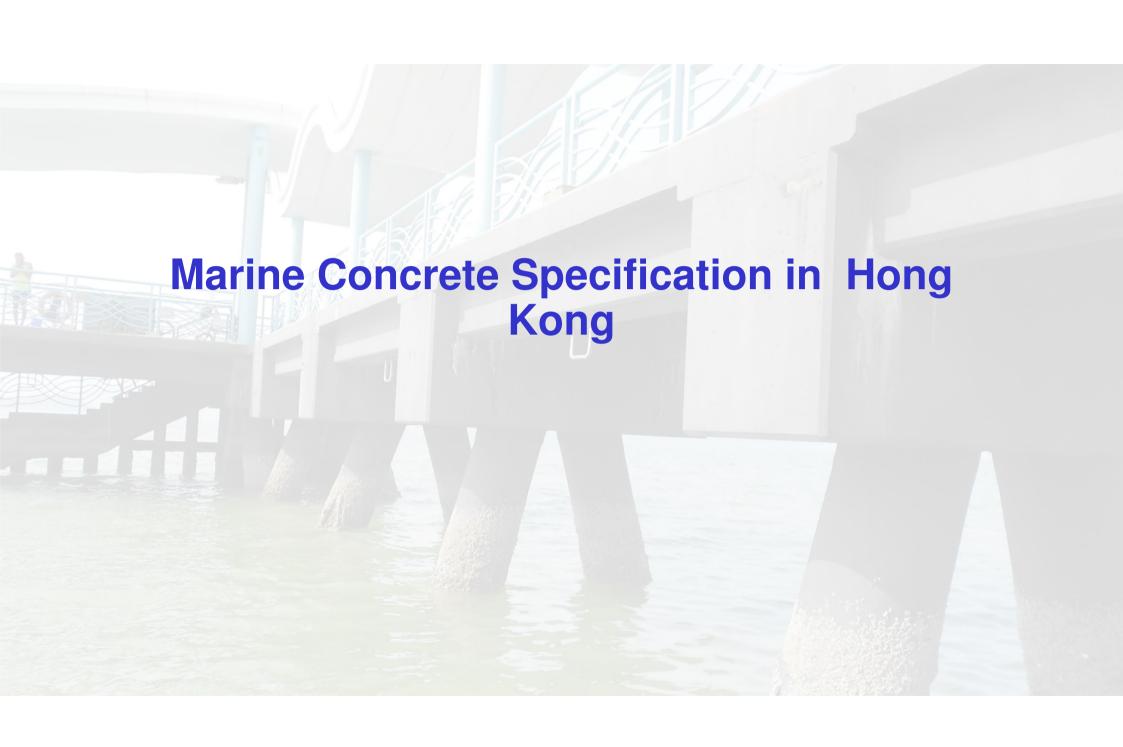
Factors Affecting Durability of Marine Structures

Other Factors

- Alkali Aggregate Reaction
- Chemical Attack
- Abrasion and Weathering
- Creep and Shrinkage
- Corrosion of Reinforcement





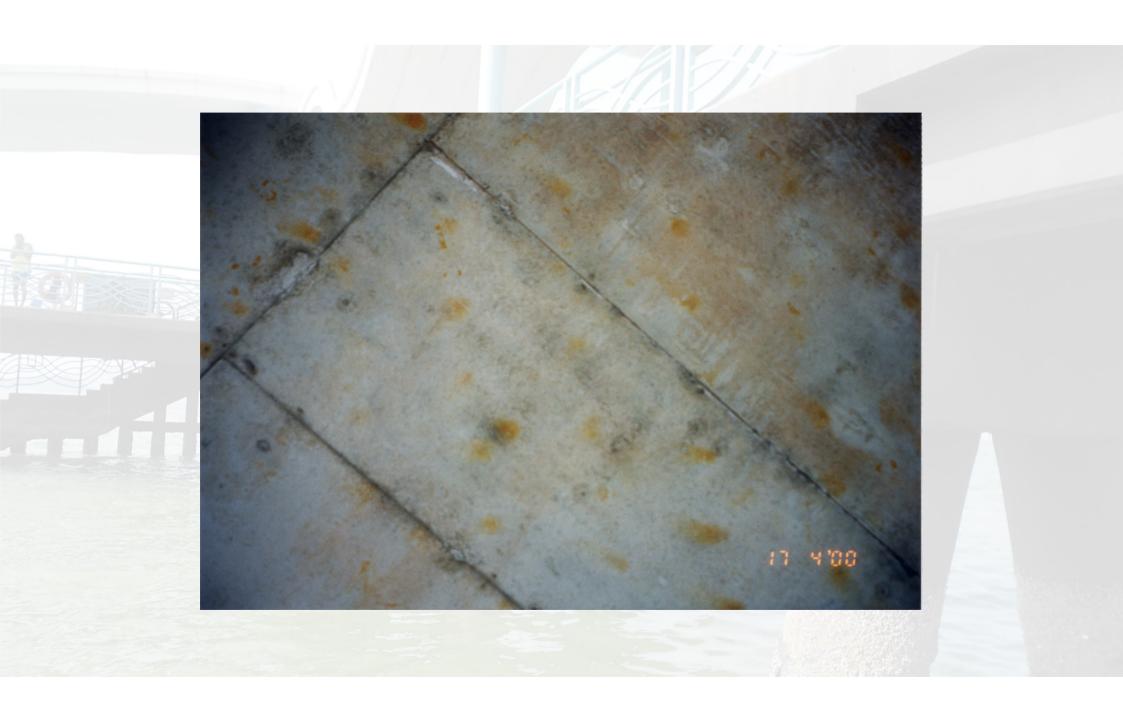


Conventional Concrete Specification

Specification	Interim Specification 1994	Port Works Manual 1992	BS8110, BS6349 Not stated			
Design life	50 years	50 years				
Minimum compressive strength	45MPa	45MPa	40MPa			
Maximum free water/cementitious ratio	0.4	0.42	BS6349 states 0.45			
Minimum concrete cover for fully immersed, tidal, and splash zones	r fully immersed, tidal,					
Minimum concrete cover for aerated zone	60mm nominal cover	50mm nominal cover				
Cement type	OPC; PFA (25-40%) replacement mandatory	OPC	SRPC not permitted. No codes specify PFA, GGBS, CSF			
Range of cementitious content	360-430 kg/m ³	375-550 kg/m ³	350-400 kg/m ³			
Minimum slump	75mm	75mm	haring the			







































Development of Marine Concrete Specification to Improve Durability

- In 1995, the PWD of CEDD instigated a consultancy to look into durability of its marine stock.
- CEDD's Public Works Central Laboratory also carried out another series of research on the influence of microsilica on the strength and durability characteristic of concrete

12 Trial Mixes for Laboratory and In-situ Test

- Laboratory Tests
 - Compressive Strength
 Test
 - Chloride Diffusion Test
 - Sorptivity Test

- Site exposure test for 3 months and 6 months
 - Chloride Diffusion Test



Durability Performance Tests

Results of Bulk Diffusion Test

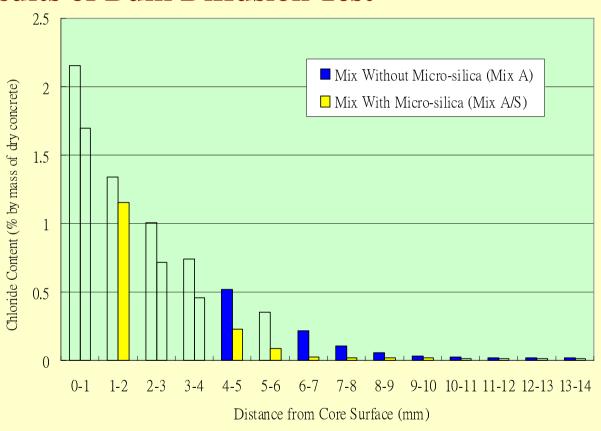


Fig 3 - Mean Choride Profiles of PFA Concretes at 84 Days

		D	etails	of Co	ncrete	Tria	l Mix	es				
Mix	1	2	3	4	5	6	_7	8	9	10	11	12
Total Cementitious Content (kg/m³)	428	430	419	437	418	438	420	418	419	417	418	419
Mineral Admixtures (kg/m³)		25% PFA	25% PFA	25% PFA	33% PFA	33% PFA	70% GGBS	70% GGB S	10% CSF	25% PFA & 5% CSF	33% PFA & 5% CSF	70% GGBS & 5% CSF
Water/Cementitious Ratio	0.42	0.40	0.38	0.35	0.38	0.35	0.38	0.35	0.38	0.38	0.38	0.38
Laboratory Test Result	ts											
Compressive Strength (MPa)	73	61	64	69	55	63	65	71	83	60	54	67
Water Sorptivity (mm/min ^{0.5})	0.175	0.150	0.125	0.105	0.110	0.115	0.085	0.095	0.110	0.120	0.130	0.10
Chloride Diffusion Coefficient (10 ⁻¹² m ² /sec)	3.25	5.10	5.15	3.60	3.35	6.20	2.10	1.75	2.75	4.50	4.50	1.40
Field Test Results (Chl	oride di	iffusio	n coef	ficient	at tida	l zone	after	exposu	re for)			
3 Months (10 ⁻¹² m ² /sec)	4.2	6.1	4.4	3.9	5.8	4.7	2.7	2.8	2.7	4.6	4.3	2.0
6 Months (10 ⁻¹² m ² /sec)	3.2	3.1	3.1	1.9	2.4	2.5	1.6	1.4	2.5	3.0	2.6	1.8

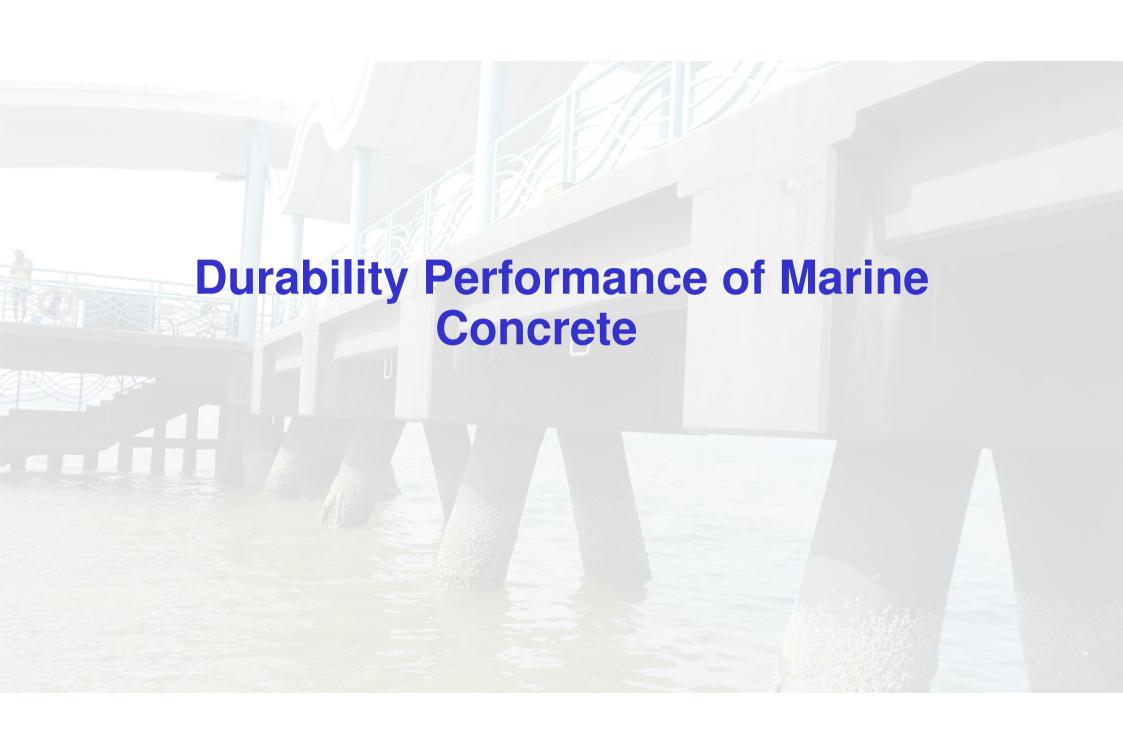


Comparison of Different of Concrete Specifications

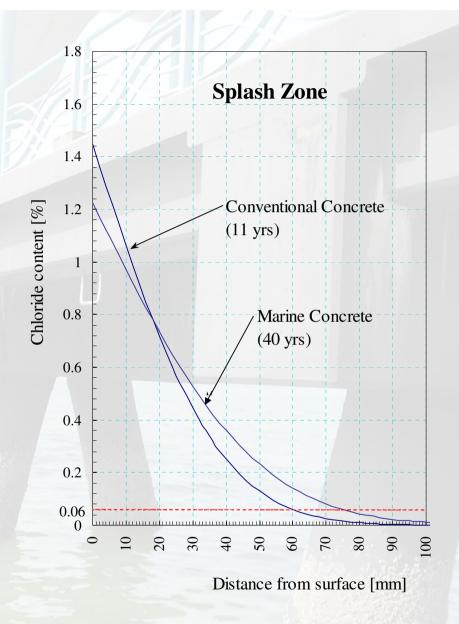
Country	Hong Kong			UK
Specification	Marine Specification 1998	Interim Specification 1994	Port Works Manual 1992	BS8110, BS6349
Design life	Not stated	50 years	50 years	Not stated
Minimum compressive strength	45MPa	45MPa	45MPa	40MPa
Maximum free water/cementitious ratio	0.38	0.4	0.42	BS6349 states 0.45
Minimum concrete cover for fully immersed, tidal, and splash zones	75mm	60mm nominal cover	60mm nominal cover	BS6349 states 50mm but preferred 75mm
Minimum concrete cover for aerated zone	75mm	60mm nominal cover	50mm nominal cover	

Comparison of Different Concrete Specifications

Country	Hong Kong			UK
Specification	Marine Specification 1998	Interim Specification 1994	Port Works Manual 1992	BS8110, BS6349
Cement type	CSF (5-10%); GGBS (60-75% for normal application and up to 90% for low heat application); PFA (25-40%), not to be used with GGBS	OPC; PFA (25-40%) replacement mandatory	OPC	SRPC not permitted. No codes specify PFA, GGBS, CSF
Range of cementitious content	380-450 kg/m ³	360-430 kg/m ³	375-550 kg/m ³	350-400 kg/m ³
Minimum slump	75mm	75mm	75mm	-
Miscellaneous	Equivalent sodium oxide per m³ of concrete < 3kg Flakiness Index < 30% Elongation Index < 35% Los Angeles Value≦ 30% Sodium sulphate soundness weighted average loss < 6%		-	



Projected chloride profiles of microsilica concrete and conventional concrete at splash zone















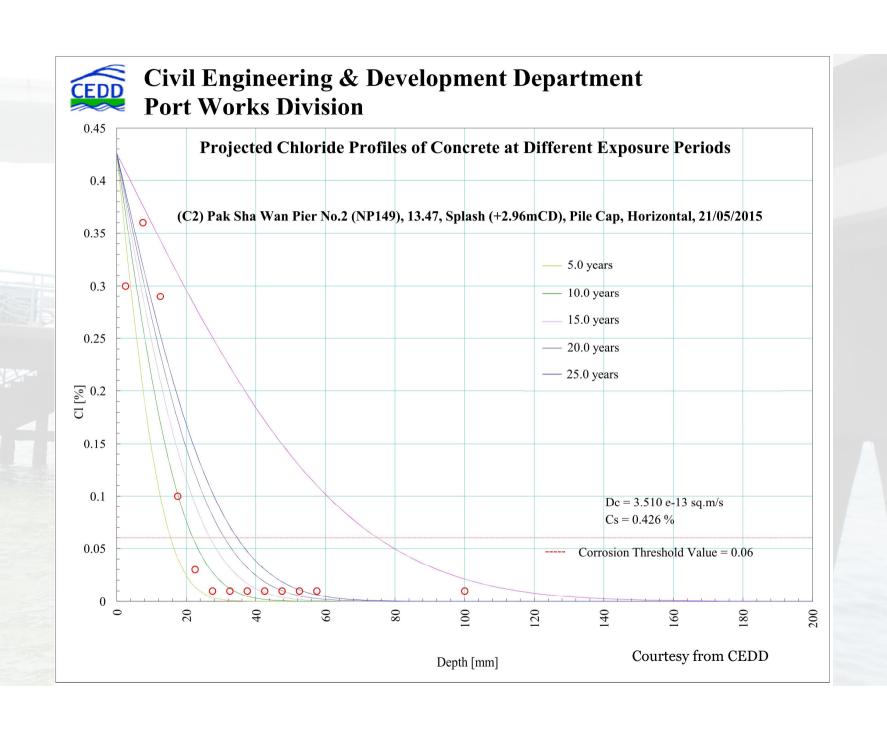






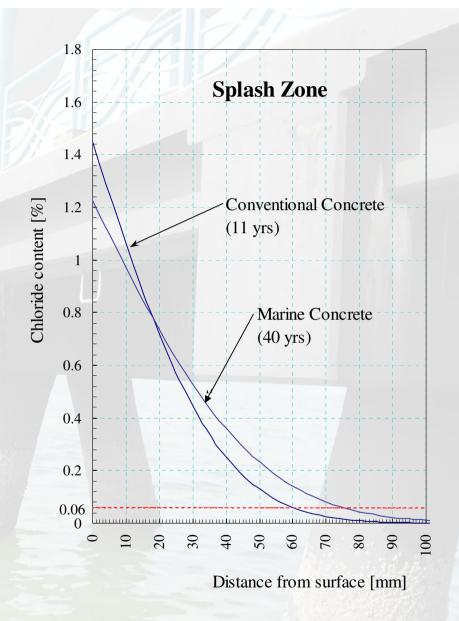








Projected chloride profiles of microsilica concrete and conventional concrete at splash zone





 Include Rapid Chloride Penetration Test (CSI: Section 19) in concrete specification

Durability Performance Tests

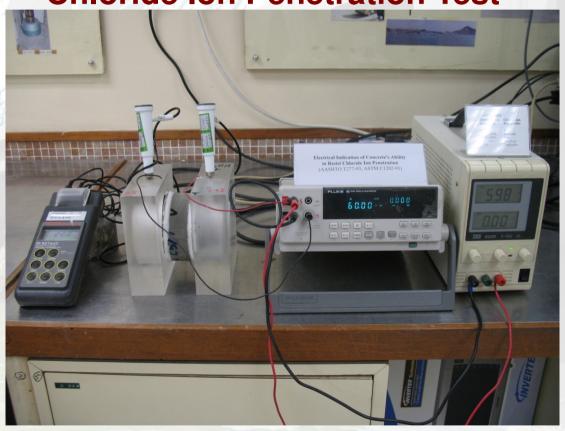
Chloride Ion Penetration Test

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

Mean value shall be less than 1,000 coulombs after curing for 28 days

Durability Performance Tests

Chloride Ion Penetration Test



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

Measures to Enhance Durability Performance

- Coating
 - Silane protection
 - Epoxy coating





Silane protection

Applying the impregnation material on the Test Panel





- Rapid Chloride Penetration Test (CSI: Section 19)
- Coating
- Stainless Steel Rebars In Outer Layers

Measures to Improve Durability

Reinforcement: Stainless Steel Bars



Source: International Molybdenum Association

Part 2: Maintenance Strategies

- Maintenance Strategy for New Marine Structures
- Maintenance Strategy for Structures less than 10 years old
- Maintenance Strategy for Structures more than 10 years old

Maintenance Strategy for New Marine Structures

Aim:

To minimize the need of concrete repair during the 50 years design life of the structure





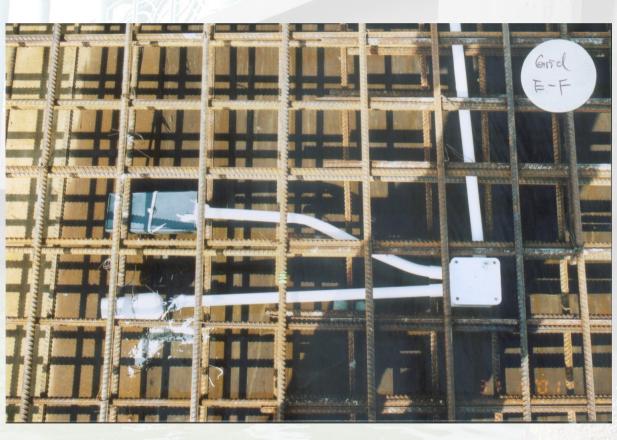
- 1.1 Marine Concrete Specification
- 1.2 Protective Coating



1. Strategy for New Marine Structures Preventive Maintenance Strategy

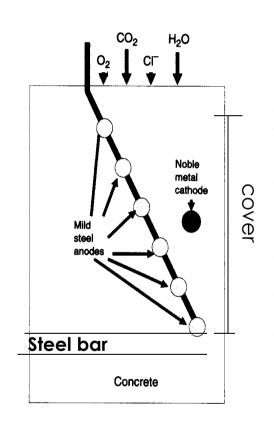
- 1.1 Marine Concrete Specification
- 1.2 Protective Coating
- 1.3 Corrosion Monitoring
 To monitor the ingress of chloride and effectiveness of coating











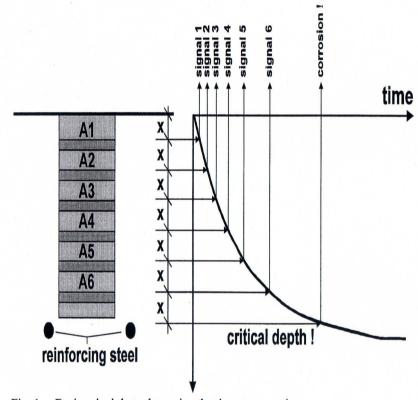


Fig. 1: Basic principle to determine the time-to-corrosion



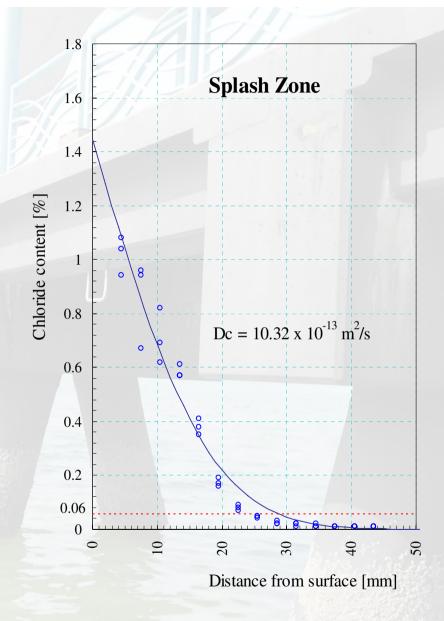
- 2.1 Assess the extent of chloride ingress
- 2.2 Protective Coating

Chloride Profile of Marine Structure After 3 Years of Exposure

(OPC concrete)

 $Dc = 10.32 \times 10^{-13} \text{m}^2/\text{s}$

Cs = 1.45%





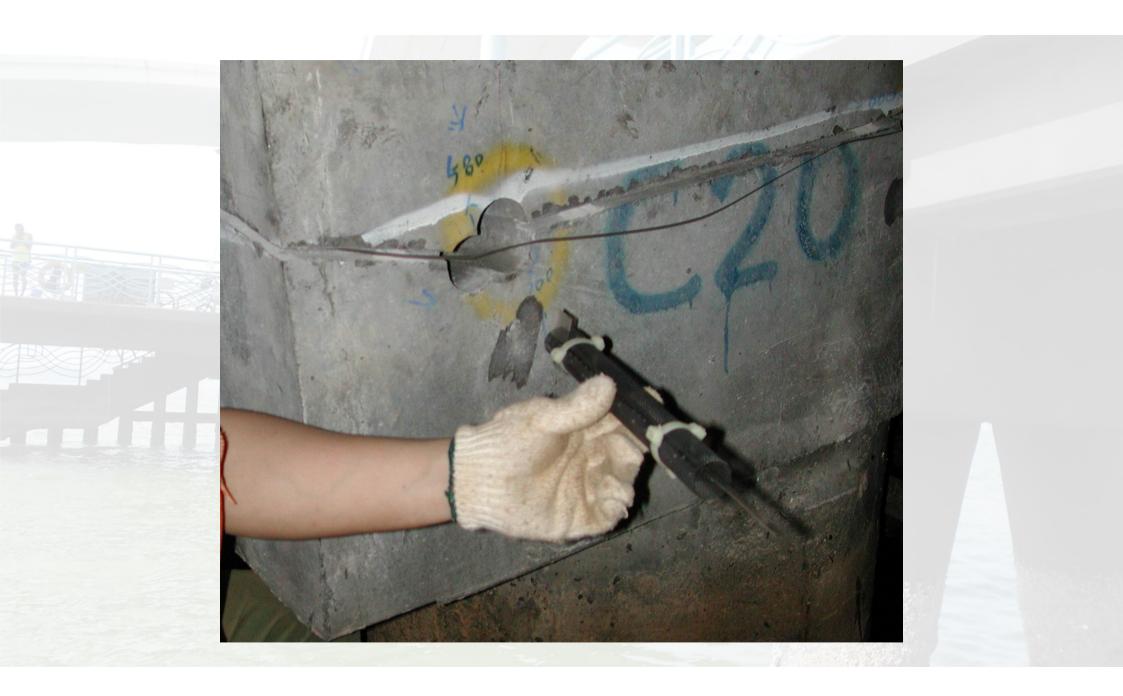


- 3.1 Install impressed current cathodic protection
 - **☞ 30** years design life
 - Stops further corrosion

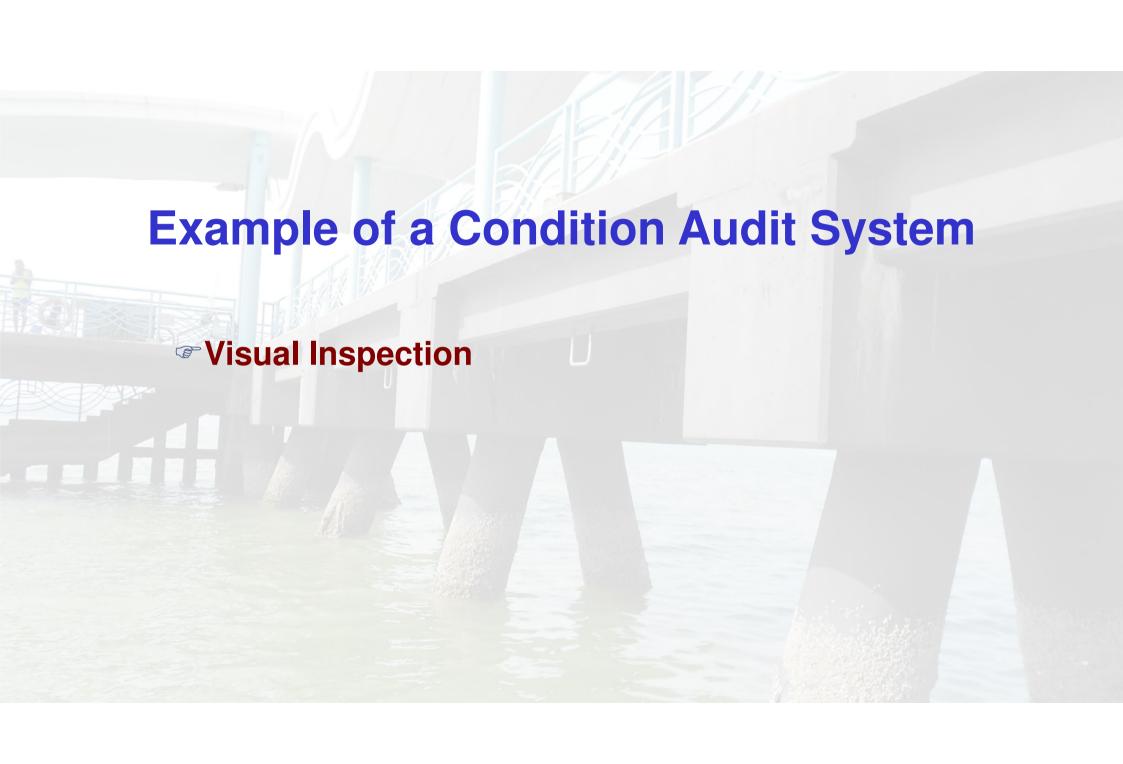


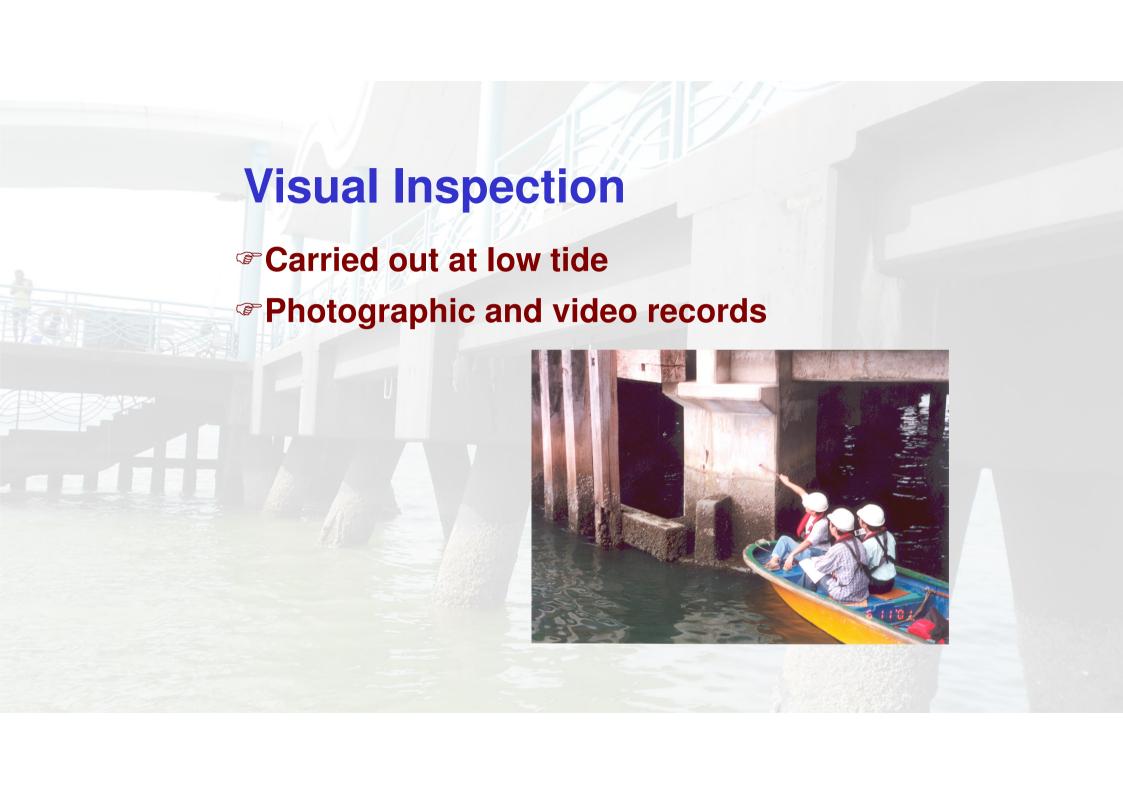


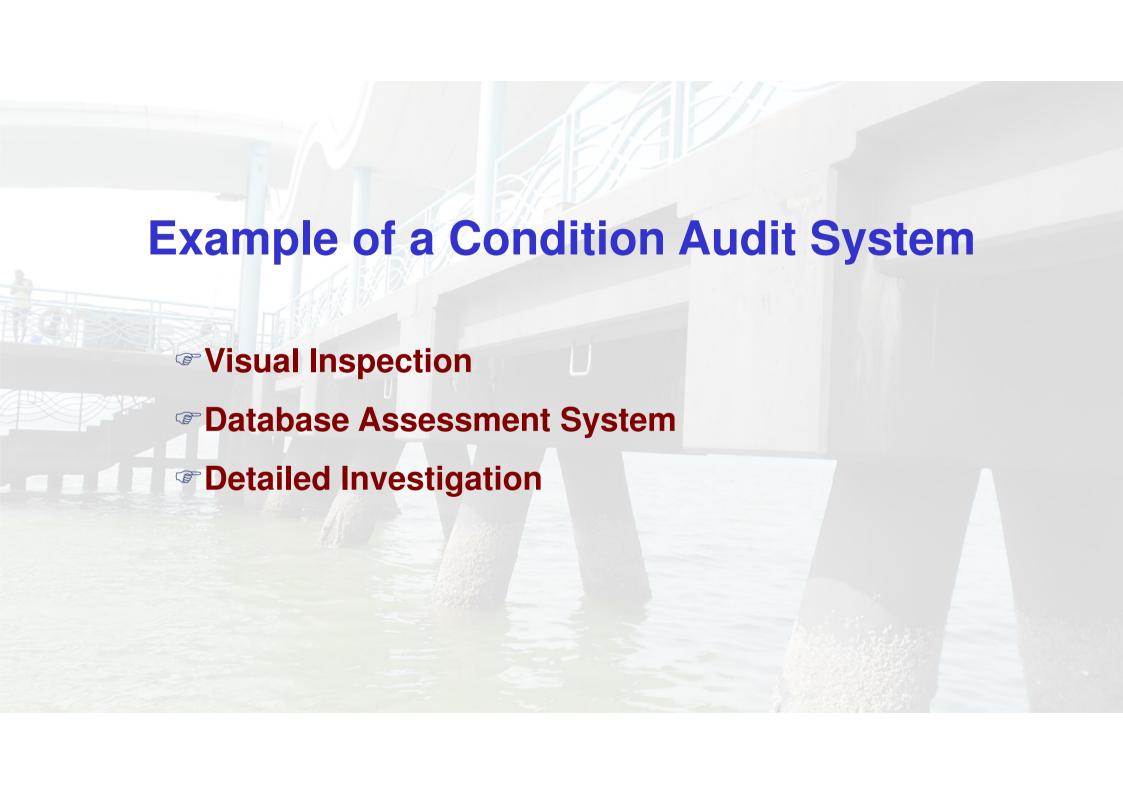




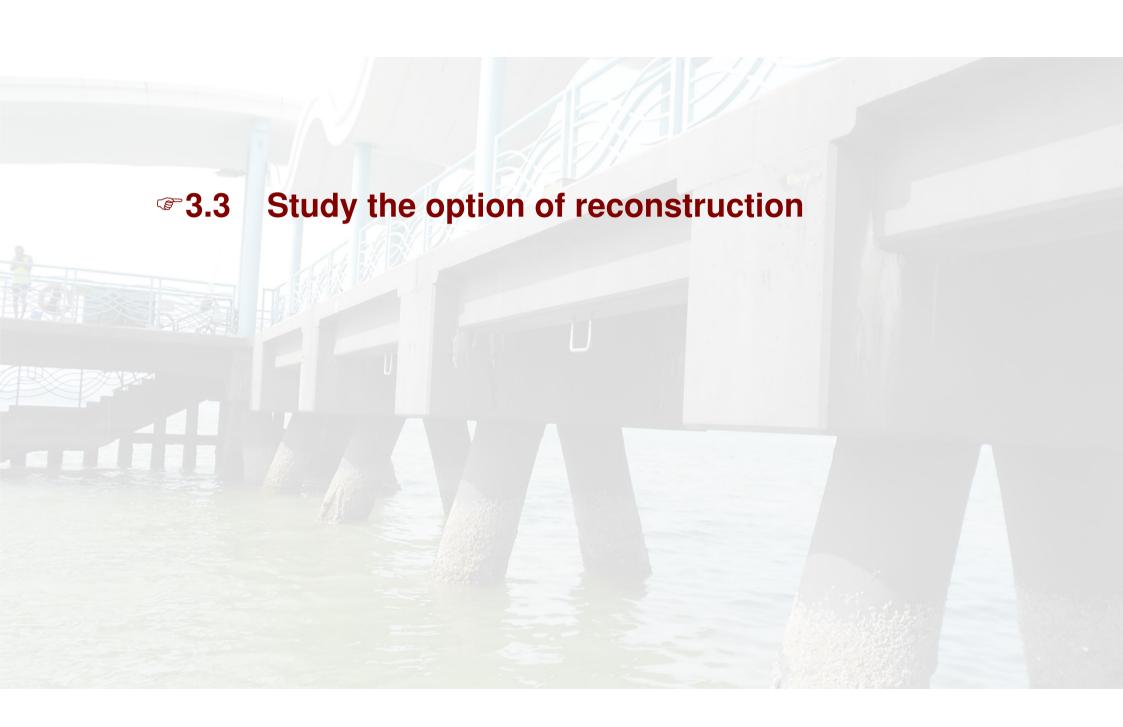












Conclusion

- Chloride ingress rate is substantially reduced by the adoption of the marine concrete specification
- Results indicated that the durability of marine structures are greatly enhanced by the marine concrete specification
- The service life will be further enhanced by the application of suitable concrete coating

Conclusion

Maintenance strategies for marine structures could be based on concrete coating, cathodic protection technique and an effective structural condition audit system to prioritize concrete repair work

