

③ Phase II エグゼクティブサマリー
(Executive Summary)



JAPAN-ASEAN COOPERATION PROGRAMME
ON
MATERIALS SCIENCE AND TECHNOLOGY

SINGAPORE PROJECT
PREVENTION OF CORROSION IN STRUCTURES

VOLUME V

THE EXECUTIVE SUMMARY
(PHASE II)

SEPTEMBER 1992

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PHASE II

Volume V
Executive Summary

PREFACE

The Singapore Project is in the area of "Prevention of Corrosion in Structures". In Phase I (August 1987 to September 1990) there were two sub-projects; Corrosion Prevention for Port and Harbour Structures and Corrosion Prevention for Drinking Water Storage Tanks. After Phase I was successfully completed, an extended programme in the area of Corrosion Prevention for Port and Harbour Structures was formulated. The Phase II programme ended in September 1992.

This Final Report on Phase II which consists of two additional volumes to the four volumes on Phase I published in September 1990, is the joint effort of all the team members from Japan and Singapore. These two volumes (Volumes V and VI), summarize the events that have taken place since the previous Report of 1990. In Volume V, in addition to the executive summary, the findings and the recommendations arising from the activities of the continuation programme are summarised. Volume VI contains the details and test data from the two areas of activities in the continuation programme.

The Phase II of the Project is indebted to the following organizations for their sponsorship and support throughout the extended project period:

- * Japan International Cooperation Agency, Japan
- * Ministry of Transport, Tokyo, Japan
- * Port and Harbour Research Institute, Ministry of Transport,
Japan
- * National Science and Technology Board, Singapore
- * Port of Singapore Authority, Singapore
- * National University of Singapore, Singapore

The results contained in all these volumes are jointly owned by the participating organizations; Japan International Cooperation Agency (JICA), the ASEAN Committee on Science and Technology (COST) and the National Science and Technology Board (NSTB).

There are many, besides those mentioned within this Report, who have made it possible for the completion of the activities and the preparation of this final manuscript. However, the following are mentioned for their special contributions to the Project: Dr Tsutomu Fukute of the Port and Harbour Research Institute, Ministry of Transport, Japan, who is the project leader of the Phase II programme; Mr Akio Ikegami, the long term expert who was with the Phase II programme from beginning to end; Mr Shigeo

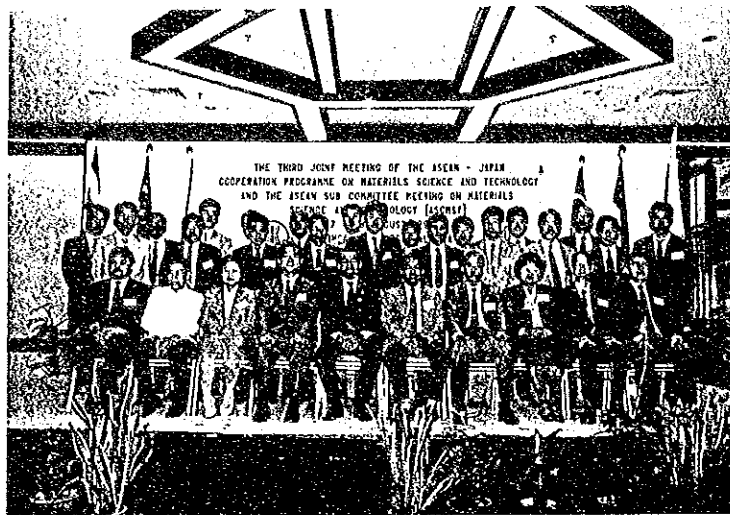
Kaneshiro, the Singapore project coordinator from JICA, who provided all the administrative support; Dr Toshikazu Minematsu of Sumitomo Cement Co Ltd, Japan; Mr Yoshio Shinoda of Nakabohtec; Mr Hidenori Hamada of the Port and Harbour Research Institute, Ministry of Transport, Japan; Mr Tatsuo Iwabata of Sumitomo Cement Co Ltd; Mr Ng Geok Kwee and Mr Tan Gak Peng of the Port of Singapore Authority for providing the liaison and coordination of the site exposure tests; the coordinators in the Department of Civil Engineering, Dr Gary Ong Khim Chye, Dr Ting Seng Kiong, and Dr Wee Tiong Huan and in particular, the technical staff of the Structures Laboratory and the Concrete Laboratory, and other staff members of the Department of Civil Engineering, National University of Singapore for their valuable support; and last but not least, the support of the staff at the National Science and Technology Board in the administration of the Project. It is with the contributions and support of these dedicated persons together with a host of others in their respective organizations that the Coordinator for the Singapore Project is able to carry out his duties in the implementation of the planned activities of this continuation programme of the Project. The successful completion of the Project owes a debt of gratitude to the combined effort of all team members and others who have contributed in one way or another, in the two phases of the Project from both the Japanese and Singapore sides.

Tam Chat Tim
Project Coordinator
Singapore
September 1992

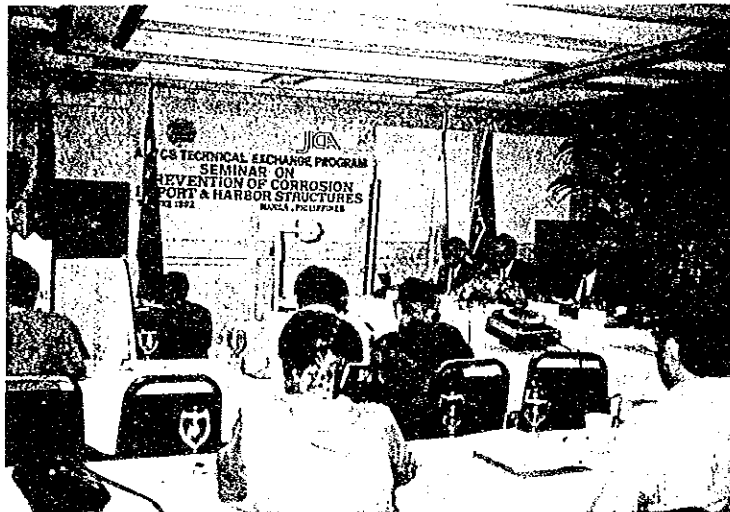
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The Third Annual Joint Meeting between Asean and Japan
(August 1990, in Genting Highlands, Malaysia)



Seminar on Prevention of Corrosion under the Technical Exchange Programme (June 1992, in Manila, Philippines)



Project Evaluation meeting between JICA Evaluation Team and Singapore Project Team (March 1992, at NSTB, Singapore)

1.0 INTRODUCTION

As part of the Japan-ASEAN effort to promote technical cooperation in the field of science and technology, an ASEAN-Japan Cooperation Programme on Materials Science and Technology was initiated, whereby a number of projects are being undertaken between the various ASEAN member countries and Japan. The projects focus on different aspects of materials technology.

The Singapore Project is in the area of "Prevention of Corrosion in Structures". In Phase I (August 1987 to September 1990) there were two sub-projects:

- (a) Corrosion Prevention for Port and Harbour Structures
- (b) Corrosion Prevention for Drinking Water Storage Tanks

After Phase I was successfully completed in September 1990, an extended programme (Phase II) in the area of Corrosion Prevention for Port and Harbour Structures was formulated. The Phase II programme was completed in September 1992.

The activities of Phase I have been reported in September 1990 as four volumes:

- Volume I : The Executive Summary
- Volume II: The Study of Corrosion and Corrosion Prevention in Drinking Water Storage Tanks
- Volume III: The Study of Corrosion Prevention in Concrete Structures at Port and Harbour
- Volume IV : Manual/Recommendations for Corrosion Investigation and Repair of Port and Harbour Concrete Structures

This Final Report on Phase II consists of two additional volumes to the four volumes on Phase I published in September 1990. These two volumes (Volumes V and VI) present a summary of the events that have taken place since the previous Report of 1990 and details of the activities of Phase II.

- Volume V : The Executive Summary - Phase II
- Volume VI : The Study on Carbonation and Chloride Penetration in Concrete, and The Study on Cathodic Protection for Port and Harbour Structures.

2.0 EXTENDED TERM OF COOPERATION

The Extended Term of Cooperation which appears in Annex 11 of Volume I, is reproduced as Annex 1 in this Volume V. The programme covers the following scope of work:

- (a) Study the countermeasures to reduce the chloride

penetration and carbonation in concrete, and

- (b) Develop the cathodic protection method for port and harbour concrete structures in Singapore.

Details of the programme appear as Annex 2.

3.0 IMPLEMENTING ORGANIZATION

The National Science and Technology Board (former the Science Council of Singapore) is the organization responsible for the implementation of the Project.

4.0 HUMAN AND MATERIAL INPUT

Only those events that have taken place since the start of the extended programme in October 1990 are summarised in chronological order below:

4.1 Japan Side

The Japan Project Team comprises members from:

- (a) Port and Harbour Research Institute (PHRI)
Ministry of Transport (MOT)
- (b) Other experts from public and private sector and universities

4.1.1 Mission Teams

- (a) December 1991

An Audit Team from Japan visited the project to carry out the audit.

- (b) March 1992

The visit of a Japanese Mutual Consultation Team to the Singapore Project took place from 16 to 21 March 1992. The Meeting reviewed and evaluated the progress of the Project and confirmed that the Project has achieved significant progress as a result of the effort and cooperative spirit of the participating organizations of the Project.

- (c) September 1992

(The visit of a Japanese Final Evaluation Team to the Singapore Project will take place from 19 September to 25 September 1992. The Meeting will review and evaluate the results of the Project based on the Final Report of Phase II programme (Volume V and Volume VI) prepared by the Singapore side. The

Meeting will consider if the planned activities of the Project had been completed by September 1992.)

4.1.2 Experts

(a) The two Long Term Experts, Mr Akio Ikegami and Mr Shigeo Kaneshiro took up their appointments in October 1990 for the Singapore Project. They were with the Project till its completion.

(b) A team of four short term experts visited the project in relation to the activities on cathodic protection tests. They were in Singapore for various periods as shown below:

Dr Toshikazu Minematsu - Sumitomo Cement Co Ltd
(28/02/91 - 21/03/91)

Mr Yoshio Shinoda - Nakabohtec
(07/03/91 - 14/03/91)

Dr Tsutomu Fukute - PHRI
(17/03/91 - 21/03/91)

Mr Noritaka Shimizuguchi - Nakabohtec
(25/03/91 - 20/04/91)

(c) A short term expert visited the project in relation to the activities on carbonation from 05/0891 to 10/08/91.

Professor Masaki Daimon - Tokyo Institute of
Technology

(d) A team of three short term experts from Japan visited the project in relation to activities of the cathodic protection tests from 23/10/91 to 03/11/91. The members of the team were:

Dr Toshikazu Minematsu - Sumitomo Cement Co Ltd
Mr Yoshio Shinoda - Nakabohtec
Mr Hidenori Hamada - PHRI

(e) A short term expert from Japan, Mr Akira Sakuma visited the Project in relation to the carbonation tests from 29 March to 4 April 1992.

(f) A team of two short term experts from Japan visited the Project in relation to cathodic protection measurements after 1 year of performance from 13 April to 3 May 1992. The members of the team were:

Dr Toshikazu Minematsu - Sumitomo Cement Co Ltd
Mr Yoshio Shinoda - Nakabohtec

(g) A team of two short term experts from Japan visited the project in relation to the evaluation of the results for the preparation of the final report. The members of the team were in Singapore for the periods

indicated:

Dr Tsutomu Fukute - PHRI
(24/06/92 - 03/07/92)
Mr Tatsuo Ikabata - Sumitomo Cement Co Ltd
(28/06/9 - 06/07/92)

4.1.3 Training in Japan

As part of the technology transfer under the Project, counterparts from Singapore team as well as nominated researchers from other ASEAN countries took on short training in Japan. Altogether, 9 persons participated in this aspect of the Project as summarised chronologically as follows:

- (a) Three ASEAN counterparts visited Japan on a training programme consisting of two from Singapore, Dr S K Ting of NUS and Mr T L Looi of PSA from the Singapore project team and Dr Mustaza Ahmadun from Malaysia. Together they visited organizations with activities on cathodic protection in Japan from 29/10/90 to 17/11/90.
- (b) One counterpart from Singapore project team, Dr T H Wee of NUS visited organizations with activities on carbonation and corrosion in Japan from 13/05/91 to 01/06/91.
- (c) One counterpart from the Singapore project team, Mr Tan Gak Peng of PSA and another researcher from Brunei Darussalam, Mr Awangku Menddin PLW Pengiram Hj Yussof jointly visited organizations with activities on corrosion prevention in Japan from 10/11/91 to 30/11/91.
- (d) One counterpart from the Singapore project team, Mr Lim Huay Bak of NUS visited organizations with activities on corrosion prevention in Japan from 31/05/92 to 14/06/92.
- (e) One counterpart from the Singapore project team, Mr Ng Geok Hwee of PSA and another researcher from Malaysia, Ms Zubaidah Bte Mohd Nasir jointly visited organizations with activities on corrosion prevention in Japan from 20/07/92 to 09/08/92.

4.1.4 Provision of Equipment

The Government of Japan provided equipment for various aspects of the Project agreed to by both the Japanese and Singapore teams. For Phase II, the shipments arrived over the duration of FY 1990/91, and FY 1991/92. These equipment were distributed to the laboratories at PSA and NUS. The list of equipment and their location of the Phase II equipment appear as Annex 3.

4.1.5 Support of Local Cost

The Government of Japan provided a substantial amount of support for local cost. This included the cost of telecommunication, office equipment, furnitures and consumables for Japanese experts and the salary of a research assistant to assist in carbonation testing from March to June 1992.

4.2 Singapore Side

Singapore Project Team comprises members from:

- (a) National Science and Technology Board (NSTB)
- (b) National University of Singapore (NUS)
- (c) Port of Singapore Authority (PSA)

In addition to the local counterparts, technical manpower from the respective organizations were assigned to assist in the activities of the programme. Members of the Singapore Project Team are listed in Annex 4.

4.2.1 Facilities

The counterpart contributions for the Project are as follows:

- (a) Scheduling and preparation of site for exposure tests.
- (b) Laboratory facilities for accelerated corrosion tests and other tests.
- (c) Laboratory space for the installation and operation of the equipment received under the Project.
- (d) Office facilities for long term and short term experts.

4.2.2 Operating Cost

The counterpart contributions to the operating cost of the Project include:

- (a) Scheduling and preparation of site for exposure tests.
- (b) Local cost for transportation of equipment, exposure test specimens, etc.
- (c) Laboratory facilities for accelerated corrosion tests and other tests such as depth of carbonation and chloride penetration, etc.

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Dr Tsutomu Fukute - PHRI
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- (c) Laboratory facilities for accelerated corrosion tests and other tests such as depth of carbonation and chloride penetration, etc.

- (d) Personnel to conduct both laboratory and site work including student assistants funded by the National University of Singapore.
- (e) Consumables and other administrative support.
- (f) Cost for the operation and maintenance of equipment.
- (g) Office facilities for long and short term experts.
- (h) Manpower, materials and transportation cost etc from October 1990 to September 1992 totalling Singapore \$200,000.

5.0 STUDY ON CATHODIC PROTECTION

5.1 Introduction

The Civil Engineering Department, National University of Singapore and the Port of Singapore Authority are counterpart organizations in Singapore for the ASEAN-Japan Project on Cathodic Protection Systems for Reinforced Concrete. The project first started as a three year programme on Prevention of Corrosion in Structures in October 1987 with the exchange of experts, training in Japan and supply of equipment by the Government of Japan through the Japan International Cooperation Agency. There were provisions for trainees and collaborative researchers from other Asean member countries to participate in the research activities carried out in Singapore. The problem of corrosion prevention had been approached from three directions, namely, inspection and assessment of corrosion in existing wharf structures, laboratory investigation and field exposure tests. For continued cooperative research activities, the project has been extended for an additional period of two years until September 1992.

The scope of the two year continuation programme includes the development of the cathodic protection method for concrete port and harbour structures in Singapore and the investigation into countermeasures to reduce the chloride penetration and carbonation in concrete.

In recent years, damage to concrete structures by chloride attack has become a subject of discussion for seaside and coastal areas where the direct effect of salt carried by wind and salts water spray are felt. The damage to concrete structures is caused by the salinity permeating into the concrete which accelerates the corrosion of the reinforcing steel bars. This corrosion of reinforcing steel bars in the form of rust creates an expansion pressure in the concrete which causes it to crack and subsequently leads to spalling of concrete.

In the past, repair works to such damage are usually carried out by :-

- (1) Partial rust-prevention treatment of the reinforcing bar surfaces.
- (2) Restoration of the damaged part with synthetic resins or polymer mortars.
- (3) Coating the concrete surface with suitable covering materials.
- (4) Reinforcement replacement and other reinforcing method.

As corrosion of steel in concrete is an electro-chemical process, the above repair methods do not directly prevent corrosion of reinforcing steel bars electrochemically.

5.2 Cathodic Protection System

With the recent developments in the field of concrete technology and concrete durability, cathodic protection system has been found to be an effective way to protect concrete against corrosion damage. In Japan, the cathodic protection system has been tried out recently and found to be effective for corrosion protection to their Port and Harbour structures. Under this project the effectiveness of the cathodic protection system for corrosion prevention in the local tropical environment were investigated.

Two methods of cathodic protection systems were experimented. One system is the impressed current method and other system is the sacrificial anode method, also called the galvanic anode method.

In the impressed current method, an insoluble electrode is placed on the concrete surface and a direct current from a rectifier is imposed on the reinforcing steel through the concrete.

The sacrificial anode system is installed by connecting a zinc sheet to the reinforcing steel through the concrete, utilizing the potential difference between zinc and the steel. A power supply is not required for the sacrificial anode system.

The effectiveness of the cathodic protection systems would be evaluated through three approaches. They are (i) site test, (ii) site exposure test and (iii) laboratory test. Only the impressed current method were tested on site.

5.3 Site and Specimen Preparation and Installation

5.3.1 Site Test

The site identified for the project is the Singapore Port Institute (SPI) Building. Two slabs and five beams were chosen for the monitoring works.

In this project, the impressed current method using the platinized titanium mesh anode was experimented. Titanium ribbon anode for groove method of installation was also examined.

The test area at SPI site had been divided into six zones as shown below :-

Zone	CP System	Area	Electrode Ref. No	Remarks
Zone 1	Mesh	27m ²	11	Beam
			12	Slab
			13	Slab
			14	Beam
			15	Beam
			16	Beam
Zone 2	Mesh	11.5m ²	17	Slab
			18	Slab
Zone 3	Mesh	3.0m ²	19	Beam
Zone 4	Ribbon ($\frac{1}{2}$ ")	5.0m ²	20	Beam
			21	Beam
			22	Slab
Zone 5	Ribbon ($\frac{1}{4}$ ")	5.0m ²	23	Beam
			24	Beam
			25	Slab
Zone 6	No Protection		26	Slab
			27	Slab
			28	Slab
			29	Beam
		51.5m ²	19 Nos Ref. Electrode	

The installation work commenced on 19 Feb 91 and completed on 20 Mar 1991.

5.4 Laboratory and Site Exposure Tests

5.4.1 Laboratory Test

A set of 44 specimens was subjected to accelerated corrosion testing in the laboratory. The mix proportion of concrete and materials used are summarised as shown below:

Unit Weight of Cement	300 kg/m ³ (Singapore) 264kg/m ³ (Japan)
Water Cement Ratio	0.60 (Singapore) 0.59 (Japan) S/a = 45%
Target Slump	75 ± 25mm
Cement	Ordinary portland cement
Coarse aggregate	Crushed aggregate, Gmax 20mm (Singapore) River gravel, Gmax 25mm (Japan)
Fine aggregate	Hill sand (Singapore) River sand (Japan)
Admixture	High range water reducing agent (Synthetic polymers) (Singapore) Water reducing agent (Air entrained type) (Japan)
Steel Bar	Round Bar. 13mm diameter, length = 350mm Surface rust layer was removed, polished and sealed by oil until specimen fabrication.

For the laboratory tests, the experimental factors considered were as follows:

- (a) Effects of presence of cathodic protection system and different methods of corrosion protection, namely, Impressed Current method with titanium mesh, Sacrificial Anode method using zinc plate anodes and no protection at all.
- (b) Effects of salt content in the concrete, namely, 0 kg/m³ and 15 kg/m³ of salt in concrete.
- (c) Effects of environment, namely, atmospheric (dry) condition (Temperature 28°C Relative humidity 80%), alternating dry and wet condition and carbonation environment. The alternating dry and wet condition consists of 5 days dry and 2 days wet using sea

water. The temperature is maintained at 50° C for both the dry as well as the wet cycle. The carbonation environment consists of keeping the specimens in a carbonation chamber at 30°C with a relative humidity of 65% and carbon dioxide concentration of 7%.

- (d) Effects of using different methods to control the current supplied for the impressed current protection method, namely constant current method and constant voltage method.
- (e) Effects of protective current density, namely -100 Mv shift and -200 Mv shift for impressed current method.
- (f) For each condition tested, 2 specimens were used with one of them having an embedded electrode. This means that 44 specimens were tested and 22 electrodes were embedded. The test conditions and the specimens are summarized in Table 5.1. The specimens are continuously monitored. The potentials are continuously recorded for those specimens with embedded electrodes. For the impressed current specimens, the current was continuously measured for those specimens with fixed voltage and the voltage was continuously measured for those with fixed current. The laboratory tests started on the 16 May 1991. Depolarization tests were carried out weekly.

When the short term experts came on 23 October 1991 to 3 November 1991, they decided to break up 8 site exposure specimens and 24 laboratory specimens to tests for chloride penetration, extent of corrosion and carbonation. The rest of the specimens were broken up when the short term experts came again on 13 April to 3 May 1992.

5.4.2 Site Exposure Test

While the site and laboratory tests were being carried out, a set of 32 specimens was also made and installed at the underdeck of the Singapore Port Institute building. Specimens prepared in Japan and Singapore were placed under the same marine environment. Three types of specimens : impressed current method applying platinized titanium mesh anode, sacrificial anode method applying zinc sheet, no protection (for comparison), were prepared. The exposure specimens were placed at about 2.5m above Chart Datum, and were subjected to the tidal actions. Their mix proportion of concrete and materials used is similar to those for laboratory specimens.

For the impressed current method, the Titanium Mesh Anode was used. The test conditions on the specimens are summarized in Table 5.2.

Table 5.1 Experimental Factors in Laboratory Test

Cathodic Protection Method		Impressed Current Method			Sacrificial Anode Method			No Protection		
		Dry	Dry and wet	CO ₂	Dry	Dry and wet	CO ₂	Dry	Dry and wet	CO ₂
Environmental										
Method of Control	Voltage Shift	Salt* (kg/m ³)								
Current	200mV	2	2	2	2	2	2	2	2	2
	200mV	2	2	2	2	2	2	2	2	2
	100mV	2	-	2	-	-	-	-	-	-
Voltage		2	-	2	-	-	-	-	-	-

* as chloride

Table 5.2 Experimental Factors in Site Exposure Test

Cathodic Protection Method		Impressed Current Method		Sacrificial Anode Method		No Protection	
Condition of reinforcing steel		With(2) Corrosion	Without Corrosion	With(2) Corrosion	Without Corrosion	With(2) Corrosion	Without Corrosion
Concrete	Salt content(1) (kg/m ³)						
Made in Singapore	0	2	2	2	2	1	1
	15	2	2	2	2	1	1
Made in Japan	0	-	-	2	2	1	1
	15	-	-	2	2	1	1

(1) as chloride

(2) Accelerated corrosion of reinforcement was induced by subjecting the steel bars to an applied current density of 0.75 mA/cm² for 7 days

5.5 Test Methods and Results

5.5.1 E Log I Test

The E log I test was performed by incrementally increasing the cathodic protection current from the installed system. At each interval, the IR drop free potential of the steel reinforcement was measured relative to the silver/silver chloride (Ag/Ag Cl) stable reference electrode. The plot of the steel reinforcement potential versus the logarithm of the current densities applied for the various zone were plotted. The current densities required for the cathodic protection for the SPI site was 40mA/m² for Zone 1 to Zone 3, 20mA/m² for Zone 4 and Zone 5 and 40mA/m² for the exposure specimens using the titanium mesh. From E log I test results, these current densities were confirmed to meet the standard corrosion protection criteria of -100mV shift.

5.5.2 Depolarisation Test

To monitor the effectiveness of the cathodic protection system using the impressed current method, depolarisation tests or polarization decay tests were periodically carried out. Depolarisation tests were carried out from the site test on 24 Apr 91, 10 May 91, 30 Jul 91, 29 Aug 91, 4 Dec 91, 22 Jan 92 and May 92.

The test was carried out by switching off the protective current supply and monitoring the reinforcement potential measured with respect to the Ag/Ag Cl stable reference electrodes embedded in the concrete.

When the protective current was switched off, there was an immediate potential shift observed. This immediate potential shift was the IR drop and this was not included in the evaluation of the cathodic protection system.

5.5.3 Chloride Penetration Test

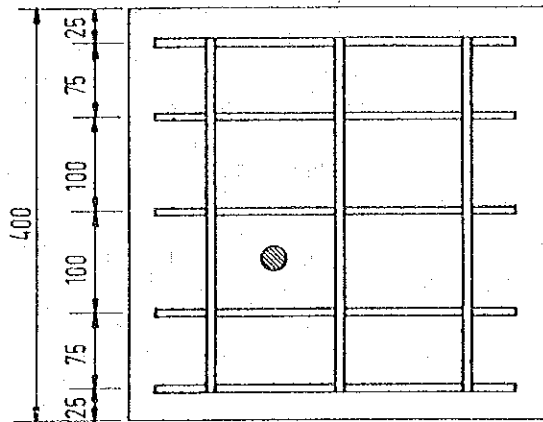
Before the site installation, potential measurement was taken at the site and the laboratory.

In addition, powder samples were collected from the test area and sent to the National University of Singapore, Civil Engineering Department Laboratory to determine the existing chloride content of the structure. The chloride content test was carried out in accordance to BS1881 Part 124 : 1988, Section 10.2.

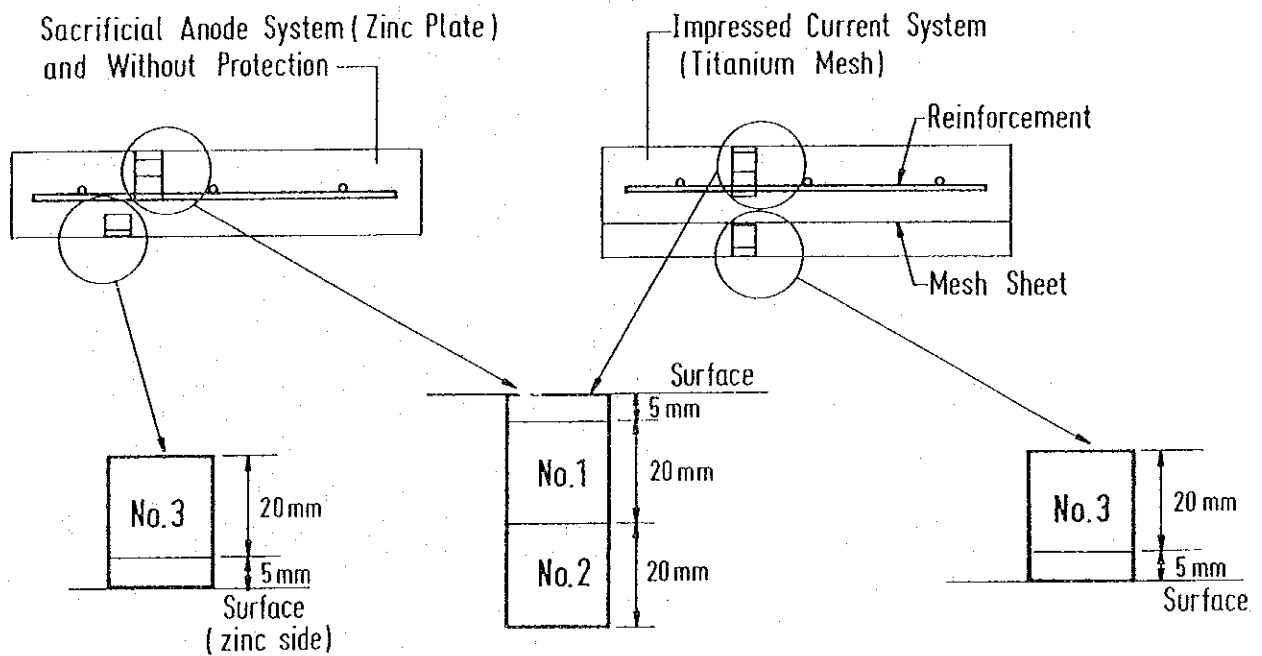
In the laboratory and site exposure tests, chloride content of the specimens were also measured. The position where the samples were taken for each type of specimen is shown in Figure 5.1. The results are presented in Table 5.3.

Table 5.3 Test Results on pH and Chloride Content
(SPI Site)

NO.	SPECIMEN	CHLORIDE CONTENT	PH VALUE	
			2-1/2 DAY	4-1/2 DAY
1.	BEAM 8	0.395	12.38	12.41
2.	BEAM 9	0.054	12.42	12.44
3.	BEAM 9/A	0.008	9.90	9.59
4.	BEAM 8-9, F-G/3	0.019	12.35	12.40
5.	SLAB 9-10, C/7	0.129	11.41	11.18
6.	SLAB 9-10, G/2	0.063	10.50	10.31
7.	SLAB 10-11, B/3	0.010	10.86	10.65
8.	SLAB 10-11, D/6	0.003	11.11	10.85
9.	SLAB 10-11/a	0.019	12.12	12.02
10.	SLAB 10-11/b	0.013	10.86	10.65
11.	SLAB 10-11, G/2	0.040	12.08	11.95
12.	SLAB 8-9, B/5	0.273	9.67	9.31
13.	SLAB 8-9, E/4	0.210	10.98	10.78
14.	CENTRE BEAM 10-11/C	0.017	12.30	12.32
15.	CENTRE BEAM 10-11/F-G	0.020	11.14	10.81
16.	CENTRE BEAM 11-12/5	0.041	12.32	12.38
17.	CENTRE BEAM 11-12/6	0.080	12.18	12.17



(a) Location for drilling



(b) Sample positions for different specimen types

Fig. 5.1 Chloride Measurement Sampling Points

5.5.4 Carbonation Test

The depth of carbonation is determined by treating a freshly broken surface with a phenolphthalein indicator solution. Where the concrete is still highly alkaline, a purple-red coloration is obtained. If no coloration occurs, carbonation has taken place and thus the depth of the carbonated surface layer can be measured. The results are shown in Table 5.4.

5.5.5 Corrosion State of Steel Bars

The extent of the corrosion on the steel bars was plotted. The depth or degree of corrosion were not measured in this study.

5.6 Discussion

5.6.1 Site Test

(a) Effect of Type of Anode

Titanium mesh anode was used for Zones 1, 2 and 3. For Zones 4 and 5, titanium anode ribbons of sizes of half inch and quarter inch were used.

The anode substrate is of high purity titanium. Titanium is one of the most stable corrosion resistant, high strength, light weight materials found on earth. Therefore, titanium is not consumed during operation and it would ensure strong concrete bond and a longer anode life.

The difference between the mesh and the ribbon types is the method of installation. The mesh is usually installed in placed with plastic fasteners and subsequently overlaid with a layer of protective covering by guniting to a thickness of approximately 25mm thick.

The ribbon type is usually installed into a groove or slots, laid directly into the concrete surface, or suspended via insulating spacers from the rebar itself.

From the depolarisation test, it was noticed that the IR drop for the titanium ribbon type anode is small as compared to the mesh type anode.

Basing on the criteria of -100mV potential shift after 4 hours when the protective current was switched off, the reference electrode at location REF 11 and REF 12 for the titanium mesh anode and REF 20 for the titanium ribbon anode appears to be slightly under protected. However, the criteria of -100mV potential shift were achieved after more than 4

Table 5.4 Carbonation Test Results (Laboratory Test : 1 year)

Specimen No	C.P. System	Environmental Condition	Electrical Control	Carbonation Depth (mm)					
				Anode side		Bottom		Side	
				Max	Mean	Max	Mean	Max	Mean
L-1	I.C.P.	Dry	I-200mV	0	0	3	2	1	1
L-2	I.C.P.	Dry	I-200mV	-	-	-	-	-	-
L-3	I.C.P.	Dry	I-200mV	0	0	5	4	2	1
L-4	I.C.P.	Dry	I-200mV	-	-	-	-	-	-
L-5	I.C.P.	Dry	I-100mV	0	0	4	4	6	3
L-6	I.C.P.	Dry	I-100mV	-	-	-	-	-	-
L-7	I.C.P.	Dry	Voltage	0	0	7	5	4	3
L-8	I.C.P.	Dry	Voltage	-	-	-	-	-	-
L-9	I.C.P.	Dry/Wet	I-200mV	0	0	0	0	15	6
L-10	I.C.P.	Dry/Wet	I-200mV	0	0	0	0	0	0
L-11	I.C.P.	Dry/Wet	I-200mV	0	0	0	0	0	0
L-12	I.C.P.	Dry/Wet	I-200mV	0	0	0	0	0	0

Table 5.4 Carbonation Test Results (Laboratory Test : 1 year) - cont'd

Specimen No	C.P. System	Environmental Condition	Electrical Control	Carbonation Depth (mm)					
				Anode side		Bottom		Side	
				Max	Mean	Max	Mean	Max	Mean
L-13	I.C.P.	ACC Carbonation	I-200mV	18	10	20	15	24	17
L-14	I.C.P.	ACC Carbonation	I-200mV	-	-	-	-	-	-
L-15	I.C.P.	ACC Carbonation	I-200mV	18	16	42	37	40	37
L-16	I.C.P.	ACC Carbonation	I-200mV	-	-	-	-	-	-
L-17	I.C.P.	ACC Carbonation	I-100mV	12	11	35	32	29	24
L-18	I.C.P.	ACC Carbonation	I-100mV	-	-	-	-	-	-
L-19	I.C.P.	ACC Carbonation	Voltage	17	16	32	31	30	28
L-20	I.C.P.	ACC Carbonation	Voltage	-	-	-	-	-	-
L-21	S.A.P.	Dry	-	0	0	3	2	2	1
L-22	S.A.P.	Dry	-	-	-	-	-	-	-
L-23	S.A.P.	Dry	-	0	0	4	3	4	2
L-24	S.A.P.	Dry	-	-	-	-	-	-	-

Table 5.4 Carbonation Test Results (Laboratory Test : 1 year) - cont'd

Specimen No	C.P. System	Environmental Condition	Electrical Control	Carbonation Depth (mm)								
				Anode side			Bottom			Side		
				Max	Mean	Max	Max	Mean	Max	Mean		
L-25	S.A.P.	Dry/Wet	-	-	-	-	-	-	-	-	-	-
L-26	S.A.P.	Dry/Wet	-	-	-	-	-	-	-	-	-	-
L-27	S.A.P.	Dry/Wet	-	0	13	4	6	2	-	-	-	-
L-28	S.A.P.	Dry/Wet	-	-	-	-	-	-	-	-	-	-
L-29	S.A.P.	ACC Carbonation	-	3	24	22	29	28	-	-	-	-
L-30	S.A.P.	ACC Carbonation	-	-	-	-	-	-	-	-	-	-
L-31	S.A.P.	ACC Carbonation	-	0	24	22	28	25	-	-	-	-
L-32	S.A.P.	ACC Carbonation	-	-	-	-	-	-	-	-	-	-
L-33	No	Dry	-	0	3	2	3	2	-	-	-	-
L-34	No	Dry	-	-	-	-	-	-	-	-	-	-
L-35	No	Dry	-	0	2	2	1	1	-	-	-	-
L-36	No	Dry	-	-	-	-	-	-	-	-	-	-

Table 5.4 Carbonation Test Results (Laboratory Test : 1 year) - cont'd

Specimen No	C.P. System	Environmental Condition	Electrical Control	Carbonation Depth					
				Anode size		Bottom		Side	
				Max	Mean	Max	Mean	Max	Mean
L-37	No	Dry/Wet	-	-	-	-	-	-	-
L-38	No	Dry/Wet	-	-	-	-	-	-	-
L-39	No	Dry/Wet	-	-	-	-	-	-	-
L-40	No	Dry/Wet	-	-	-	-	-	-	-
L-41	No	ACC Carbonation	-	13	5	29	26	22	20
L-42	No	ACC Carbonation	-	-	-	-	-	-	-
L-43	No	ACC Carbonation	-	0	0	30	22	16	18
L-44	No	ACC Carbonation	-	-	-	-	-	-	-

hours. This is possibly due to the application of fine repair materials used for repair work before the cathodic protection system was applied.

(b) Effect of Ribbon Spacing

In Zone 4 and Zone 5 of the test site, the titanium ribbons of size half inch and quarter inch were installed. The spacings of the ribbons were as follows :-

	Ribbon Size	Spacing (mm)	Remarks
(a)	Half Inch	400	Beam
		300	Beam
		300	Slab
(b)	Quarter Inch	300	Beam
		200	Beam
		200	Slab

From depolarisation tests conducted, it may be commented that the closer spacing of the titanium ribbons of both half inch and quarter inch gave better cathodic protection to the beams and slabs. Basing on the criteria of -100mV potential shift after 4 hours when the protective current was switched off, the spacing of 400mm centre to centre for half inch titanium ribbon anode [REF 20] appears to be slightly under protected. However, the closer spacing of 300mm centre to centre for half inch titanium ribbon anode is adequate for the beams and slab in Zone 4. From these test results, it may be suggested that less than 300mm spacing be recommended for titanium ribbon anodes for tropical condition.

(c) Effect of Current Supply Control Method

The five zones of the test site were controlled by 5 unit of rectifiers. For Zone 1, the rectifier was also used to provide protective current to the exposure specimens.

During the evaluation of the system by the Japanese Experts in Apr 92, the current supply control method was changed from the constant current method to the constant voltage method.

It was observed that tidal action which caused the specimens to undergo the drying and wetting process has caused the protective current to fluctuate for Zone 1. This was because of the parallel connection of single power supply source.

By using the constant voltage method, the fluctuation of the protective current was much reduced.

5.6.2 Laboratory and Site Exposure Tests

(a) Effects of Cathodic Protection System

The effect of cathodic protection on the corrosion products of the reinforcement is that the products are black in colour, thin, smooth and non-expansive. For specimens without any cathodic protection, the corrosion products are reddish brown and expand in volume causing cracks in the concrete cover along the lines of the reinforcement. Even though the corroded area seems to be larger for those specimens cathodically protected, the lack of cracks indicate the non-expansive nature of the products and possibly smaller amounts of corrosion. Cathodic protection seems to reduce the corrosion rate by spreading the corrosion over a wider areas instead of pitting type of corrosion found in unprotected specimens.

(b) Effects of salt content

The natural electrode potential of those specimens before the application of cathodic protection with salt was about -350 Mv to -450 Mv. For those without salt, E was about -100 Mv to -200 Mv. The trend was also observed in actual structures in Japan. The higher negative value means that greater impressed current must be used to effectively protect the reinforcement in the concrete. Corrosion rate was higher for those specimens that have salt added.

(c) Effect of test environment

In the case of impressed current methods, the voltage required to generate the same constant current density was greater for those specimens in the carbonation chambers than those in the open air conditions. The voltage requirements were lowest for those in the accelerated dry and wet condition. In the case of sacrificial anode method, the current density decreased in specimens in the carbonation chamber, on the other hand, it increased under wet and dry condition. This was due to the increasing conductivity of the concrete in the wet condition. Carbonated specimens tend to have a higher resistivity. In the carbonation chamber, required voltage to provide protective current density became high because of dry condition of concrete specimens. Furthermore, modification of protection criteria owing to the lack of a alkalinity of concrete around steel bars seems to be necessary. In the dry and wet accelerated testing condition, salt tends to

accumulate in the concrete especially in the case of those specimens that had no chloride initially. In the case of cathodic protected specimens, the chloride was attracted towards the anode.

For the specimens in the carbonation chamber, the chloride moved towards the reinforcement even those under protection but the rate of movement is slower than that without protection.

(d) Effect of Protective Current Density

From the results of E Log I tests, the necessary current density for effective protection of the reinforcement in concrete seems to be larger than that usually required in moderate climate. This was especially so in those specimens that had a large chloride content.

The results showed that more durable anode materials were needed for our hotter and more humid environment compared to that in more moderate environmental condition.

5.7 Observation on Site and Exposure Test

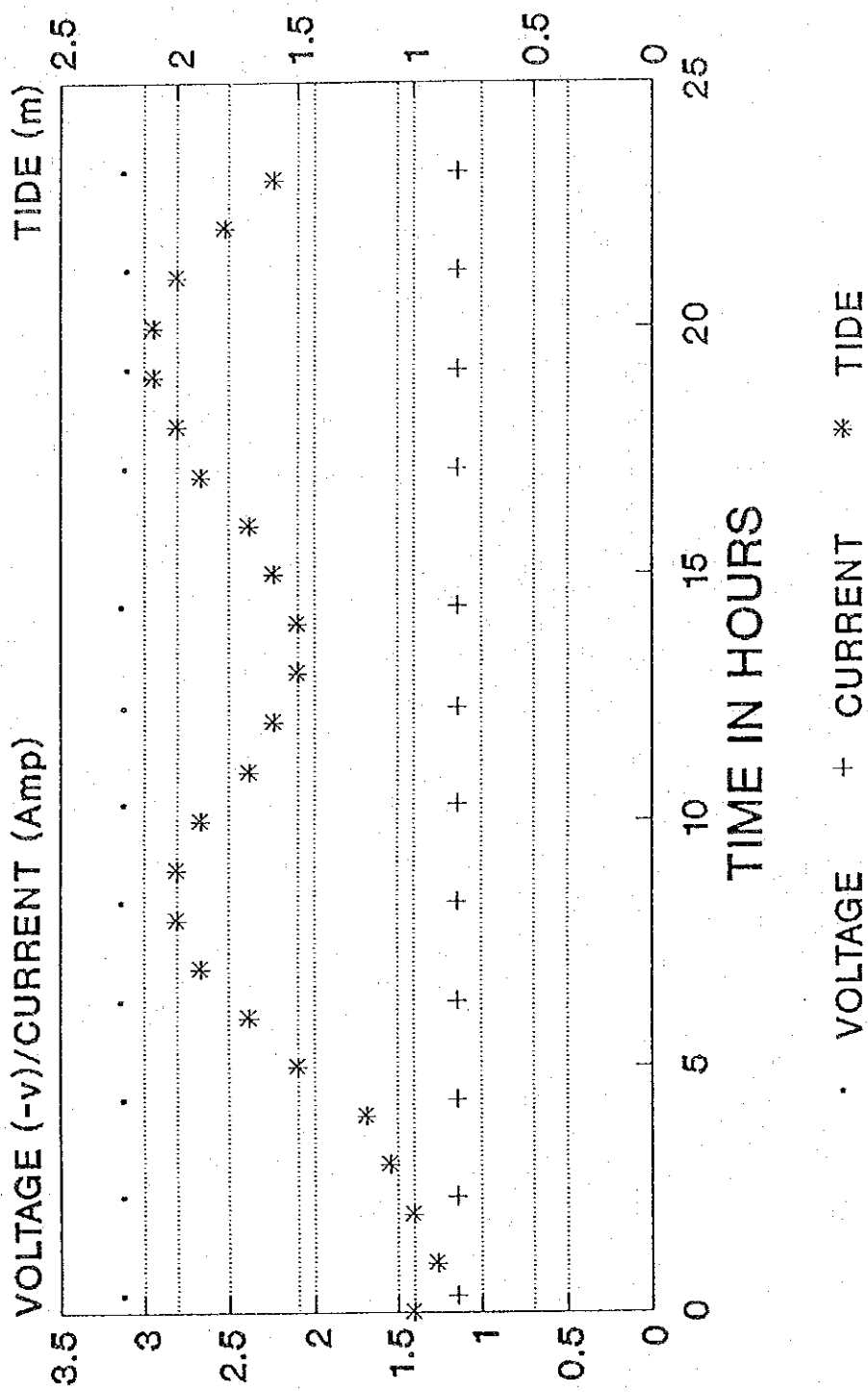
Fig. 5.2 to Fig. 5.11 show the relationship between electrical potentials of site and exposure specimens and tide level. Test results show that electrical potentials of the site change depending on the tidal condition of exposure specimens.

When the exposure specimens were under sea water, electrical potentials of the site become slightly noble, and maintain stable potential value when the specimens were above sea water.

Potential change was more in the case of constant current method than in constant voltage method. On the other hand, electrical potentials in exposure specimens due to tidal conditions become more noble when the specimens were under sea water. Leakage of protective current to sea water might be a cause of the change.

Separate electric circuits to structures in atmosphere and tidal zone is recommended for cathodic protection. Table 5.5 shows the actual current density of exposure specimens when the specimens were above sea water. Actual current densities of exposure specimens were above 40mA/m². These results suggest that wetter specimens get more protective current supply than the site.

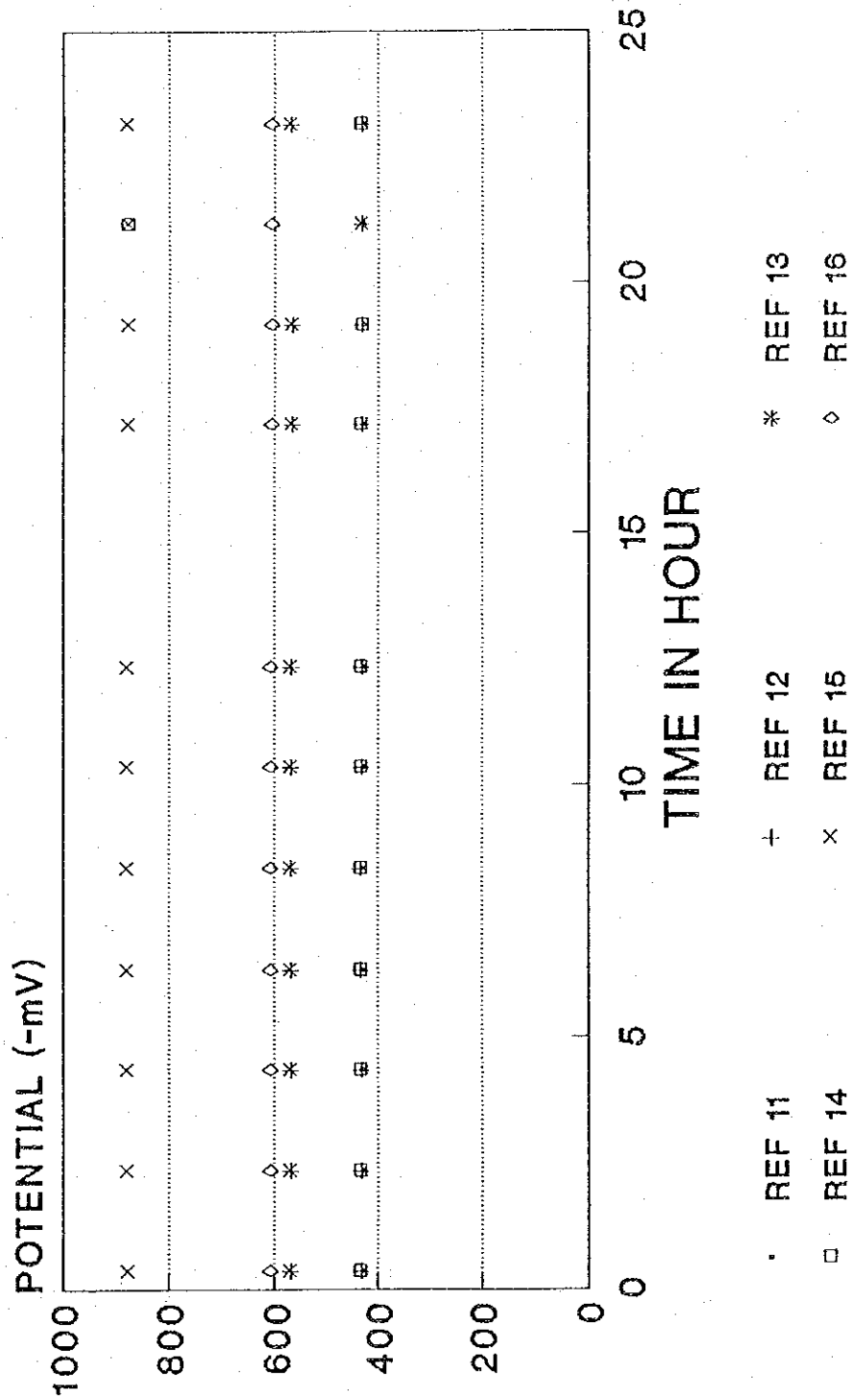
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 18 OCT 1991



ZONE ONE

Fig. 5.2 Relationship between Electrical Potential/Current and Tide

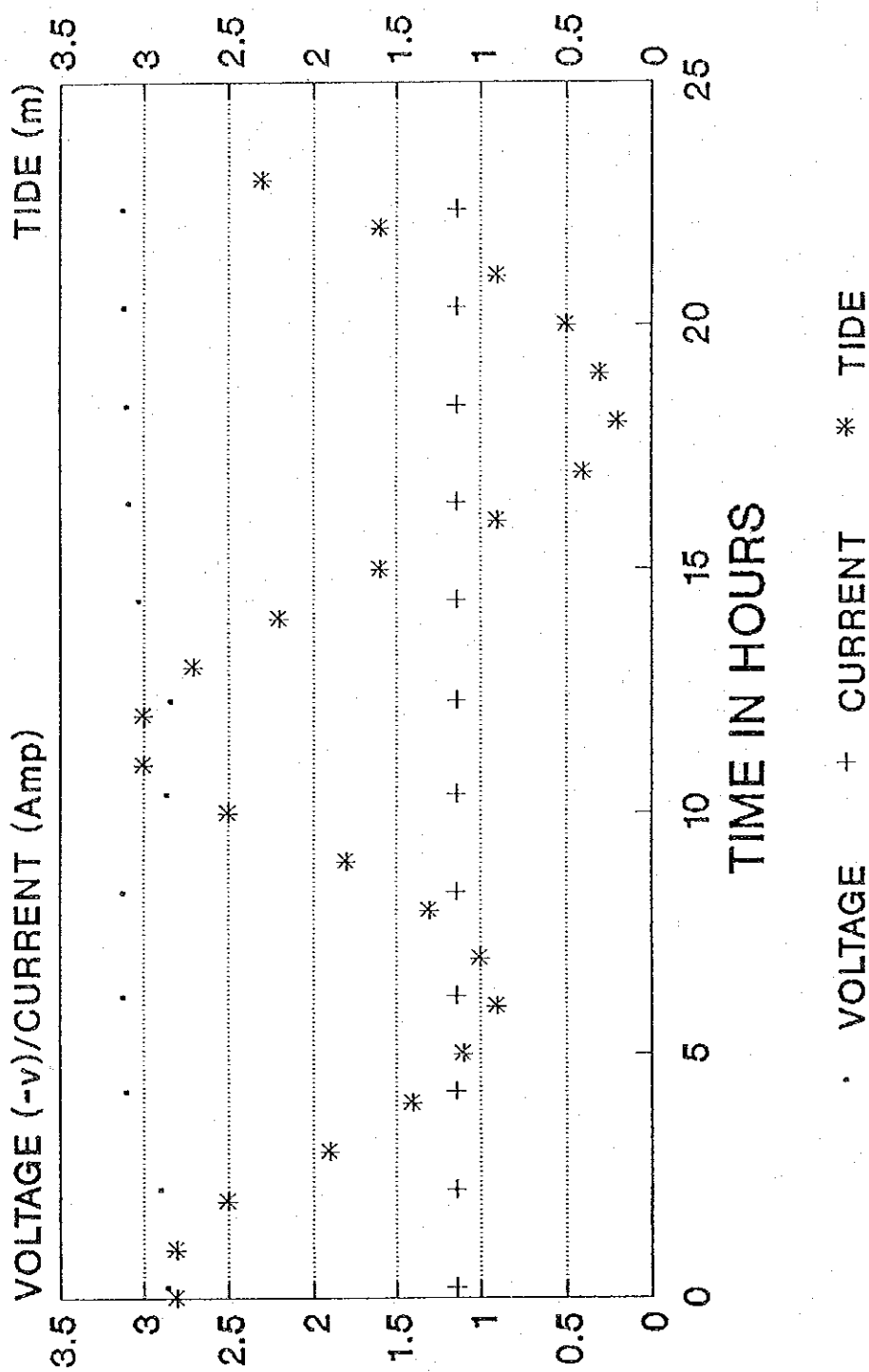
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 18 OCT 1991



ZONE ONE

Fig. 5.3 Relationship between Electrical Potential/Current and Tide

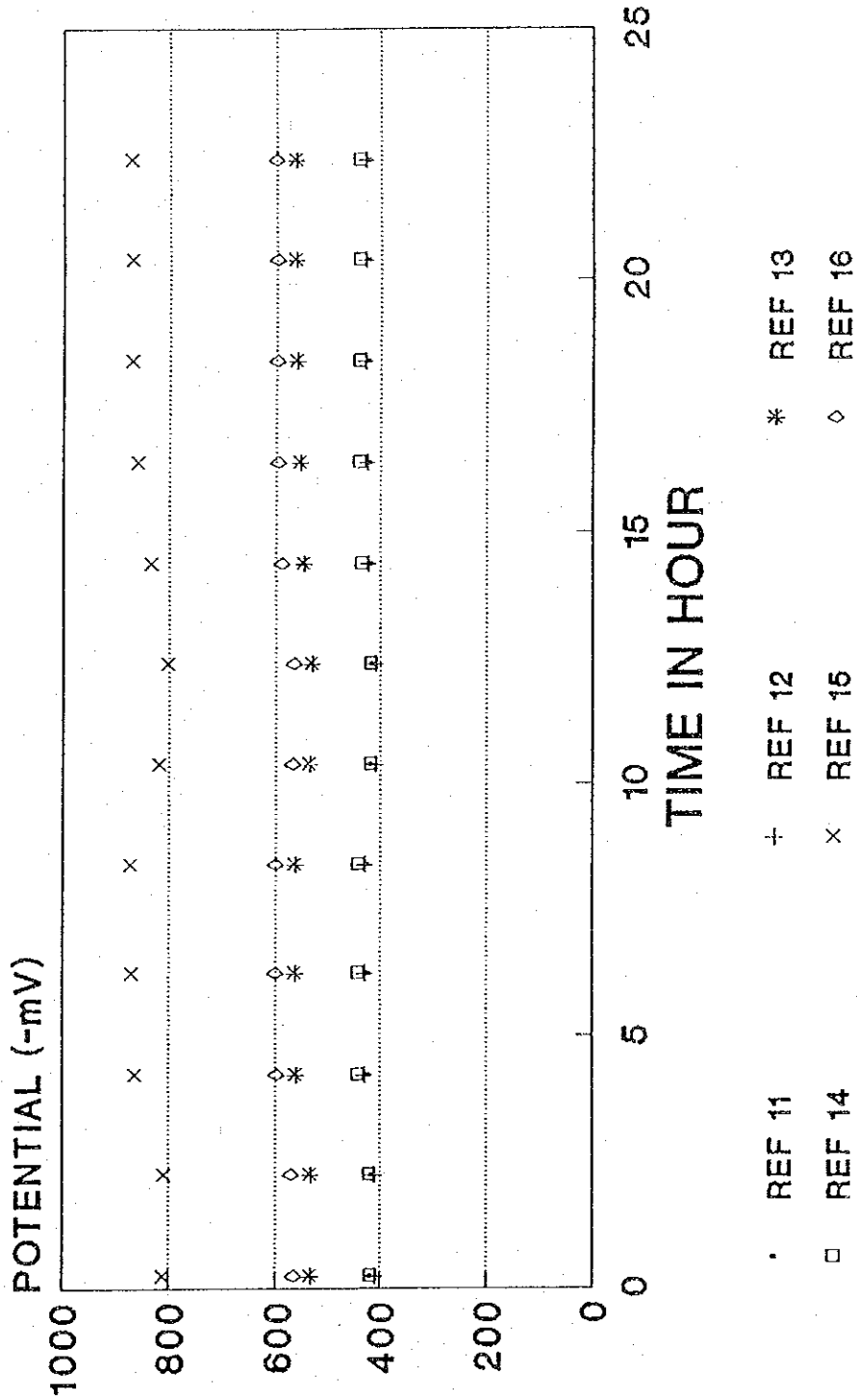
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 25 OCT 1991



ZONE ONE

Fig. 5.4 Relationship between Electrical Potential/Current and Tide

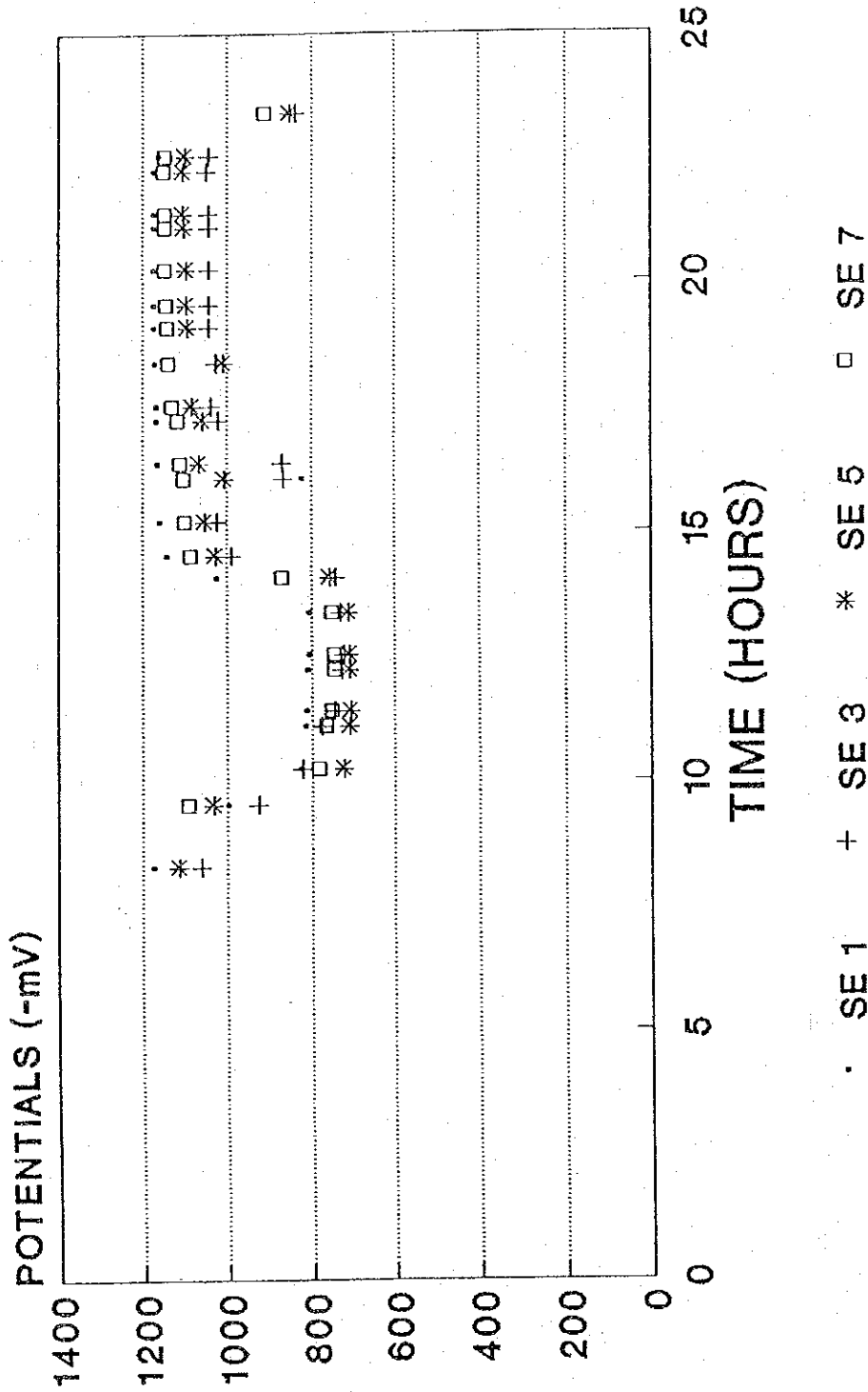
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 25 OCT 91



ZONE ONE

Fig. 5.5 Relationship between Electrical Potential/Current and Tide

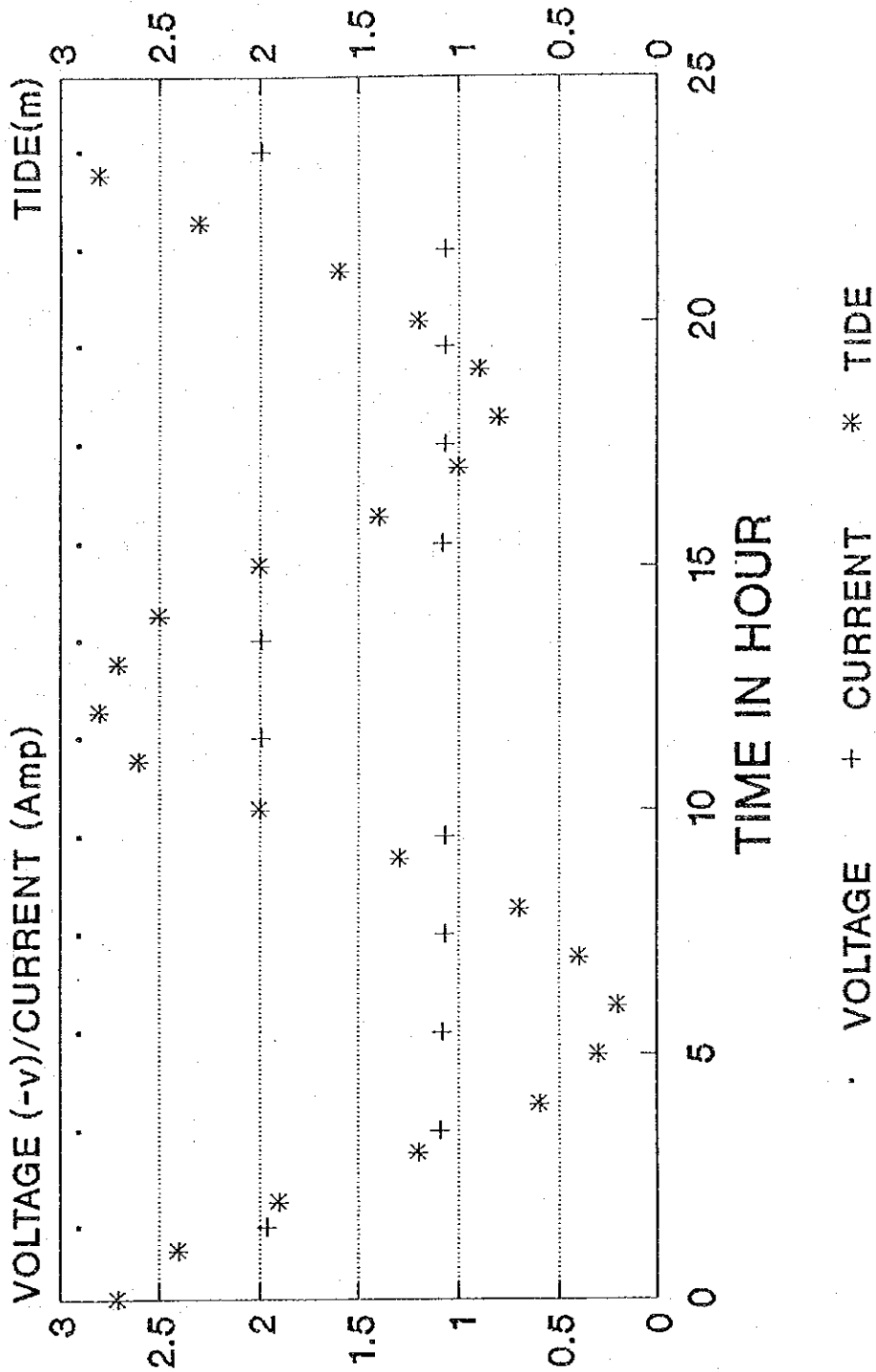
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 25 OCT 1991



EXPOSURE SPECIMEN

Fig. 5.6 Relationship between Electrical Potential/Current and Tide

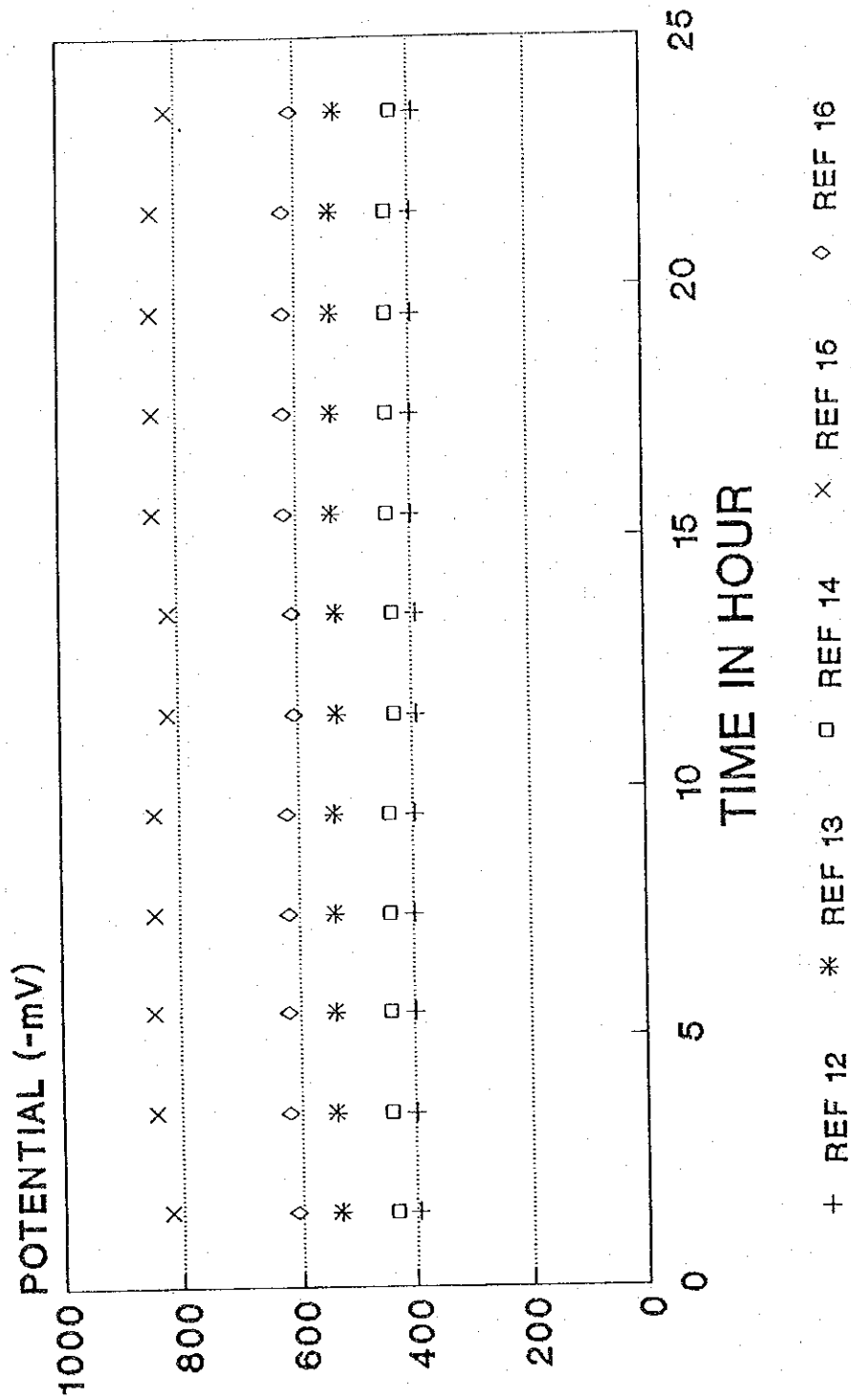
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 18 APR 92



ZONE ONE

Fig. 5.7 Relationship between Electrical Potential/Current and Tide

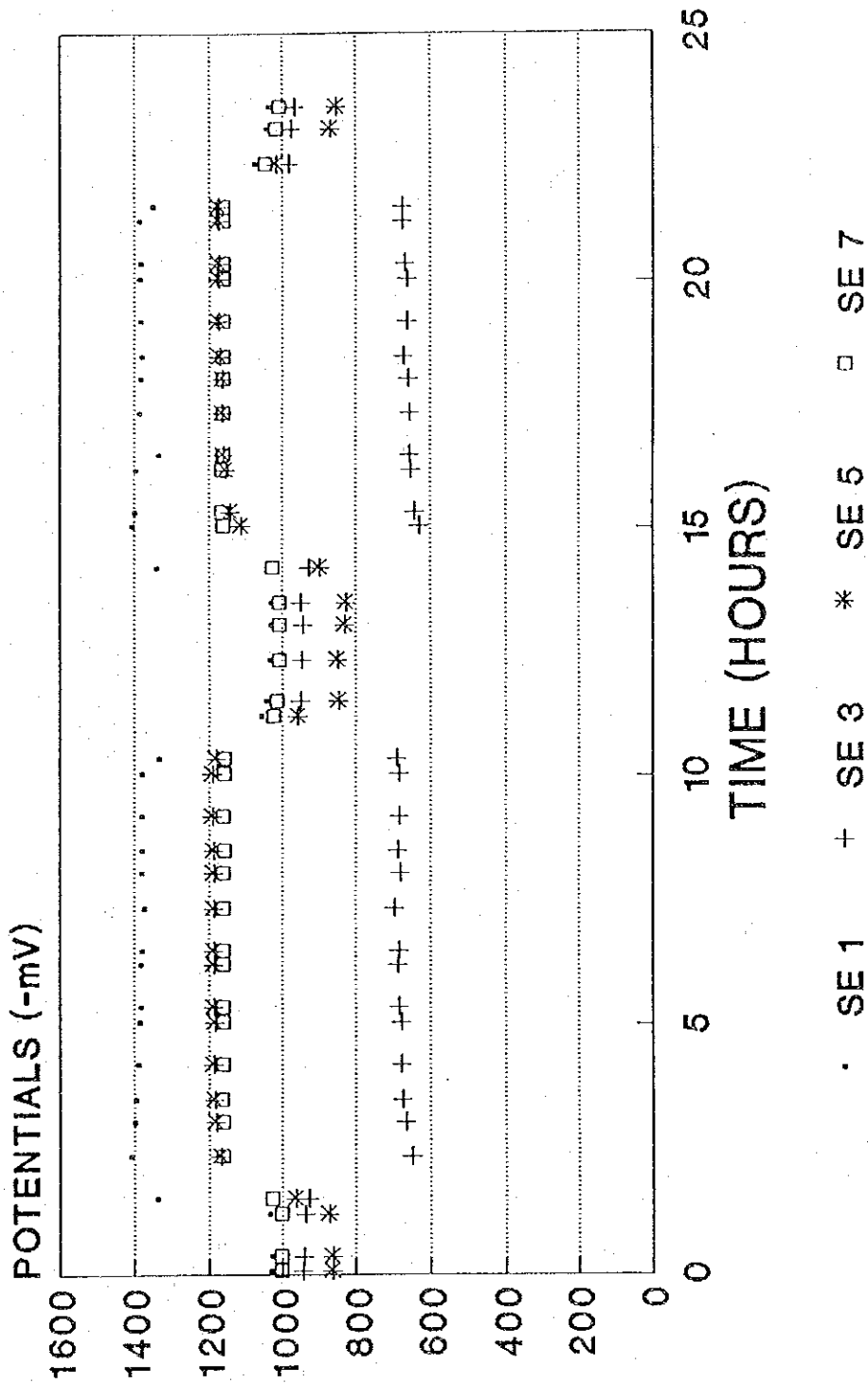
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 18 APR 92



ZONE ONE

Fig. 5.8 Relationship between Electrical Potential/Current and Tide

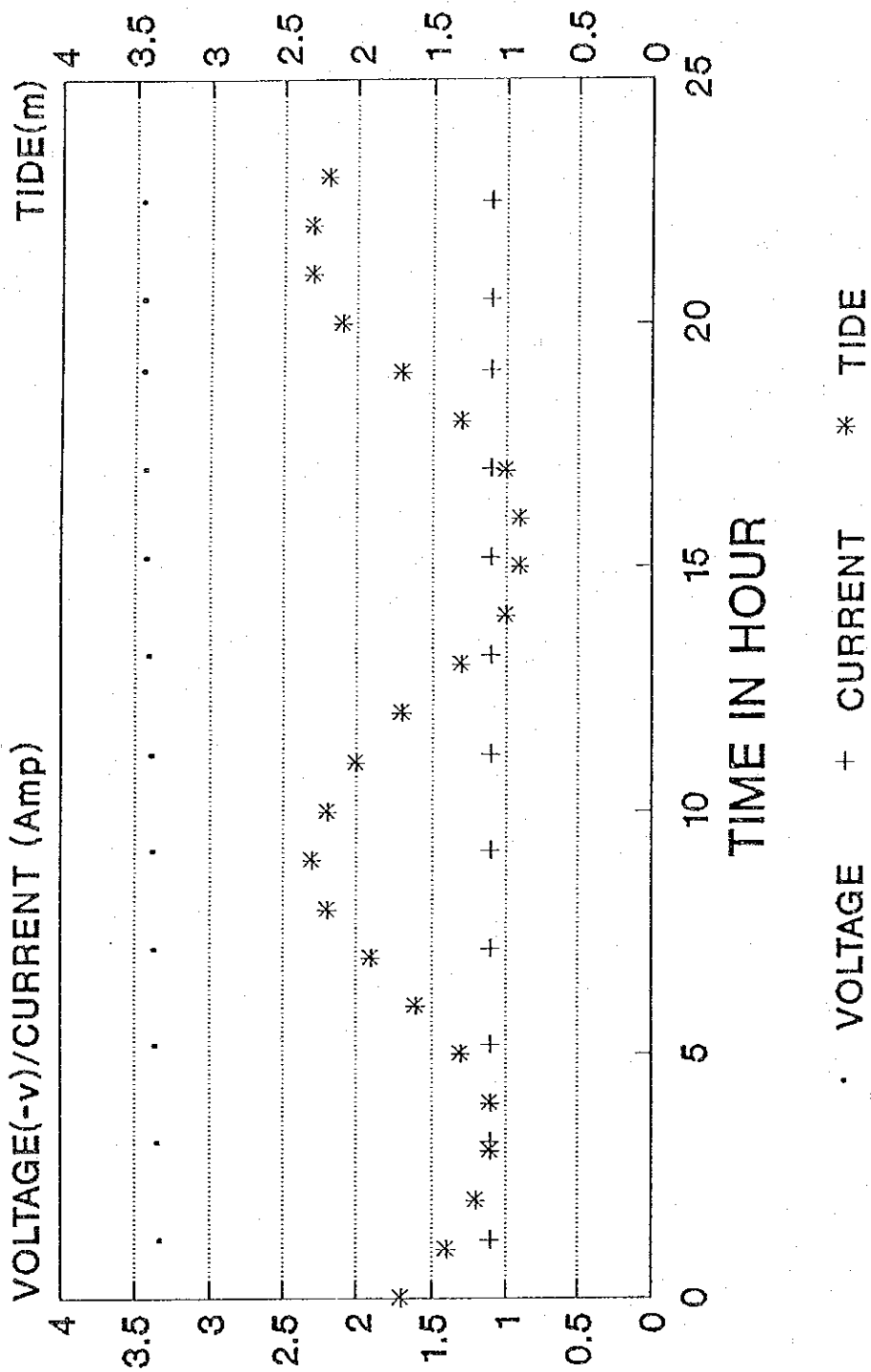
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 18 APR 1992



EXPOSURE SPECIMEN

Fig. 5.9 Relationship between Electrical Potential/Current and Tide

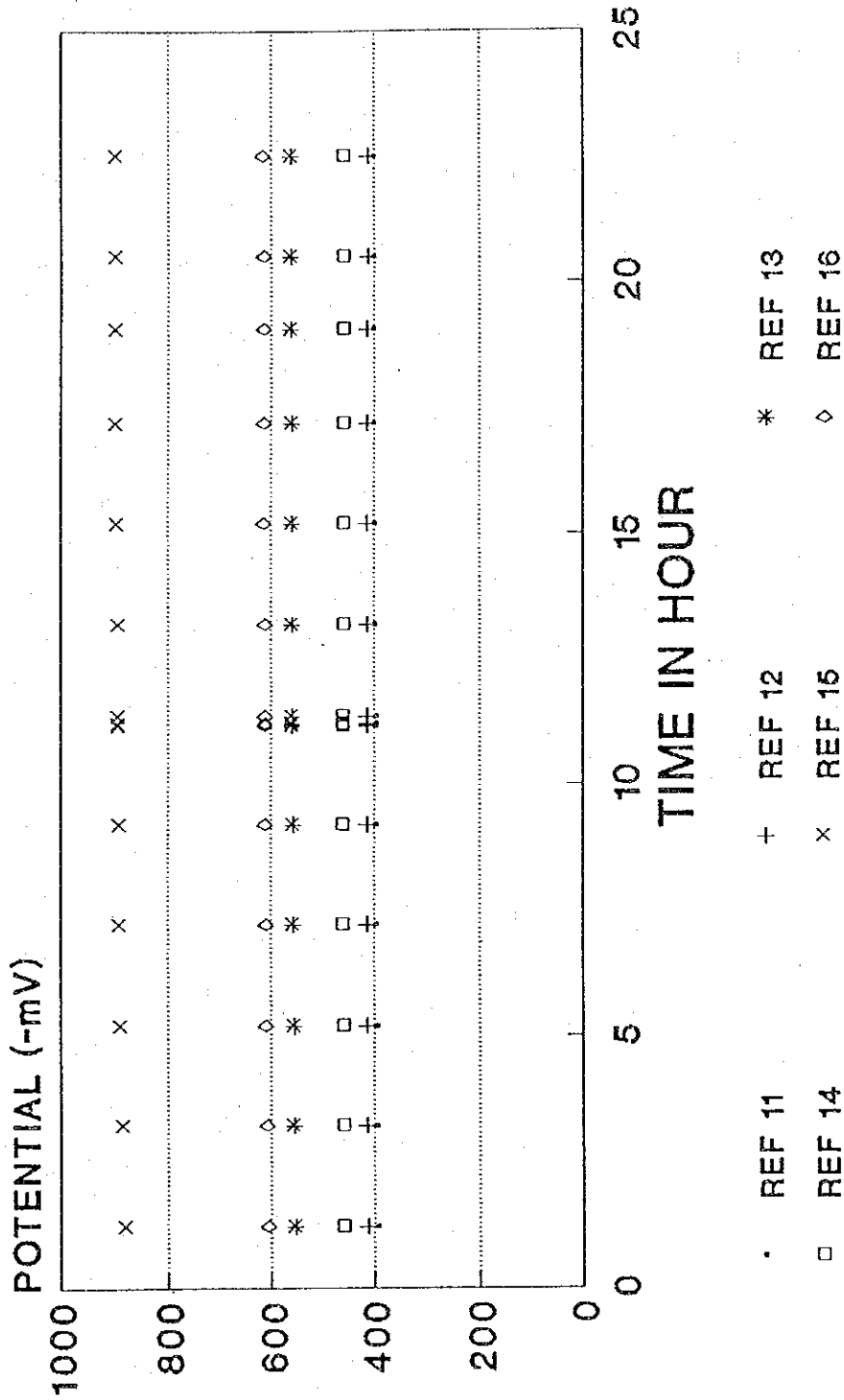
CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 29 APR 92



ZONE ONE

Fig. 5.10 Relationship between Electrical Potential/Current and Tide

CATHODIC PROTECTION SYSTEM AT SPI BLDG POTENTIAL MEASUREMENT ON 29 APR 92



ZONE ONE

Fig. 5.11 Relationship between Electrical Potential/Current and Tide

Table 5.5 Actual Current Density of Exposure Specimens Above Sea
(measured 14/4/92)

Specimen No	Current	Current density
SE-1	14.96 mA	93.5 mA/m ²
SE-2	13.80 mA	86.3
SE-3	8.01 mA	50.1
SE-4	0.0	0.0
SE-5	16.48 mA	103.0
SE-6	0.0	0.0
SE-7	15.36 mA	96.0
SE-8	12.55 mA	78.4
Total	81.16 mA	1

5.8 Conclusions

The study indicates the following:

- (a) Separate electric circuit is recommended when the cathodic protection is applied to structures with some parts located in the atmospheric zone and others in the tidal zone at the same time.
- (b) It is recommended that the spacing for the titanium ribbons of sizes half inch and quarter inch should not be more than 300mm spacing.
- (c) The corrosion products for cathodically protected specimens are thin, smooth and non-expansive. They are less likely to cause cracking in the concrete cover.
- (d) Pitting corrosion commonly found in unprotected concrete is less in cathodically protected members.
- (e) The tropical climate condition is more severe than that of the temperate condition. Hence a higher protective current density is required for effective protection.
- (f) Cathodic protection has the advantage of attracting the chloride towards the anode, away from the reinforcement.
- (g) Carbonation lessens the effectiveness of cathodic protection.

More detailed research is required to study the effect of cathodic protection method on carbonated reinforced concrete members. The other area is to determine the optimum protection criteria for effective cathodic protection of reinforcement in concrete in tropical regions.

The cost effectiveness of this systems compared to other repair methods will be evaluated during the long term monitoring programme.

6.0 STUDY ON CARBONATION

6.1 Introduction

Concrete structures are to variable degrees permeable to fluids and gases. Carbon dioxide, a small constituent of our atmosphere, but, may penetrate and diffuse inwards from the member surface of structures. This inward progress is accompanied by a reaction with the constituents of the concrete.

The effect of carbon dioxide from the atmosphere on cementitious system of concrete is called Carbonation. In the carbonation phenomenon, carbon dioxide penetrates concrete and reacts with the constituents of concrete, in particular, calcium hydroxide (CH). In time the concrete becomes stratified into two layers with differing chemical and physical characteristics. The carbonated layer will extend inwards from the surface to a depth which will depend on the various factors mainly the concentration of carbon dioxide, period and condition of exposure, properties of constituent materials and curing regime.

It is well accepted that the pore solution in concrete is normally high alkaline with pH values above 12.5. Under this high alkaline pH environment, the embedded steel is surrounded by a layer of protective oxide film called passive film which maintains the steel in a passive condition. Non-carbonated concrete has maintained an alkaline pH value approximately 12.5 whereas the carbonated concrete layers is more neutral with a pH value which may decrease to 8.3. Lowering of pH adjacent to the reinforcing steel may initiate the loss of passivity of embedded steel and thus lead to the corrosion of embedded steel.

This research project is to study factors influencing carbonation of concrete such as mix proportions, the use of mineral admixtures and curing regime, with an aim to improve the resistance of concrete against carbonation.

6.2 Test Methods and Results

6.2.1 Materials

(a) Cement

The cement used in this study is Ordinary Portland Cement (OPC) with its physical properties and chemical composition shown in Tables 6.1 and 6.2.

Table 6.1 : Physical properties of OPC

1. FINENESS		
Residue (90 μm)	:	1.5
(45 μm)	:	20.4
Blaine (cm^2/gm)	:	3070
2. SETTING		
Initial (min)	:	125
Final (hr:min)	:	2:55
Water Consistency	:	27.5
3. SOUNDNESS		
Le Chatelier (mm)	:	0.5

Table 6.2 : Chemical Composition of OPC

1. SiO_2	:	22.30
2. R_2O_3	:	6.80
Al_2O_3	:	4.50
Fe_2O_3	:	2.30
3. $\text{CaO} + \text{MgO}$:	65.50
CaO	:	64.50
MgO	:	1.00
4. SO_3	:	2.70
5. $\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O}$:	0.61
Na_2O	:	0.23
K_2O	:	0.57
6. Ig. Loss	:	1.00
SUM	:	99.10
7. Free CaO	:	0.74
8. Insol Residue	:	0.18
9. Compound Composition		
LSF	:	90.35
LCF	:	89.23
CaSO_4	:	4.59
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$:	5.81
10. Compound Ratio		
S.M.	:	3.28
I.M.	:	1.96
H.M.	:	2.15
11. Cement Compound		
C_3S	:	52
C_2S	:	25
C_3A	:	8
C_4AF	:	7

(b) Ground Granulated Blast-Furnace Slag (GGBFS)

The chemical composition and physical properties of the ground granulated blast furnace slag used in this study are shown in Table 6.3.

Table 6.3 : Chemical composition and physical properties of GGBFS

1. Physical properties	
Specific gravity	: 2.90
Fineness (cm ² /g)	: 3220
2. Chemical composition (%)	
Silicon dioxide (SiO ₂)	: 32.5
Aluminium oxide (Al ₂ O ₃)	: 13.8
Ferric oxide (Fe ₂ O ₃)	: 0.2
Calcium oxide (CaO)	: 42.9
Magnesium oxide (MgO)	: 5.8
Sulfur trioxide (SO ₃)	: 2.0
Total	: 97.2

(c) Pulverised Fuel Ash (PFA)

The physical properties and chemical composition of the pulverised fuel ash used in this study are shown in Table 6.4.

Table 6.4 : Chemical composition and physical properties of PFA

Type of PFA	Specific Gravity	Fineness (cm ² /gm)	Ig. Loss (%)	SiO ₂ (%)	Al ₂ O ₃ (%)
TYPE 3000	2.28	3560	1.2	59.9	24.5

(d) Silica Fume (SF)

The physical properties and chemical composition of the silica fume used in this study are shown in Table 6.5.

Table 6.5 : Chemical composition and physical properties of SF

Specific Gravity	Fineness (cm ² /gm)	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO
2.0	250,000	0.12	93.0	0.2	0.03	0.05	0.51

(e) Fine Aggregate

The fine aggregate used in this project was natural sand of specific gravity of 2.60 and its average fineness modulus is 3.1.

(f) Coarse Aggregate

Crushed granite with maximum size of 20 mm and a specific gravity of 2.65 was used in this project. Its average fineness modulus is 6.5.

6.2.2 Mix Proportion

The mix proportions of the concrete specimens studied in this project are shown in Table 6.6. To study the effect of W/C ratio on carbonation, the W/C ratio of the concrete specimen without containing any mineral admixture, i.e., OPC concrete, was varied from 0.5 to 0.6 by weight. For the study on the effect of using ground granulated blast furnace slag as a partial replacement of cement in concrete, the replacement percentage was studied up to 55% by weight of cement.

For the replacement of OPC with PFA, the replacement percentage was studied with 15% and 30% by weight. The replacement percentage of OPC with silica fume (SF) was studied with 5% and 10% by weight.

The compressive strength, air content and workability of the specimens studied in this project are shown in Table 6.7.

6.2.3 Preparation of Specimen

Specimens used for accelerated carbonation test were cast with a dimension of 100 x 100 x 400 in mm. For compressive strength test, cube specimens with dimension of 100 x 100 x 100 in mm were cast. 24 hours after the casting, specimens were demoulded and cured in air (at $28 \pm 2^\circ\text{C}$, average relative humidity of 80%) or in water at $26 \pm 1^\circ\text{C}$. They were cured for a scheduled period of 1, 3, 7 or 28 days prior to the exposure to the accelerated carbonation condition.

6.2.4 Accelerated Carbonation Condition

The accelerated carbonation chamber (model AF-1800-NSST) used in this project is from ASAHI KAGAKU CO. LTD, TOKYO. The accelerated exposure condition of concrete prisms in the chamber was controlled as follows:

- Relative Humidity : 65%
- Temperature : 30°C
- CO_2 Concentration : 7%

Table 6.6 Mix Proportions of Test Specimens

Sr No	Mix	Mineral Admixture Replacement (%)	W/C	Total Cementitious Material (kg/m ³)		Water Content (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Fine Aggregate/ Total Agg. Ratio(%)
				OPC	Admixture				
1	OPC N50	—	0.5	380	NIL	190	826	932	47
2	OPC N60	—	0.6	317	NIL	190	869	941	48
3	Blast Furnace Slag B-30	30	0.5	265	114	189	824	929	47
4	Blast Furnace Slag B-55	55	0.5	170	208	189	821	926	47
5	Fly Ash F-15	15	0.5	321	57	189	820	925	47
6	Fly Ash F-30	30	0.5	262	112	187	815	919	47
7	Silica Fume SF-5	5	0.5	360	19	189	823	928	47
8	Silica Fume SF-10	10	0.5	340	38	189	820	925	47

Table 6.7 Compressive Strength, Air Content and Workability of Test Cube

Sr No	Mix	28 days Avg. Com. Strength (MPa)	Air content (%)	Slump (mm)
1	N50	42.09	1.85	40
2	N60	31.92	1.70	45
3	B-30	43.98	1.00	85
4	B-55	46.92	1.00	85
5	F-15	38.38	0.95	85
6	F-30	38.97	0.80	95
7	SF-5	44.83	1.50	50
8	SF-10	50.26	1.40	60

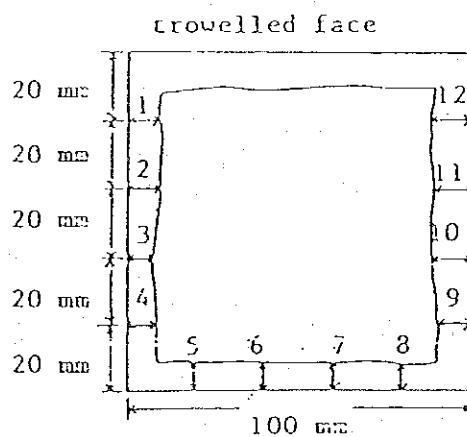


Figure 6.1 Determination of Carbonation Depth

6.2.5 Measurement of Carbonation Depth

The carbonation depth of specimens were measured at the 1st, 2nd, 4th, 6th, 12th, 16th and 24th week after exposure to the controlled environment in the carbonation chamber. Specimens were first split by using compression machine, freshly broken surfaces were then sprayed with a solution of 1% phenolphthalein in 70% ethyl alcohol. Carbonation depth was determined by the depth of discoloured portion from the exposure faces at 20mm interval as shown in Figure 6.1.

6.3 Discussion

6.3.1 OPC Concrete

(a) Effect of Curing Period in Air

Carbonation depths of specimens, with different period of curing in air prior to the exposure to the accelerated carbonation condition, with W/C ratio of 0.5 and 0.6 show that for W/C ratio of 0.5, air curing of 3 days and above leads to a decrease in carbonation depth as compared to that of only one day of curing. However, no significant difference in carbonation depth is observed for specimens with curing period of 3 days and above. For W/C ratio of 0.6, the result also shows that a longer air curing period can help to reduce the carbonation depth. However, the effect is not significant as compared to the case of W/C ratio of 0.5.

Therefore the results suggest that a longer period of curing will generally help to improve the resistance of concrete against carbonation.

(b) Effect of Curing Period in Water

Carbonation depths of specimens, with different period of curing in water prior to the exposure to the accelerated carbonation condition, with W/C ratio of 0.5 and 0.6 show that for W/C ratio of 0.5, water curing of 3 days and above leads to a significant reduction in carbonation depth as compared to only one day of curing. Similar to the case of air curing, no significant difference in carbonation depth among specimens with water curing period of 3 days and above. For W/C ratio of 0.6, the result shows that the longer the curing period the smaller will be the carbonation depth. However, there is no significant difference in carbonation depth between water curing of 7 days and 28 days.

Therefore the results also suggest that from the point of view of improving the resistance of concrete against carbonation, it is important to have the

concrete cured with sufficient curing period.

(c) Effect of Curing Condition

From the comparison between water curing and air curing with the curing period of 3 days, 7 days and 28 days for specimen with W/C ratio of 0.5, it can be seen from these figures that water curing will improve the resistance of concrete against carbonation as compared to air curing. Similarly, improvement of resistance of concrete against carbonation with water curing is also observed in the case of specimens with W/C ratio of 0.6. Therefore, it can be concluded that proper curing of concrete, especially with sufficient water, is also a measure in reducing the carbonation depth.

(d) Effect of W/C Ratio

From the comparison of carbonation depth between specimens with W/C ratio of 0.5 and 0.6 with the same curing period and condition, it can be concluded that a lower W/C ratio will improve the resistance of concrete against carbonation and this effect is much more significant than that of the curing period and conditions.

6.3.2 Concrete Containing GGBFS as Partial Replacement of Cement

(a) Effect of Replacement Percentage

From the comparison of carbonation depth among concrete specimens, with W/C ratio of 0.5 containing different replacement percentage of OPC with GGBFS, subjected to 7 days of water curing and air curing, it can be observed from both the figures that replacement of OPC with ground granulated blast furnace slag will result in an increase in carbonation depth.

(b) Effect of Curing Condition

Comparison of carbonation depth between concrete specimens subjected to water curing and air curing shows that with the same replacement percentage and the same period of curing, water curing leads to a lower carbonation depth of concrete. In other words, from the point of view of improving the resistance of concrete against carbonation, proper curing of concrete especially with sufficient water is important not only for OPC concrete but also for concrete containing GGBFS.

6.3.3 Concrete Containing PFA as Partial Replacement of cement

(a) Effect of Replacement Percentage

From the comparison of carbonation depth among concrete specimens, with W/C ratio of 0.5 containing different replacement percentage of OPC with PFA, subjected to 7 days of water curing and air curing, it can be observed from both the figures that replacement of OPC with PFA will also result in an increase in carbonation depth.

(b) Effect of Curing Condition

Comparison of carbonation depth between concrete specimens subjected to water curing and air curing shows that with the same replacement percentage and the same period of curing, water curing leads to a lower carbonation depth of concrete. In other words, from the point of view of improving the resistance of concrete against carbonation, proper curing of concrete especially with sufficient water is important not only for OPC concrete and concrete containing GGBFS but also for concrete containing PFA.

(c) Comparison of the Effect of GGBFS and PFA on Carbonation of Concrete

Between the carbonation depth of concrete containing 30% of GGBFS or PFA as partial replacement of OPC with W/C ratio of 0.5, a larger carbonation depth is observed in concrete with PFA as compared to that with GGBFS for the same curing condition and period.

6.3.4 Concrete Containing Silica Fume as Partial Replacement of Cement

(a) Effect of Replacement Percentage

From the comparison of carbonation depth among concrete specimens, with W/C ratio of 0.5 containing different replacement percentage of OPC with silica fume, subjected to 7 days of water curing and air curing, it can be observed that under water curing condition, there is no significant difference in carbonation depth between OPC concrete and concrete containing only 5% of silica fume. However, concrete containing 10% silica fume has a slightly larger carbonation depth as compared to concrete containing not more than 5% of silica fume. For the case of air curing condition, there is no significant difference in carbonation depth between OPC concrete and concrete containing not more than 10% of silica fume. Therefore the results suggest that replacement of cement with not more than 10% of silica fume should

not result in any significant decrease in resistance of concrete against carbonation.

(b) Effect of Curing Condition

From the comparison of carbonation depth between concrete specimens subjected to water curing and air curing, it can be observed that with the same replacement percentage and the same period of curing, water curing leads to a lower carbonation depth of concrete. However, this water curing effect is not as significant as compared to the concrete containing PFA or GGBF as partial replacement of cement.

6.4 Conclusions

Based on the results obtained in this study, the following conclusions can be made:

- (a) A longer period of curing will generally help to reduce the carbonation depth. In other words, from the point of view of improving the resistance of concrete against carbonation, it is important to have the concrete cured with sufficient curing period.
- (b) From the point of view of improving the resistance of concrete against carbonation, proper curing of concrete especially with sufficient water is important not only for OPC concrete and concrete containing GGBFS or PFA but also for concrete containing silica fume.
- (c) A lower W/C ratio will improve the resistance of concrete against carbonation and this effect is much more significant than that of the curing period and conditions.
- (d) Partial replacement of OPC with ground granulated blast furnace slag or pulverised fuel ash will result in an increase in carbonation depth.
- (e) A larger carbonation depth is observed in concrete with PFA as compared to that with GGBFS for the same curing condition and period.
- (f) Replacement of cement with not more than 10% of silica fume should not result in any significant decrease in resistance of concrete against carbonation.

7.0 UPDATING OF PHASE I SITE EXPOSURE TEST RESULTS

7.1 Site Exposure Test

7.1.1 Objective

Site exposure test is intended to provide a correlation between the results of accelerated corrosion test cycles and the rate of corrosion due to actual exposure on site.

7.1.2 Method

In the first phase of the programme using only Series I specimens, 15 concrete specimens corresponding to those for accelerated corrosion test were installed at the under-deck of the ESD Building of the Port of Singapore Authority in July 1988. In addition, six mortar cylinders of 50mm diameter by 100mm long each with an embedded bar, ten concrete cylinders of 100mm diameter and 200mm long and four steel bars (one of salt resisting type SRB), one coated with epoxy resin (ERB), and two plain bars) were also placed at the same exposure site.

All the specimens were placed in the tidal zone to provide the most aggressive marine environment. The inspection and evaluation of the effect of exposure after every six months had been conducted. The same test as those described in Section 7.2.1 of Volume III were carried out on all the specimens. They were recently evaluated in early 1992 after 42 months of exposure. However, instead of splitting open the 15 concrete specimens for further evaluation, they were returned to the exposure site at the ESD Building for further exposure.

Series II specimens corresponding to those for the accelerated corrosion test were similarly exposed at the same site next to those of Series I. The inspection and evaluation after every six months was carried out as per Series I specimens.

The same test as those described in Section 7.2.1 of Volume III were carried out on all the specimens. They were recently evaluated in early 1992 after 30 months of exposure. However, instead of splitting open the concrete specimens for further evaluation, they were returned to the exposure site at the ESD Building for further exposure.

Series III exposure specimens differ from the first two only in that there are two similar sets of specimens corresponding to those for the accelerated corrosion test, one of which is exposed at the ESD Building site and the other at the Tanjong Pagar Terminal (TPT) site. Monitoring is conducted like those of Series I and II. They were recently evaluated in early 1992 after 30 months of exposure. However, instead of splitting open the

concrete specimens for further evaluation, they were returned to the respective exposure site at the ESD Building and at Tanjong Pagar Terminal (TPT) for further exposure.

7.1.3 Specimens

See Section 7.2.1 in Volume III and as shown in Tables 7.1 to 7.3.

7.1.4 Exposure Sites

There are two exposure sites. Series I, II and III specimens were exposed at ESD Building site. The layout is shown in Figure 8.1 in Volume III. Only Series III specimens were exposed at the Tanjong Pagar Terminal site. TPT layout is shown in Figure 8.2 in Volume III.

7.1.5 Period and Testing Organisation

Series I specimens were first monitored prior to being subjected to exposure in July 1988. Subsequent monitoring was carried out approximately every six months. Results after 1 year 6 months of exposure was last reported in September 1990 (Volume III). Two subsequent evaluation after 2 years 10 months and 3 years 6 months exposure is reported herein. The latter was carried out between January to February 1992.

Series II and III specimens were first monitored prior to being subjected to exposure in June and July 1989 respectively. Subsequent monitoring was carried out after approximately six months of exposure. Results after 6 months of exposure was reported in September 1990 (Volume III). Two subsequent evaluation after 1 year 10 months and 2 years 6 months exposure is reported herein. The latter was carried out between January to February 1992.

7.2 Test Results

Visuals inspection results and Graphs and Tables are found in ANNEX 4 and ANNEX 5 respectively in Volume VI.

7.2.1 Series I

The graded results in tabular form and the general trends of the various elements of the different specimen types are found in ANNEX 5 (Volume VI).

Table 7.1 Series I Specimen Types

SPECIMEN SERIES I	Surface Treatment	Cement Type	W/C Ratio (X)	Steel Bar	Remarks		
A-1-1	None	Ordinary Portland Cement Cement (OPC)	40	Deformed bar SD-30 D13	Non-repair type (Type A)		
A-2-1			50				
A-3-1			60				
A-4-1		Blastfurnace Slag Cement	50			Deformed bar SD-30 D13 coated with epoxy resin	
A-5-1		Sulfate Resisting Cement					
A-6-1		Ordinary Portland Cement					Salt resisting steel bar SD-30 D13
A-7-1							
B-8-1	Chloroprene gum	Ordinary Portland Cement	50	Deformed bar SD-30 D13	Non-repair type (Type A)		
B-9-2	Acrylic polymer cement						
B-10-1	Epoxy resin						
C-11-1	None	Shrinkage Compensating Cement Mortar	50	Deformed bar SD-30 D13 coated with pigment type primer	Exposed bar type (type C)		
D-12-1					Repair type (type D)		
E-13-1	Chloroprene gum	SBR Gum Cement Mortar	50	Deformed bar SD-30 D13 coated with pigment type primer	Repair type (type E)		
E-14-1		Shrinkage Compensating Cement Mortar	(OPC)				
D-15-1	None	SBR Gum Cement Mortar			Repair type (type D)		

Table 7.2 Series II Specimen Types

SPECIMEN	Surface treatment of concrete			Cement type	Steel bar treatment	Other conditions		
	Sectional restoration	Primer	Top coat					
A-1-1	None	None	None	Ordinary portland cement	None			
A-2-1			Silane Monomer					
D-3-1	Polymer cement mortar (I)	None	Acrylic silicon type top coat					
A-4-1	None							
D-5-1	Polymer cement mortar (I)	Polymer cement type inhibitor (I)	Acrylic silicon type top coat				Polymer cement type inhibitor (I)	None
D-6-1								
D-7-1	Grouting							
A-8-1	None	None	Epoxy resin for under water application				Polymer cement type inhibitor (II)	Crack provided
D-9-1	Polymer cement mortar (II)							
A-10-1	None							
D-11-1	Polymer JET shotcreting	Polymer cement type waterproofing material	Acrylic type paint				Polymer cement type inhibitor (I)	None
D-12-1		Polymer cement type inhibitor (I)	Acrylic silicon type top coat					
A-13-1	None	None	Polymer JET shotcreting				None	Four face shotcreted
A-14-1			None					Low heat cement

Remarks:

1. Steel bars : Deformed bars (SD35-D13)
2. Cracks : Introduced to the specimen on purpose to evaluate the repair

Table 7.3 Series III Speciment Types

Size of Specimens - 115 mm x 115 mm x 800 mm

SPECIMEN	MAKE UP					Remarks
	SERIES III	Surface Treatment	Cement Type	W/C Ratio (%)	Concrete Cover (mm)	
G1-1	Control	OPC	35	50	Deformed bar	
G2-1		-do-	40	50	-do-	
G3-1		-do-	45	50	-do-	
G4-1		BFSC 30%	40	50	-do-	
G5-1		BFSC 55%	40	50	-do-	
G6-1	None	BFSC 70%	40	50	-do-	
G7-1		OPC	40	40	-do-	Type A
G8-1		-do-	40	60	-do-	New
G9-1		-do-	40	70	-do-	
G10-1		BFSC 55%	40	40	-do-	
G11-1		-do-	40	60	-do-	
G12-1		-do-	40	70	-do-	
G13-1		OPC	40	50	Deformed bar Epoxy coated	
G14-1		-do-	40	50	Deformed bar Galvanized	
G15-1	Epoxy Coating (DIMET)	OPC	40	50	Deformed bar	New
G16-1		BFSC 55%	40	50	-do-	Type B
G17-1	Epoxy Coating (DIMET)	OPC	40	50	-do-	Shape and size similar as type B
G18-1	Full Jacketing	BFSC 55%	40	50	-do-	
G19-1		OPC	40	50	-do-	
G20-1	Full Jacketing w/o coating	BFSC 55%	40	50	-do-	Existing repair methods (type A)
G21-1		OPC	35	50	-do-	
G22-1		BFSC 55%	35	50	-do-	
G23-1	Guniting w/o coating	OPC	40	50	-do-	Type A
G24-1		BFSC 55%	40	50	-do-	
G25-1	Repaired section + Jacketing	OPC	40	50	-do-	To simulate old & new concrete in repair methods (Type C)
G26-1		BFSC 55%	40	50	-do-	
G27-1	Repaired section + Guniting	OPC	40	50	-do-	To simulate old & new concrete in repair methods (Type D)
G28-1		BFSC 55%	40	50	-do-	

Abbreviations:

BFSC Blastfurnace Slag Cement
OPC Ordinary Portland Cement

Size of specimens:

40mm cover - 95mm x 95mm
60mm cover - 135mm x 135mm
70mm cover - 155mm x 155mm

Debonding of the repair material away from the parent concrete is clearly visible in specimens E-13-1 and D-15-1 after 3 years 6 months of exposure (ANNEX 4, Volume VI).

(a) Corrosion Potential

After 2 years 10 months of exposure, corrosion potentials of all specimens (Table B2 Volume VI) are more noble than -228 Mv AgCIE (Grade 3.0) except for surface treated specimens B-8-1, B-10-1, E-13-1 and E-14-1, and among the non-surface treated specimens except A-6-1, A-7-1, C-11-1 and D-15-1.

After 3 years 6 months of exposure, corrosion potentials of all specimens (Table B2 Volume VI) are more noble than -228 Mv AgCIE (Grade 3.0) except for surface treated specimen E-13-1 (repair type), and for non-surface treated specimens A-2-1, A-6-1, A-7-1, C-11-1 (exposed bar type) and D-15-1 (repair type).

(b) Cover Resistance

The concrete cover resistance of all surface treated specimens continued to decrease after 2 years 10 months. After 3 years 6 months of exposure however, cover resistance of Specimen E-13-1 dropped from Grade 4 to Grade 2.5.

For non-surface treated specimens, concrete cover resistance increased from Grade 3.2 to Grade 4.2 after 3 years 6 months except C-11-1 and D-15-1 where resistance dropped lower than their initial measurement.

(c) Polarization Resistance

Initial measurements on polarization resistance of all surface treated specimens showed corrosion rates below 10mm/year (in Grade 4 to 5). Later polarization resistance values stabilized at around the 6 months value even after 3 years 6 months of exposure with the exception of E-13-1 and E-14-1. E-13-1's value dipped after 3 years 6 months exposure from Grade 4 to 5 to Grade 1.7. In the case of Specimen E-14-1 its 1 year value appears to be erroneous as later polarization values stabilized around Grade 3.4.

For non-surface treated specimens, the initial corrosion grades ranged from Grade 2.4 to 3.2 for non-repair type specimens and Grade 2.7 for both the repair type specimens. Amongst these specimens, C-11-1 consistently has the lowest Grade, reaching a minimum of 1.3 after 1 year of exposure. Specimen D-15-1 showed a dip from Grade 2.75 after 1 year 6

months to 1.85 after 3 years 6 months of exposure.

(d) Anodic Polarization

All surface treated specimens (except E-14-1) were evaluated at Grade 5 initially and after 1 year 6 months of exposure. All grades dipped to Grade 3 after 3 years 6 months. E-13-1's Grade dipped further to Grade 0. In the case of E-14-1, its Grade stabilized at Grade 3 after 3 years 6 months of exposure.

Non-surface treated specimens also showed a decrease in Grade with time. They stabilized at around Grade 2 or Grade 3 after 3 years 6 months except for C-11-1 with a Grade of 0 since initial measurements and D-15-1 whose Grade dropped to 0 after 1 year 6 months of exposure.

7.2.2 Series II

The graded results in tabular form and the general trends of the various elements of the different specimen types are found in ANNEX 5 (Volume VI).

(a) Corrosion Potential

Except for specimens D-6-1, A-8-1, D-9-1, A-10-1, D-12-1 and A-13-1, all specimens have corrosion potential values higher than -228 Mv AgCIE (Grade 3.0) after 1 year 10 months of exposure. Minor shifting of values was noted after 2 years 6 months of exposure with specimens D-5-1 and D-7-1 becoming less and Specimens D-6-1, D-9-1 and D-12-1 remaining more active than -228 Mv AgCIE after 2 years 6 months of exposure.

(b) Cover Resistance

After 2 years 6 months of exposure, resistance grades were higher than initial values except for Specimens D-3-1, A-4-1, D-9-1 and D-11-1. The resistance grades ranged from 3.2 to 3.9.

(c) Polarization Resistance

Most of the gradings remained better than 3 ($<10\mu/y$) after 1 year 10 months and 2 years 6 months of exposure. Specimen A-1-1, A-2-1, D-12-1 and A-13-1 have grading ranging from 2.95 to 2.65 after the latter period of exposure.

(d) Anodic Polarization

After 2 years 6 months of exposure anodic polarization gradings stabilized at Grade 2 to 3.

It is noted that Specimens D-3-1, D-5-1, D-9-1, A-10-1 and D-12-1 showed significant changes in grade from Grade 0 after 6 months of exposure to the present values.

7.2.3 Series III

The graded results in tabular form and the general trends of the various elements of the different specimen types are found in ANNEX 5 (Volume VI).

(a) Corrosion Potential

Most of the specimens are more noble in potential than -228 Mv AgCIE after 1 year 10 months except for G-24-1 for the ESD exposure and G-17-3 for the TPT exposure. After 2 years 6 months only specimens G-11-1, G-16-1, G-17-1, G-22-1 and G-27-1 for the ESD exposure have corrosion potentials lower than -228mV AgCIE.

(b) Concrete Cover Resistance

All specimens except G-2-1, G-3-1, G-13-1, G-15-1, G-16-1, G-17-1 and G-18-1 for the ESD exposure and G-2-3, G-15-3, G-16-3, G-17,3, G-18-3 for the TPT exposure improved in cover resistance grading after 2 years 6 months.

(c) Polarization Resistance

After 1 year 10 months and 2 years 6 months, all specimens except G-12-1, G-17-1, G-18-1 and G-27-1 of ESD exposure and G-5-3, G-12-3, G-16-3, G-17-3, G-18-3 and G-27-3 of TPT exposure showed improvement in corrosion grades.

(d) Anodic Polarization

After 2 years 6 months anodic polarization gradings stabilized at Grade 2 to 3 for most of the specimens at the ESD and TPT sites. Only specimen G-27-1 of ESD exposure and G-28-3 of TPT exposure show a reduction to Grade 1. Specimens G-14-3, G-15-3 and G-24-3 show a Grade 4 anodic polarization grading after 2 years 6 months of TPT exposure. Test results were analysed on the basis of methods and related factors.

7.3 DISCUSSION

7.3.1 Series I

(a) Non-Surface Treatment Type

(i) Type A (Non-repair Type)

(1) Type of Cement

Specimen A-4-1 cast with Blast Furnace Slag Cement (BFSC) performed best after 3 years 6 months of exposure among the non-surface Treatment Type of the methods (Type A and Type D).

(2) Type of Steel Bar

Corrosion rates of Specimen A-6-1 is ranked the lowest after 3 years 6 months of exposure. This confirms observations made in the series subjected to accelerated tests in the laboratory reported earlier (Section 7.4.1 Volume III). However, A-6-1 showed a drop in anodic polarization grading from 5 to 3 after 2 years 10 months of exposure. Its corrosion rate dropped from Grade 5 to Grade 3.6 after 3 years 6 months of exposure.

(3) Water Cement Ratio

Specimen A-3-1 with a water cement ratio of 60% showed the worst corrosion resisting characteristics. Specimens A-1-1 (w/c = 40%) and A-2-1 (w/c = 50%) did not show significant differences in corrosion grades. This was also the case in specimens subjected to accelerated tests in the laboratory (Section 7.4.1 Volume III).

(ii) Type D (Repair Type)

Accelerated Tests results show corrosion protection characteristics of Type D specimens as equal to Type A. Exposure after 3 years 6 months of specimen D-12-1 confirm this. Specimen D-15-1 however showed significant corrosion due to debonding of the repair material away from the parent concrete.

(iii) Type C (Exposed Bar Type)

As expected, Specimen C-11-1 showed a high degree of corrosion with no passivation (Grade 0) since July 1988.

(b) Surface Treatment Type

(i) Type B (Non-Repair Type)

Epoxy resin coated method (B-10) was reported to show the best corrosion protection characteristics among Type B methods from the electrochemical test results (Section 7.4.1 Volume III). This series of specimens however show no significant difference in the corrosion protection characteristics among Type B specimens.

(ii) Type E (Repair Type)

Specimen E-13-1 was evaluated equal to B-10 (Non-Repair Type) after 6 months of exposure. Electrical test results remained stable after exposure for 1 year 6 months. A drop in corrosion protection characteristics was observed after exposure for 2 years 10 months before it dropped to Grade 0 after 3 years 6 months. This is caused by debonding of the repair material away from the parent concrete. Corrosion protection characteristics of E-14 was slightly inferior compared to B-8 (Non-Repair Type: coated with chloroprene gum).

7.3.2 Series II

(a) Type of Cement

Low heat cement consistently ranked higher than A-1 (OPC) in corrosion protection characteristics even after 2 years 6 months.

(b) Specimen Type

(i) Sectional Restoration Type

Among the restoration methods, the method of polymer jet shotcreting (D-11-1) showed consistently the highest corrosion resistance. Specimen D-7-1 also showed high corrosion resistance. However, the influence of the type of surface coating and bar treatment on the restored specimens makes comparisons inconclusive.

(ii) Non-Restored Specimens

Among the non-restored methods without steel bar treatment specimen A-4-1 (with Polymer cement type inhibitor primer and Acrylic silicon type top coat) showed consistently the highest corrosion protection. Specimen A-2-1 (with SM

top coat but without primer) is ranked second.

(iii) Surface Treatment Type

Specimen A-8-1, top coated with epoxy resin for underwater applications showed the best corrosion protection but comparisons are inconclusive due to influence of inhibitor used.

(iv) Treatment of Steel Bar

Comparison of Specimen D-6-1 (with polymer cement inhibitor I) and D-5-1 (without steel bar treatment) show that the inhibitor did not increase the corrosion protection resistance. This confirms results obtained for accelerated laboratory specimens reported earlier (Section 7.4.2 Volume III).

(v) Crack Provision

No signs of deterioration due to corrosion was detected in Specimen A-10-1 even after 2 years 6 months of exposure.

7.3.3 Series III

(a) Non-Surface Treatment Type

(i) Control Specimen

(1) Water Cement Ratio

As reported earlier for Series I specimens A-1-1 (w/c = 40%) and A-2-1 (w/c = 50%) did not show significant differences in the corrosion protection characteristics. Similarly, G-1-1 (w/c = 35%) and G-2-1 (w/c = 40%) are difficult to differentiate. Specimen G-3-1 at ESD appeared to show marginally worse corrosion protection characteristics.

(ii) Amount of Cover

Comparing Specimens G-7-1, G-2-1, G-8-1 and G-9-1 cast using OPC and G-5-1, G-10-1, G-11-1 and G-12-1 cast using 55% BSFS subjected to ESD and TPT exposure, it is seen that although a thicker cover provides better corrosion protection, the trends observed with the electrochemical measurements for the specimens are not conclusive.

(iii) Type of Cement

In Series I, specimens cast using only BFSC

performed consistently better than specimens cast using only OPC. Results after exposure at ESD and TPT sites of specimens cast using 30%, 55% and 70% of BSFC and a w/c ratio of 40% do not show significant differences in grading compared with OPC specimens. Performance of Specimen G-6-3 cast using 70% BSFC did not conclusively demonstrate improvement in corrosion resisting characteristics with time.

(iv) Type of Steel Bar

Comparing Specimens G-13-1, G-14-1 and G-2-1 cast using epoxy coated, galvanised and ordinary deformed bars respectively show that G-13 and G-14 specimens performed better after 2 years 6 months of exposure at the TPT site. The difference in performance is not so significant at the ESD site. G-13 specimens show a drop in grading from Grade 5 to Grade 3 after 2 years 6 months of ESD exposure. No change in the grading of G-13 specimen was observed after TPT exposure for 2 years 6 months.

(v) Non-Repair Type

Specimen G-19-1 (Full Jacketing w/o coating) and G-23-1 (Guniting w/o coating) both show a corrosion grade of 2 to 3 after 2 years 6 months exposure at the ESD and TPT sites.

(vi) Repair Type

For OPC, Specimen G-25-1 (Jacketing) and G-27-1 (Guniting) show similar corrosion resisting characteristics. For OPC, Specimen G-26-1 (Jacketing) and G-28-1 (Guniting) also have similar grading at the ESD site. However, specimen G-26 performed much better than G-28 at the TPT site after 2 years 6 months exposure.

(b) Surface Treatment Type

(i) Non-Repair Type

Specimens G-15 and G-16 (Epoxy Resin coating) performed consistently better after TPT exposure for 2 years 6 months. However, similar specimens performed not as well at the ESD site.

7.4 Conclusions and Recommendation

- (a) Blast Furnace Slag Cement clearly exhibits better protection against corrosion than Ordinary Portland Cement. BFSC performance improves with time.
- (b) Epoxy resin coating of concrete and bar is the most outstanding method of passive protection against corrosion. Epoxy resin is durable both at temperatures of 70°C and normal exposure conditions for up to 3 years 10 months.
- (c) Two concrete materials of different class or age if bonded together and subjected to exposure in the splash zone exposure may show signs of debonding as in the case of Series I repair type specimens. Adopting surface coating as passive protection on repaired RC structures will be effective for only a few years of exposure but might prove futile in the long term unless the bond between the repair material and the parent concrete do not deteriorate with time.
- (d) The trend of some results were erratic. Errors may have arisen during reading, or been caused by faulty connections. Errors attributed to the measuring equipment is also possible. Verification of accuracy is standard in all measuring instrument/equipment. To obtain a set of reliable data, provision for accuracy verification of the Corrosion Monitoring Device is highly recommended.
- (e) Decrease in cover resistance of the surface coated specimens with time may be due to a decrease in the thickness of the coating which is subjected to aggressive environment in the splash zone. Thus periodic measurement of the thickness surface coating should be instituted in future.

8.0 MULTILATERAL ACTIVITIES

The multilateral activities under the Japan-ASEAN Cooperation Programme on Materials Science and Technology as provided for by the Japan-ASEAN Experts Meeting on February 5, 1987 in Bandung, Indonesia are venues to cater for the ASEAN characteristics of the Programme through such activities within ASEAN.

8.1 Annual Joint Meeting

In addition to the three meetings held during Phase I of the Singapore Project (in 1988, 1989 and 1990), the Fourth Joint Meeting for the Japan-ASEAN Cooperation Programme on Materials Science and Technology was held in Manila, Philippines on 3 to 5 September 1991. The Meeting reviewed the progress of the Programme. The Meeting

agreed to the conduct of a Final Regional Seminar in Singapore in September 1992 as part of the Third ASEAN Science and Technology Week. The preliminary planning paper appears as Annex 5.

8.2 Collaborative Research

(a) January-March 1991

Two ASEAN researchers, one from Brunei Darussalam and the other from Thailand each carried out a three-month period of studies as part of the multilateral activities in Singapore under the terms of collaborative research. Mr Hamiddon Hj Said from Brunei Darussalam took on a project in the area of carbonation of concrete. Mr Wuththipong Moungoi from Thailand carried out a study on the effectiveness of a modified accelerated corrosion testing regime.

(b) January-March 1992

Two ASEAN researchers, one from Indonesia and the other from Philippines each carried out a three-month period of studies as part of the multilateral activities in Singapore under the terms of collaborative research. Ms Rochati Dachlan from Indonesia took on a project to study the porosity of concrete by mercury porosimetry. Mr Jose Luis S Gamboa from Philippines carried out the progress evaluation on corrosion monitoring of reinforced concrete specimens exposed in Singapore tidal zone.

8.3 Technical Exchange Visit

The Singapore Project Team visited the other five ASEAN countries to conduct a Seminar to disseminate the results of the Phase I activities on the Corrosion Prevention of Port and Harbour Concrete Structures. In addition, they visited a major port facility in each country and held discussion with the port authorities on matters related to the design, maintenance and repair of port and harbour structures. On these occasions, the team was joined by Dr T Fukute from PHRI Japan who delivered additional papers on the practices and experience of Japan on similar areas of activities. About 20 to 40 participants took part in each of the Seminars.

(a) June 1991

Visits to Malaysia and Thailand from 16 to 22 June 1991. The team visited Port Klang of Malaysia and Port Authorities of Thailand in Bangkok.

(b) June 1992

Visits to Brunei Darussalam, Philippines and Indonesia from 14 to 24 June 1992. The team visited the Philippine Port Authority in Manila and the Port of Tanjung Priok in Jakarta.

8.4 Final Regional Seminar

The Final Regional Seminar was held on 21 to 23 September 1992 as part of the Third ASEAN Science and Technology Week in Singapore. The tentative programme appears as Annex 6.

9.0 TRANSFER OF TECHNOLOGY

Although there have been some research activities in the area of Phase II programme such carbonation in concrete, the area of cathodic protection is relatively new to Singapore. The activities in Phase II provided the opportunity for the transfer of technology in these areas to the participating organizations. This has been achieved through the activities in Singapore at which the knowledge and expertise from Japan are transferred by working together with both the long and short term experts from Japan. In addition, the visits and training available to Singapore counterparts and other researchers from ASEAN in Japan also enabled first hand observation of corrosion studies in Japan.

9.1 Specific Areas

The areas of transfer of technology are:

- (a) Fundamentals of cathodic protection for reinforced concrete structures.
- (b) Laboratory and on-site cathodic protection systems for reinforced concrete.
- (c) Standard methods for operating and monitoring the performance of cathodic protection systems.
- (d) Methods for investigating carbonation and chloride penetration in concrete
- (e) Laboratory techniques for studying the pore structure and chemical changes in cement due to carbonation and chloride ingress.

9.2 Multilateral Aspect

The implementation of the Singapore Project as part of the Japan-ASEAN Cooperation Programme on Materials Science and Technology and in particular, the multilateral activities

arising out of the Project has provided the opportunities for the exchange of knowledge and experiences amongst researchers and engineers in the field of corrosion prevention in port and harbour concrete structures not only between Japan and Singapore, but also amongst member countries of ASEAN. Thus the declared purpose stated in the Bandung Meeting of 1987 "to strengthen the basis and to contribute to the upgrading of the level of research on Materials Science and Technology of ASEAN" in terms of corrosion prevention in port and harbour concrete structures has been achieved.

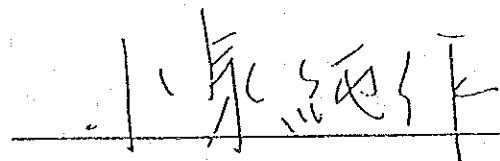
A N N E X 1

THE MINUTES OF DISCUSSIONS
BETWEEN
THE JAPANESE EVALUATION TEAM
AND
THE AUTHORITIES CONCERNED OF
THE REPUBLIC OF SINGAPORE
ON
THE JAPANESE TECHNICAL COOPERATION FOR
THE ASEAN PROJECT ON PREVENTION OF CORROSION IN STRUCTURES

The Japanese Evaluation Team (hereinafter referred to as "the Team") organized by the Japan International Cooperation Agency (JICA) and headed by Mr Junsaku Koizumi visited THE REPUBLIC OF SINGAPORE from 24 May to 2 June 1990, for the purpose of evaluating the achievements of technical cooperation for the ASEAN Project on Prevention of Corrosion in Structures (hereinafter referred to as "the Project"), as agreed to in the Record of Discussions signed between the Singapore and Japan side on 13 August 1987, and discussing the issues involved in implementation of the Project with the authorities concerned of THE REPUBLIC OF SINGAPORE.

During their stay in THE REPUBLIC OF SINGAPORE, the Team observed the project sites, exchanged views and had a series of discussions referring to the Progress Report and Draft Final Report with the Singapore authorities concerned in respect of the project activities.

As a result of the discussions, both parties agreed to report on the result of the evaluation and to recommend the extension of cooperation on the Study of Corrosion Prevention in Port and Harbour Structures, to their respective governments as referred to in the attached document.



Mr Junsaku Koizumi
Leader,
Evaluation Team
Japan International Cooperation
Agency



Dr Tam Chat Tim
Singapore Coordinator,
Japan ASEAN Cooperation
Programme on Materials
Science and Technology

1. General Evaluation

Both parties recognized that the technical cooperation in the area of prevention of corrosion in structures commencing on 1 October 1987 and slated for completion on the 30 September 1990 is making satisfactory progress and that the multilateral activities hosted by Singapore has contributed to the development of technology in respective areas in Singapore and ASEAN member countries. Further, both parties confirmed that the Final Report will be completed according to the following schedule incorporating advice made by the Team:

- Revised draft to be submitted to JICA by 30 June 1990
- Return of revised draft to Singapore by the 31 July 1990
- Final Report printed by 31 August 1990.

2. Evaluation of Sub-projects

2.1 Study on Corrosion Prevention of Drinking Water Storage Tanks

- Based on the results of field investigations, laboratory tests and actual tank cathodic protection tests on the cause and prevention of corrosion, it was concluded that the crevices are the main cause of corrosion in existing panel constructed tanks and that cathodic protection is the most effective method for prevention of corrosion. With the successful completion of the transfer of technology, both parties confirmed that the objective of this technical cooperation has been realized.
- Technical cooperation for the Study on Corrosion Prevention of Drinking Water Storage Tanks will come to an end on 30 September 1990.
- The Singapore side agreed to continue with activities in the area of corrosion and its prevention, building upon the results of this technical cooperation.

2.2 Study of Corrosion Prevention in Port and Harbour Structures

- Transfer of technology with regards to (1) the implementation of site investigation for deterioration condition and evaluation of the results and (2) the development of corrosion prevention measures against chloride penetration, have been successfully completed.
- The result of field investigations show that the carbonation as a cause of corrosion cannot be ignored in the tropical marine environment of Singapore.
- Therefore, the technical cooperation on the further study of measures against carbonation in addition to chloride penetration is necessary to develop effective corrosion prevention measures and manuals.

3. Measures to be taken in future

- 3.1 Technical cooperation for Study of Corrosion Prevention in Port and Harbour Structures will be extended for the period of two (2) years to continue research activities and finalize the manuals for corrosion prevention. The details of activities during the extended period appear in the Annex.
- 3.2 The following are measures to be taken by Singapore side during the extended period for effective implementation of the Project:
- (1) to secure and assign counterparts necessary for effective implementation with clearly defined terms of reference.
 - (2) to reinforce the project implementation organization with clear delineation of authority/responsibility at each level.
 - (3) to provide office space for Japanese Experts.
- 3.3 Japan, through JICA, will continue the cooperation under the Project-Type Technical Cooperation Scheme of the Government of Japan.
- 3.4 Both parties agreed to establish respective management committees to provide necessary guidance and advice on matters pertinent to the effective implementation of the technical cooperation.

ANNEX I MASTER PLAN

1. Background Information

Through the current studies of accelerated corrosion, site exposure and site investigation of existing port and harbour concrete structures in Singapore, which has a tropical climate, it is observed there is considerable difference in the behaviour of these structures from that in a temperate country, like Japan.

2. Extended Term of Cooperation

The duration of extended cooperation for the project will be two (2) years from 1 October 1990 to 30 September 1992.

3. Scope of Work

- (1) Study the countermeasures to reduce the chloride penetration and carbonation in concrete, and
- (2) Develop the cathodic protection method for port and harbour concrete structures in Singapore

ANNEX II PROJECT TEAM AND PARTICIPATING ORGANIZATIONS

The Project will be jointly implemented by the Japanese Project Team and the Singapore Project Team.

1. The Japanese Project Team comprises members from:
 - a. Port and Harbour Research Institute (PHRI)
Ministry of Transport (MOT)
 - b. Researchers and engineers from Japan will be dispatched as short-term experts when the need arises.

The Japanese Project Team consists of:

Long-Term Expert:

- i. Team Leader
- ii. Coordinator

Short Term Experts in the fields of:

- i. Port and harbour structures
- ii. Cathodic protection
- iii. Carbonation
- iv. Concrete materials
- v. Installation of equipment

2. The Singapore Project Team comprises members from:
 - a. Science Council of Singapore (SCS)
 - b. National University of Singapore (NUS)
 - c. Port of Singapore Authority (PSA)

The Singapore Institute of Standards and Industrial Research (SISIR) will assist the Singapore Project Team when the need arises.

The Singapore Project Team consists of:

Singapore Coordinator/Singapore Project Team Leader
Sub Team Leaders

Researchers/Experts in the fields of:

- i. Port and harbour structures
- ii. Cathodic protection
- iii. Carbonation
- iv. Concrete materials

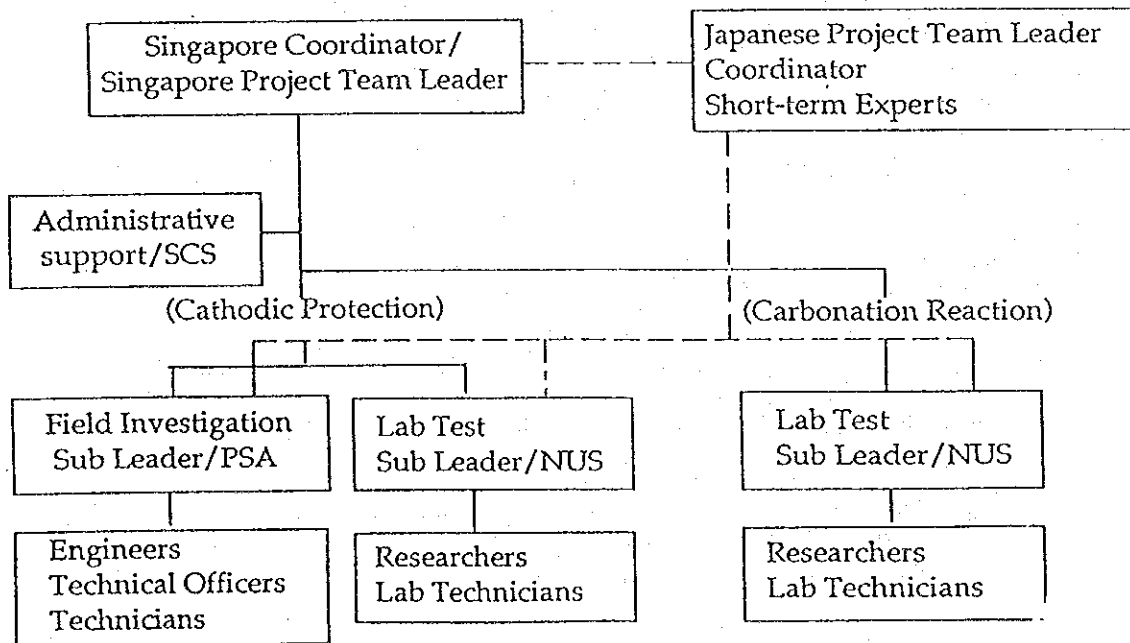
ANNEX III ADMINISTRATION OF THE PROJECT

For the more effective and successful implementation of the Project, a Management Committee will be established to support strongly operational activities of the Singapore Project Team as follows:

- Name : Management Committee
- Compositions : Chairman
Singapore Coordinator/Singapore Project Team Leader
- Members
Sub Leader, PSA
Sub Leader (Carbonation Study, NUS)
Sub Leader (Cathodic Protection, NUS)
Representative of Singapore Science Council
Japanese Project Team Leader
Japanese Coordinator
Representative of JICA Singapore Office
- Functions : To review the overall progress

To control each composition for smooth implementation in terms of manpower, budget, etc.
- Operation : Meetings will be held on a monthly basis or more frequently if necessary.

The total organization chart of the Project is given below. Technical matters will be reviewed and discussed between the Japanese Project Team and Singapore Sub-Leaders on a weekly basis.



ANNEX IV EQUIPMENT

Tentative list of areas for which equipment will be provided by Japan:

- a. Carbonation Testing
- b. Cathodic Protection Testing
- c. Electrochemical Analysis
- d. Chemical Analysis
- e. Physical Analysis
- f. Spare Parts/Others

**ANNEX V TENTATIVE IMPLEMENTATION SCHEDULE
FOR EXTENDED TERM**

ACTIVITIES	1990				1991				1992			
	4	7	10	1	4	7	10	1	4	7	10	1
1. Management Committee					(monthly basis)							
2. Main Activities												
(i) Cathodic Protection												
• Field Investigation												
• Laboratory Test												
(ii) Carbonation Test												
3. Purchasing, delivery and installation of equipment												
4. Invitation of personnel to Japan												
5. Assignment of Japanese experts												
(i) Long-term (Team Leader, Coordinator)												
(ii) Short-term								(when need arises)				
6. Report and Evaluation of the project												
							Interim				Final	

* Multilateral activities will be decided upon at future Japan-ASEAN Joint Meetings.

A N N E X 2

APPCS PROJECT SCHEDULE

Prepared : 06/03/92

Fiscal Year	1990				1991								1992																		
Calendar Year	1990				1991								1992																		
Month	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9									
CATHODIC PROTECTION TEST																															
Preparation Work	-----																														
a) Site Test	-----																														
Installation			+		-----																										
Measurement	-----																														
b) Laboratory/Exposure Test	-----																														
Installation		+		-----																											
Measurement	-----																														
Destructive Test	-----																				+										
c) Analysis and Summary of Report	-----																														
(SIEs from Japan)																															
Installation and Current Adjustment				+	-----																										
Check and Test	-----																														
Final Evaluation	-----																														
CARBONATION TEST																															
Arrival of Materials	-----																														
Preparation of Specimens																															
Carbonation Test	-----																														
Index Test	-----																														
Chemical/Microstructural Analysis	-----																														
Analysis of Results	-----																														
Summary of Report	-----																														
(STEs from Japan)																															
Preparation	-----																														
Check and Test	-----																														
Final Evaluation	-----																														
Other Activities																															
Collaborative Research	(2 x 3M)				-----														(2 x 3M)												
Interim Evaluation (JICA)	-----				-----																										
Final Evaluation (JICA)	-----																														
Seminar/Workshop	-----																														
Training in Japan	-----																														
(Carbonation Test 1 x 3W)																															
(C.P Test 2 x 3W)																															
(Kulti (2x5:2W)																															
Technology Exchange																															
Exposure Test (Phase I)																															
Series I																															
Series II & III																															

A N N E X 3

APPCS EQUIPMENT DONATED BY JICA (NUS ASSETS) - 1989*
 平成元年度供与機材リスト (NUS分)

NO.	*NAME OF ITEM & MODEL NO. *機材名	MANUFACTURER メーカー名	QTY 数量	U/PRICE 単価(K円)	TTL AMT 金額(K円)	D.O.A. 搬入日
1	WHITTEMORE STRAIN GAUGE Ws-2 長さ変化測定器	MARUTO TESTING MACH (株)丸東製作所	1 set	365	365	25/09/90
2	SPECIMEN SURFACER MIC-196-1-74 供試体端面仕上器	MARUI CORP (株)マルイ	1	1,400	1,400	"
3	PETROCHEMICAL RESISTIVITY METER MCP-HT250 比抵抗測定器	MITSUBISHI PETRO- CHEMICAL CORP 三菱石油(株)	1 set	675	675	"
4	MICRODIGEST A-300 マイクロウェーブ式全自動湿式灰化装置	PRO-LABO アーンスト・ハンセン社	1 set	7,047	7,047	"
5	AUTOMATIC POLARIZATION UNIT HZ-1A 液抵抗補正装置付分極測定装置	TOHO GIKEN 東方技研(株)	1 set	2,544	2,544	"
* 仕様書別添				合計:	12,031	

*(not listed in Annex 3, Volume I - Phase I)

APPCS EQUIPMENT DONATED BY JICA (NUS ASSETS) - 1990

平成二年度供与機材リスト (NUS分)

NO.	*NAME OF ITEM & MODEL NO. *機材名	MANUFACTURER メーカー名 (取扱業者)	QTY 数量	U/PRICE 単価(円)	TTL AMT 金額(円)	D.O.A. 輸入日
1	C.P. TEST MATERIALS (ZINC PLATE, BACK-FILL, ANCHOR BOLT, BOLT-CAP, FILLER PASTE) 電気防食室内試験用材料	NAKAGAWA CORR PROT CO 中川防蝕㈱	1 set	505	505	08/02/91
2	POTENTIOSTAT/GALVANOSTAT HA-151 行ジボスクット/加バスクット	HOKUTO DENKO 北斗電工㈱	5	164.30	821.50	"
3	ZERO-SHUNT AMMETER HM-103 零抵抗電流計	HOKUTO DENKO 北斗電工㈱	7	160.50	1,123.50	"
4	RECORDER 4082-31-01 30打点用記録計	TOKYO DENKI SANGYO 東京電器産業㈱	2	965	1,930	"
5	C.P. EXPOSURE TEST SPECI- MEN 電気防食暴露試験体	NAKAGAWA CORR PROT CO 中川防蝕㈱	6	100	600	"
6	MERCURY POROSIMETER 4000 ポロシメーター	CARLO ERBA STRUMENTA- ZIONE カール・エルバ社	1 set	7,450 (S\$96,884)	7,450 (S\$96,884)	25/03/91 現地調達
7	TORQUE DETECTOR SS-202 トルクディテクター	ONO SOKKI 小野測器㈱	1	746 (S\$9,700)	746 (S\$9,700)	28/03/91 現地調達
8	PARTS FOR DATA RECORDER (CASSETTE RIBBON, CHART, MEMORY CARDS) 記録計用部品、消耗品	YOKOGAWA ELECTRIC ASIA PTE LTD 横河電器㈱	1 set	234 (S\$3,040)	234 (S\$3,040)	26/03/91 現地調達
9	PARTS FOR CO ₂ GAS SAMPLER (BAG SKC-232-15) (COMPRESSOR THOMAS CDC18) ガスサンプラー用部品	CONSULTANCY & SVCS PTE LTD	2 2	23.50 33.60 (S\$742)	47 67.20 (S\$1,484)	20/03/91 現地調達
10	MOISTURE BALANCE OHAUS MB200 骨材水分計	ENGRG LAB ELECTRONICS	1	462 (S\$6,000)	462 (S\$6,000)	19/12/90 現地調達
11	HOBART MIXER A200 ホバートミキサー	ENGRG LAB ELECTRONICS	1	538 (S\$7,000)	538 (S\$7,000)	"
12	HOBART MIXER N50 ホバートミキサー	ENGRG LAB ELECTRONICS	1	231 (S\$3,000)	231 (S\$3,000)	"
13	PORE SOLUTION EXPRESSION APPARATUS 孔隙水抽出装置	THOR HYDRAULICS & ENGINEERING PTE LTD	1	92.30 (S\$1,200)	184.60 (S\$2,400)	20/03/91 現地調達
* 仕様書別添				合計:	14,939.80	

APPCS EQUIPMENT DONATED BY JICA (PSA ASSETS) - 1990

平成二年度供与機材リスト (PSA 分)

NO.	*NAME OF ITEM & MODEL NO. *機材名	MANUFACTURER メーカー名 (取扱業者)	QTY 数量	U/PRICE 単価(円)	TTL AMT 金額(円)	D.O.A. 記入日
1	REINFORCEMENT DETECTOR PROFOMETER 3 鉄筋探査計	FUJI CORP.	1 set	750	750	08/02/91
2	DIGITAL MULTIMETER 8060A マルチメーター	NIHON DENKEI CO LTD 日本電計	3 set	65.8	197.40	"
3	STANDARD ELECTRODE 基準電極	HOKUTO DENKO 北斗電工(株)	6 pcs	8.70	52.20	"
4	REFERENCE ELECTRODE 参照電極	NAKAGA CORR PROT CO 中川防蝕(株)	63 pcs	27.55	1,735.65	"
5	TITANIUM MESH, ELGARD #210 チタンメッシュ	ELGARD CORP. エルガード(株)	68 m ²	16.50	1,122	"
6	TITANIUM RIBBON 1/2 & 1/4 in チタンリボン 1/2 & 1/4in	ELGARD CORP. エルガード(株)	100m	4.40	440	"
7	CURRENT DISTRIBUTOR BAR 導電バー	ELGARD CORP. エルガード(株)	74m	3.30	244.20	"
8	ANODE MESH CLIP メッシュ用クリップ	ELGARD CORP. エルガード(株)	1 set	44	44	"
9	JET CEMENT ジェットセメント	SUMITOMO CMNT CO LTD 住友セメント(株)	33 bg	6.35	209.55	"
10	OVERLAY POLYMER オーバーレイ用ポリマー	SUMITOMO CMNT CO LTD 住友セメント(株)	10 pcs	16	160	"
11	POTENTIOSTAT/GALVANOSTAT HA-151 ポテンショスタット/加電ポスタット	HOKUTO DENKO 北斗電工(株)	5	164.30	821.50	"
12	POTENTIOSTAT/GALVANOSTAT HA-305 ポテンショスタット/加電ポスタット	HOKUTO DENKO 北斗電工(株)	4	530	2,120	"
13	ZERO-SHUNT AMMETER HM-103 零抵抗電流計	HOKUTO DENKO 北斗電工(株)	7	160.50	1,123.50	"
14	RECORDER 4082-31-01 30打点用記録計	TOKYO DENKI SANGYO 東京電器産業(株)	2	965	1,930	"
15	CORROSION MONITOR TGCM-1 コロージョンモニター	TOKYO GAS ENGRG CO LTD 東京ガスエンジニアング(株)	1	1,370	1,370	"
16	C.P. EXPOSURE TEST SPECI- MEN 電気防食暴露試験体	NAKAGAWA CORR PROT CO 中川防蝕(株)	6	100	600	"
* 仕様書別添				合計:	12,920	

APPCS EQUIPMENT DONATED BY JICA (NUS ASSETS) - FY1991

*平成3年度供与機材リスト (NUS分)

NO.	NAME OF ITEM & MODEL NO. 機材名	MANUFACTURER メーカー名	QTY 数量	TTL AMT 金額(K円)	D. O. A 搬入日	REMARKS 備考
1	X-RAY DIFFRACTOMETER XD-D1 X線解析装置	SHIMAZU CORP. 島津製作所	1	13,306 (S\$167,000)	24/01/92	現地調達
2	OMNI MIXER OM-30A オムニミキサー	PACIFIC SOWA CORP. 太平洋機工㈱	1	2,680 (S\$33,500)	07/01/92	"
3	SUPER DOUBLE MIXER SD-100 ダブルミキサー	PACIFIC SOWA CORP. 太平洋機工㈱	1	2,632 (S\$32,900)	07/01/92	"
4	DIONEX ION CHROMATOGRAPH SYSTEM 2000i/SP イオンクロマトグラフ	DIONEX CORP. ダイオネックス社	1	2,976 (S\$37,200)	20/11/91	"
5	RAPID CHLORIDE PERMEABILITY TEST EQPT, VERSION 2.3 塩素浸透性測定装置	G.M. IDORN INSTRUMENTS	1	4,080 (S\$51,000)	28/01/92	"
6.	LASER PRINTER, HP LASER-JET III レーザープリンター	HEWLETT PACKARD	1	230 (S\$2,880)	16/03/92	"
7.	HIGH RESOLUTION SPUTTER- COATING SYSTEM, SC-500A スパッターコーター	V.G. MICROTECH	1	1,888 (S\$23,605)	26/03/92	"
8.	TISSUE DRIER UNIT, ETD-4 ティッシュドライヤー	EDWARDS (UK)	1	2,028 (S\$25,355)	26/03/92	"
合計:				29,820 (S\$373,440)		

APPCS EQUIPMENT DONATED BY JICA (NUS ASSETS) - FY1992
平成4年度供与機材リスト (NUS 分)

NO.	NAME OF ITEM & MODEL NO. 機材名	MANUFACTURER メーカー名	QTY 数量	TTL AMT 金額(K円)	D.O.A 搬入日	REMARKS 備考
1.	RE-BAR CORROSION SENSOR MODEL 3 鉄筋腐食センサー	NIPPON STEEL CORP. 新日本製鉄㈱	1 UNIT	2,369 (S\$30,000)	Sept. 92	現地調達
2.	250KN AUTOMATIC COMPRES- SION & 15KN AUTOMATIC FLEXURAL MACHINE, G5L18/E 自動圧縮試験機	CONTROLS S.p.A	1 UNIT	3,056 (S\$38,700)	"	"
3.	VIBRO SCREEN, SH-90-180 振動スクリーン	大東振動工学㈱	1 UNIT	3,819 (S\$48,355)	"	"
4.	VACUUM/VAPOR TRAP, VT8900 真空ベーパートラップ	FTS SYSTEMS INC.	1 SET	1,469 (S\$18,606)	"	"
5.	LABORATORY MILL, UT-22 AGATE MORTAR & ACCESSORIES ラボミル、めのう乳鉢、乳棒他	YAMATO SCI. CO., LTD ヤマト精器㈱	1 SET	1,225 (S\$15,519)	"	"
6.	OMNI MIXER, OM10-E オムニミキサー	CHIYODA T&I CO., LTD 千代田技研工業㈱	1 UNIT	926 (S\$11,723)	"	"
7.	PAN TYPE MIXER, 55C-199 パンタイプミキサー	CONTROLS S.p.A	1 UNIT	769 (S\$9,741)	"	"
8.	ELECTRONIC ANALYTICAL BA- LANCE, OHAUS AP2500 分析用電子天秤	OHAUS CORP.	1 UNIT	355 (S\$4,500)	"	"
9.	MULTI-FUNCTIONAL ANALYTICAL BALANCE, FR-300 分析用電子天秤	A & D CORP.	1 UNIT	261 (S\$3,300)	"	"
10.	JOLTING APPARATUS, G5L-12 振動テーブル	CONTROLS S.p.A	1 UNIT	474 (S\$6,000)	"	"
11.	THREE GANG MOULD 三連式型枠	WENG YEW ENGRG WRKS	30 SETS	758 (S\$9,600)	"	"
12.	WATER PURIFICATION SYSTEM D4745 & ACCESSORIES 純水製造装置	BARNSTEAD	1 SET	488 (S\$6,184)	"	"
13.	VACUUM DESICCATOR 真空デシケーター	SIBATA S & T CO.,LTD	3 UNITS	610 (S\$7,728)	"	"

<u>NO.</u>	<u>NAME OF ITEM & MODEL NO.</u> 機材名	<u>MANUFACTURER</u> メーカー名	<u>QTY</u> 数量	<u>TTL AMT</u> 金額(円)	<u>D.O.A</u> 搬入日	<u>REMARKS</u> 備考
14.	UNIVERSAL OVEN, ULM700 器具乾燥器	MEMMERT GmbH & CO.	1 UNIT	333 (S\$4,213)	Sept. 92	現地調達
15.	DATA ACQUISITION SYSTEM AUTO TUNING PID CONTROLLER, SERIES SR25 温度調整及び記録装置	SHIMADEN CO., LTD	1 UNIT	716 (S\$9,080)	"	"
16.	CIRCULATING WATER BATH 循環水槽	S&I INSTRUMENTN	1 UNIT	669 (S\$8,480)	"	"
17.	AGATE MORTAR & PESTLE メノウ乳鉢 乳棒	KITAGAWA DENKO	2	347 (S\$4,400)	"	"
18.	REPETITIVE DISPENSER デイスペンサー	KITAGAWA DENKO	8	151 (S\$1,920)	"	"
合計:				18,795 (S\$238,049)		

A N N E X 4

ASEAN PROJECT ON PREVENTION OF CORROSION IN STRUCTURES
PROJECT ON CORROSION PREVENTION IN CONCRETE STRUCTURES
AT PORT AND HARBOUR

SINGAPORE PROJECT TEAM
(APPCS - PHASE II)

Coordinating Body - NSTB
Ms Kang Siew Kheng
Manager, International Affairs/Corporate Relations
(Ms Rosa Tan - up to May 1992)

Laboratory Test

by NUS

- . (Counterparts)
- . . .
- ..*Dr Tam Chat Tim
- . Associate Professor
- . Vice Dean
- . . .
- ...Dr Ong Khim Chye, Gary
- . Senior Lecturer
- . Dept of Civil Engineering
- . . .
- ...Dr Ting Seng Kiong
- . Senior Lecturer
- . Dept of Civil Engineering
- . . .
- ...Dr Wee Tiong Huan
- . Lecturer
- . Dept of Civil Engineering
- . . .
- Research Assistant
(supported by funds from JICA)

Mr Lim Huay Bak
Principal Technologist
Dept of Civil Engineering

Mr Koh Yian Kheng
Technologist
Dept of Civil Engineering

Field and Exposure Test

by PSA

- . (Counterparts)
- . . .
- ...Mr Ng Geok Kwee
- . Executive Engineer
- . Planning & Design Dept
- . . .
- ...Mr Tan Gak Peng
- . Civil Engineer
- . . .
- ...Mr Radhakrishnan
(up to August 1991)

Notes : NSTB - National Science and Technology Board
NUS - National University of Singapore
PSA - Port of Singapore Authority

* : Chairman/Project Team Leader

A N N E X 5

INTERIM PLANNING PAPER ON
SECOND JAPAN ASEAN SEMINAR ON CORROSION
17 - 21 SEPTEMBER 90, SINGAPORE

It is proposed that JICA of the Government of Japan and Science Council of the Government of the Republic of Singapore cooperate with each other in implementing the Second Japan-ASEAN Seminar on Corrosion, tentatively scheduled for 17 - 21 September 90 in Singapore.

The Programme in the Japanese fiscal year 1990 will be implemented in accordance with the following:

1 Title

The Seminar is entitled "Second Japan ASEAN Seminar on Corrosion".

2 Purpose

The Seminar is intended to provide an opportunity for persons in ASEAN countries involved in corrosion studies to exchange information on corrosion studies and to learn and benefit from experience gained in Singapore under the Japan-ASEAN Cooperative Programme on Materials Science and Technology and from Japanese expertise in this area.

3 Duration

The Seminar is scheduled for 17 - 21 September 90 in Singapore.

4 Programme

The programme will consist of 3 days of paper presentations. Relevant Japanese experts will be invited to talk about corrosion research activities in Japan related to the activities in Singapore under the cooperation programme. The 2 project groups in Singapore will present papers on their research activities. In addition speakers from the ASEAN countries will also be invited to submit papers focussing on their corrosion research activities. A final session of discussion may be provided for exchange of views.

2 days of the programme will be devoted to a workshop to give participants the opportunity to have hands-on experience with the equipment used for the project in Singapore. Site visits may also be arranged.

5 Participating Countries

Brunei Darusalam, Indonesia, Malaysia, the Philippines and Thailand will be invited to send participants.

6 Number of Participants

There will be 60 participants, 3 participants each from Brunei Darussalam, Indonesia, Malaysia, Philippines and Thailand, and 45 from Singapore.

7 Qualifications of Participants

To be eligible for admission, participants should be those involved in corrosion activities.

8 Japanese Experts

6 Japanese experts will be invited to present papers. Visits of other short term experts involved in the projects could be arranged to coincide with the seminar so that they could participate. The numbers will be confirmed by JICA. Japanese long term experts will also attend.

9 Selection of ASEAN Participants

On confirmation of funding and dates by JICA, the Science Council Singapore (SCS) will invite ASEAN member countries through their respective COST focal points to disseminate information regarding the call of papers for the Seminar.

10 Undertaking of Both Governments

In preparing for and implementing the seminar, both organisations will undertake the following responsibilities:

10.1 Science Council Singapore

- 1) To finalise the programme.
- 2) To arrange accommodation for the participants.
- 3) To submit details of participants nominated by ASEAN countries to the JICA Singapore Office.
- 4) To arrange for international travel for participants, including meeting and sending services at the airport in Singapore.
- 5) To arrange for domestic study tours.
- 6) To submit a seminar evaluation report to JICA Singapore Office and a copy thereof to the Embassy of Japan in Singapore.
- 7) To co-ordinate all matters related to the seminar.

10.2 JICA

- 1) To bear the following expenses for the Seminar:
 - a) international economy-class air fare, accommodation, per diem and medical insurance premium for participants from outside Singapore.
 - b) expenses for the seminar, material procurement, preparation of papers, study tours, and secretarial services.

11 Schedule of Implementation

A recommended schedule of implementation of the seminar is follows:

Date	Activities
31 Mar	Approval by JICA
1 April	Invitation to ASEAN member countries
1 April	Invitation to Singapore organizations
15 June	Deadline for submission of abstracts
30 June	Confirmation of acceptance of papers
31 July	Confirmation of participants
31 August	Submission of final papers
1 Sept	Printing of Seminar papers

A N N E X 6

MATERIALS SCIENCE & TECHNOLOGY CONFERENCE

"Materials Science & Technology -
Their Significance to Economic Development"

PROGRAMME

21 - 23 SEPTEMBER 1992

VENUE : MANDARIN SINGAPORE

MATERIALS SCIENCE & TECHNOLOGY CONFERENCE

PROGRAMME

DAY ONE : 21 SEPTEMBER 1992

OPENING CEREMONY AND TASTW PLENARY SESSIONS

VENUE : MANDARIN BALLROOM

08:30 REGISTRATION

09:30 OPENING CEREMONY

BY BG LEE HSIEN LOONG, DEPUTY PRIME MINISTER

09:50 TEA BREAK

10:30 TASTW PLENARY SESSION I

Keynote Address

Prof Baruch S Blumberg
Nobel laureate and Lee Kuan Yew Distinguished Visitor
from Balliol College, Oxford University

*Basic Science and Its Application : Maintaining the
Balance*

11:00 TASTW PLENARY SESSION II

- Keynote Address by Minister 1
- Keynote Address by Minister 2
- Keynote Address by Minister 3

TECHNICAL SESSIONS I TO IX AT THE BELVEDERE ROOM

DAY ONE : 21 September 92

TECHNICAL SESSION I : CERAMICS (12:00 - 13:00)

CHAIRMAN : SINGAPORE

- 12:00 Opening Address by Chairman, ASCMST
Mr. Arjuno Brojonegoro
- 12:05 Opening Address by H.E. Mr Jun Yokota, Minister Coun-
sellor, Embassy of Japan in Singapore
- 12:10 Y. Inomata/Japan
*Vapour Pressure and Solubility Equilibria in Fine
Particle System*
- 12:40 B.P.Chang, M.Z.A.Malek, G.R.Kumar/Malaysia
I.Kitano/Japan
*Properties of Rare Earth Aluminosilicate Glasses and
Glass-Ceramics*
- 12:50 Discussion
- 13:00 LUNCH

TECHNICAL SESSION II : CERAMICS (14:30 - 15:30)

CHAIRMAN : INDONESIA

- 14:30 S Karim/Malaysia
Microstructure of Sintered Kaolin-Alumina Mixtures
- 14:40 S. T. Bernardo, E. R. Martinez, B.A. Basilia,
J.R.Celorico, E.L. Bedia, J.B.Salvador, C.F.Reynales,
C.B.Zambrano/Philippines
*Characterization and Some Practical Uses of "Pinatubo"
Pyroclastic Fall Deposits*
- 14:50 L.de la La Cuesta, R.Antinopo, N. Ladines, C. Doria,
S. Bernardo/Philippines
*Development of Porcelain Insulators for Use in Power
Lines and Distribution Transformers*
- 15:00 Discussion
- 15:10 TEA BREAK
- 15:30 END OF DAY ONE

19.30 TASTW BANQUET DINNER AT THE MANDARIN BALLROOM

DAY TWO : 22 September 1992

TECHNICAL SESSION III : POLYMERS (09:00 - 10:40)

CHAIRMAN : MALAYSIA

- 09:00 Y.Watanabe/Japan
Weatherability of Polymeric Materials - Effect of Fine Structure of Polypropylene for Degradation
- 09:30 W.S. Subowo, B.Hendiswara H. Novia/Indonesia
Starch-based Biodegradable Polymer
- 09:40 A. Reani, N.M. Surdia/Indonesia
Weathering Influence on Polypropilen Film
- 09:50 S.H. Ahmad/Malaysia
Impact Behaviour of LDPE and Nylatron at High Strain Rates
- 10:00 N.M. Surdia, A.J. Perdana/Indonesia
The Influence of Polymer Structure on the Permeation of N and O Gases Through Polyolefin Films
2 2
- 10:10 Jacob Leidner/Canada
Non-woven Pu Vascular Grafts-Materials and Manufacturing Technologies
- 10:20 S. H. Ahmad, I. Abdullah/Malaysia
Strain-Rate Dependence on LNR Compatibilised NR-PP Blends
- 10:30 Discussion
- 10:40 **TEA BREAK**

TECHNICAL SESSION IV : ATMOSPHERIC CORROSION (11:00 - 12:30)

CHAIRMAN : THAILAND

- 11:00 T.Kodama/Japan
Application of Chemical Potential Diagrams to Metallic Corrosion
- 11:30 A. S. Vilorio/Philippines
T. Kodama/Japan
Characterization of Rust on Carbon Steel Exposed in Selected Atmospheres in the Philippines
- 11:40 C.R.Habana/Philippines
Study on the Corrosion Behaviour of Metals Exposed in Wet/Dry Cycle Chamber and in Natural Environment
- 11:50 R. C. Astrawinat, S. Soepriyanto, S. Purwadaria,
E. Sanwani/Indonesia
Numerical Modelling of Local Potential and Current Density in a Galvanic Corrosion System
- 12:00 L. Chotimongkol et al/Thailand
ASEAN-Japan Project on Atmospheric Corrosion : Organic Coatings
- 12:10 Somchai Thongtem/Thailand
The Chlorination of Selected Commercial Alloys at High Temperature
- 12:20 Discussion
- 12:30

LUNCH

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TECHNICAL SESSION V : OPEN SESSION (14:00 - 15:10)

CHAIRMAN : JAPAN

- 14:00 A.G. McMullen/Canada
Advanced Materials Developments at Westaim
- 14:30 C. T. Tam, H. P. Seow, L. L. Khoo, G. P. Tan/Singapore
T. Fukute, N. Kashino, A. Ikegami, N. Shimizuguchi/Japan
An Overview of Singapore Project on Prevention of Corrosion in Structures
- 14:40 Tan S. A., Fwa T. F./Singapore
Rutting Potential of Asphalt Mixtures
- 14:50 Paper to be confirmed
- 15:00 Discussion
- 15:10

TEA BREAK

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**ASEAN SUB-COMMITTEE MEETING
(15:30 - 1700)**

DAY THREE : 23 SEPTEMBER 1992

TECHNICAL SESSION VI: CORROSION IN STRUCTURES (09:00 - 10:30)

CHAIRMAN : PHILIPPINES

- 09:00 H. Tamura/Japan
Electrochemical Investigation on Factors Affecting Macro-Cell Corrosion
- 09:30 T. H. Wee/Singapore
T. T. Aung/Mynamar
T. Fukute, T. Iwabata, A. Ikegami/Japan
Carbonation of Concrete Under Accelerated Exposure Condition
- 09:40 S. H. Lee/Brunei
Basic Corrosion Research Study - Autoclave Test (I)
- 09:50 Dy Suzana Haji Awang Adenan/Brunei
Chemical Analysis on Brunei Structures
- 10:00 Discussion
- 10:30 TEA BREAK
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TECHNICAL SESSION VII: CORROSION IN STRUCTURES (11:00 - 11:50)

CHAIRMAN : BRUNEI

- 11:00 N. Kashino/Japan
Introducing of the Study on Investigation into the Limit of Initial Corrosion Occurrence in Existing Reinforced Concrete Structures
- 11:30 M. T. Arnaiz/Philippines
Corrosion of Reinforcing Bar in Concrete using Pyroclastic Fall Deposits as Aggregates
- 11:40 Discussion
- 11:50 LUNCH

TECHNICAL SESSION VIII : CORROSION IN STRUCTURES (14:00 - 15:00)

CHAIRMAN : JAPAN

- 14:00 N. Otsuki/Japan
Underwater Concreting in Japan - Especially Antiwashout Underwater Concrete
- 14:30 G. K. Ng, G.P. Tan/Singapore
T. Minematsu, Y. Shinoda, T. Fukute/Japan
Cathodic Protection for a Port & Harbour Structure in Singapore
- 14:40 S.K. Ting, K.C.G. Ong/Singapore
T. Minematsu, Y. Shinoda, A. Ikegami/Japan
Site Exposure and Accelerated Corrosion Testing of Cathodic Protection Systems
- 14:50 Discussion
- 15:00

TEA BREAK

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TECHNICAL SESSION IX: CORROSION IN STRUCTURES (15:30 - 16:35)

CHAIRMAN : INDONESIA

- 15:30 T. Fukute/Japan
Rehabilitation and Protection of Marine Concrete Structures using Electro-Deposition Method
- 16:00 Hamiddon B.Hj.Md.Said/Brunei
Study on the Corrosion of Steel in Reinforced Concrete Structures - Assessment of Existing Corrosion Damaged Reinforced Concrete Structures
- 16:10 Discussion
- 16:30 *Closing Address by Chairman, Conference Working Committee, Dr C. T. Tam*

JICA