MINISTRY OF TRANSPORT
ARAB REPUBLIC OF EGYPT

FOLLOW-UP COOPERATION STUDY ON THE PROJECT FOR CONSTRUCTION OF THE SUEZ CANAL BRIDGE

FOLLOW-UP COOPERATION STUDY REPORT

NOVEMBER 2011

JAPAN INTERNATIONAL COOPERATION AGENCY

ORIENTAL CONSULTANTS CO., LTD.
CHODAI CO., LTD.

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PREFACE

Japan International Cooperation Agency (JICA) decided to conduct the follow-up cooperation Study and entrust the study to a consortium of consultant consist of Oriental Consultants Co., Ltd. and Chodai Co., Ltd.

The study team held a series of discussions with the official concerned of the Government of Egypt, and conducted a field investigations. As a result of further studies in Japan, the present report was finalized.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of Egypt for their close cooperation extended to the study team.

November, 2011

Kazunori Miura
Director General
Financing Facilitation and Procurement Supervision Department
Japan International Cooperation Agency

CHAPTER 1 SUMMARY OF THE SITE SURVEY

1.1 Objectives of the Study

The Suez Canal Bridge, being a symbol of the friendship between Egypt and Japan, was constructed by cooperative works of both the countries with Japan's Grant Aid.

The bridge was handed over in September 2001 and the Authority for Roads, Bridges and Land Transport (hereinafter called GARBLT), the implementation agency in Egypt, notified the Embassy of Japan in March 2010 that the Suez Canal Bridge was found to display damage in the Japanese constructed section. The Japanese contractor in cooperation with GARBLT immediately carried out the first investigation and reported that delaminations of the concrete were found in the piers located on the Sinai Peninsula side, the east bank of the Canal. Inside the concrete, having removed the delaminations, rust was also found on the surface of the reinforcing steel.

Soon after this report, JICA executed a monitoring survey of the current situation for 13 days after the incidents from 16th April 2010. The objective of the survey was to investigate the damage to the concrete in the piers of the Suez Canal Bridge, to estimate the extent of the areas affected by the damage and to discuss with the concerned parties of Egypt about investigations, analyses and measures needed to be taken in the future.

The analyses of the 17 core drilled samples were carried out from June to July 2010.

Under these circumstances a follow-up cooperation Study is executed to investigate in detail all the piers including those in the Egyptian constructed sections. The objectives of the Study based on the detailed investigations shall be to infer the causes of the deterioration and evaluate the degree of the soundness so as to determine the extent of the necessary repairs and also to study the repair and maintenance plan and finally to suggest to the implementation agency in Egypt a method of repair as well as a method of maintenance in the future.

1.2 Summary of the Study

1.2.1 Study Items

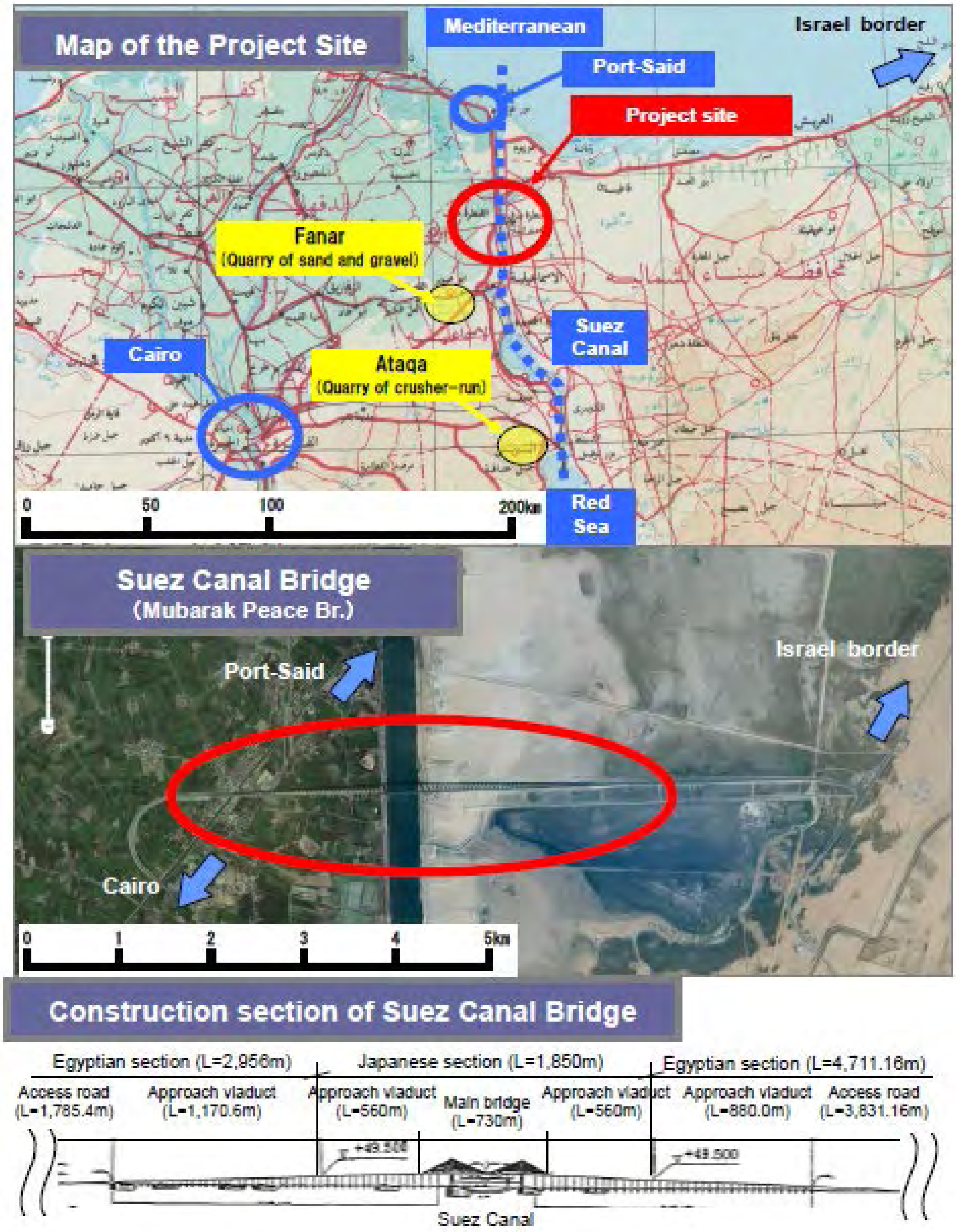
Study items in the follow-up cooperation study are shown in Table 1.

Table 1 Study Item

	Study Item
Site Investigations	1. Investigation on Concrete Pier 2. Site Investigation 3. Analysis of Concrete Material
Study / Analysis / Evaluation	1. Observation of Concrete Core Sample 2. Compressive Strength and Static Modulus of Elasticity 3. Carbonation Depth 4. Chloride Content 5. Concrete Element Analysis

1.2.2 Study Area

Study area is shown below.



CHAPTER 2 SITE INVESTIGATION

2.1 Investigation on Concrete Pier

The following tests or surveys were carried out for investigation on concrete pier.

- Hammer Test
- Crack Survey

- Infrared Thermo Graphic Camera Survey
- Concrete Cover Survey by RC Radar
- Chipping Survey
- Chloride Content Survey by Drilling
- Half-cell Potential Survey

Table 2 Investigation on Concrete Pier

Investigation Item	Column / Pile Cap	Quantity			
		West (Local)	West (Japanese)	East (Japanese)	East (Local)
Hammer Test	Column	• All columns (60 columns) x 4 faces • Total: 240 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (52 columns) x 4 faces • Total: 208 faces
	Pile Cap	• All piers (30 piers) x 4 faces, except faces under the ground. • Total: 98 faces	• All piers (17 piers) x 4 faces • Total: 68 faces	-	-
Crack Survey	Column	• All columns (60 columns) x 4 faces • Total: 240 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (52 columns) x 4 faces • Total: 208 faces
	Pile Cap	• All piers (30 piers) x 4 faces • Total: 120 faces	• All piers (17 piers) x 4 faces • Total: 68 faces	-	-
Infrared Thermo Graphic Camera Survey	Column	• All columns (60 columns) x 4 faces • Total: 240 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (52 columns) x 4 faces • Total: 208 faces
Concrete Cover Survey by RC Radar	Column	• All columns (60 columns) x 4 faces • Total: 240 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (34 columns) x 4 faces • Total: 136 faces	• All columns (52 columns) x 4 faces • Total: 208 faces
	Pile Cap	• All piers (30 piers) x 4 faces, except faces under the ground. • Total: 84 faces	• All piers (17 piers) x 4 faces, except faces under the ground. • Total: 63 faces	-	-
Chipping Survey	Column	• 7 areas in 5 piers	• 7 areas in 4 piers	• 7 areas in 5 piers	• 15 areas in 10 piers
	Pile Cap	• 2 areas in 2 P/C	• 2 areas in 2 P/C	-	-
Half-cell Potential Survey	Column	• 6 faces in 4 piers	• 4 faces in 4 piers	• 6 faces in 4 piers	• 22 faces in 6 piers
	Pile Cap	• 6 faces in 3 P/C	• 8 faces in 4 P/C	-	-

Major survey result is as follows.

- Insufficient concrete covers were approximately 50% of total.
- No tendency of corrosion of reinforcing bar was found at all chipping points including with minimum cover depth and minimum natural potential.
- Carbonation depths will not reach to the design cover depth of 70 mm in 100 years.
- Chloride contents in deeper than 60 mm were less than critical value of 1.2 kg/m^3.
- High chloride content of 1.5 kg/m^3 in PE21 will not influence on corrosion of reinforcing bar because it is still stable inside coarse aggregates.
- It is considered that delaminations have occurred by chloride attack with water and oxygen supply from ground surface.
- It is considered that cracks have occurred by thermal restraint with heat of cement hydration.

2.2 Site Investigation

The following surveys were carried out for site investigation.

- Underground Water Level
- Chloride and Sulfate Contents of Underground Water
- Soil Survey
- Meteorological Conditions Survey

Table 3 Site Investigation

Investigation Item	Quantity			
	West (Local)	West (Japanese)	East (Japanese)	East (Local)
Underground Water Level	• 1 position	• 1 position	• 1 position	• 1 position
Chloride and Sulfate Contents of Underground Water	• 1 position	• 1 position	• 1 position	• 1 position
Soil Survey	• 14 positions	• 10 positions	• 10 positions	• 14 positions
Meteorological Conditions Survey	• 1 position		• 1 position	

Major survey result is as follows.

- Underground water level in the west side is high, although it is lower than the bottom level of pile cap (-0.15 to -0.40 m).
- It is considered that underground water level in the east side is lower than the bottom level of pile cap (-1.45 to -0.35 m).
- Chloride content of underground water in the west side is low, which is classified as brackish water (CL: 0.05% - 3.5 %).
- High chloride content was found at PE 32 although it is lower than that of seawater.
- Chloride contents of fill materials at 20 m south from the bridge are high since salt lake used to exist there before.
- Chloride contents of fill materials in some areas of east side are high.
- Chloride contents of fill materials in the west side are low.
- Chloride contents of coarse and fine aggregates obtained from quarry site meet the criteria.

2.3 Analysis of Concrete Material

2.3.1 Analysis of Fine Aggregate from Quarry Site

Element analysis was carried out by Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDX).

As a result, sand containing rock salt was found.

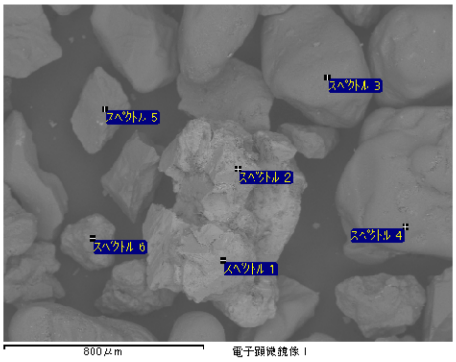


Figure 1 SEM Image

Figure 2 Microscope Image

2.3.2 Analysis of Coarse Aggregate from Concrete Core

Chloride ion contents of coarse aggregates vary from 0.015 to 0.064 wt%, and the average is 0.035 wt%.

CHAPTER 3 STUDY, ANALYSIS AND EVALUATION

3.1 Analysis of Concrete Core Sample

The following analyses were carried out for 32 concrete core samples.

3.1.1 Observation of Concrete Core Sample

(1) Visual Investigation

Negative conditions such as gel deposition around aggregates, expansion of aggregates and unusual crack were not found in all concrete core samples.

More voids in concrete cores from the Japanese section are observed than in those from the local section.

Figure 3 Core Sample in Japanese Section in the West Side (PW39CS0.5)

(2) Unit Weight

Average unit weights of piers are 2,380 kg/m^3 for local section in the west side, 2,410 kg/m^3 for Japanese section in the west side, 2,350 kg/m^3 for Japanese section in the east side and 2,330 kg/m^3 for local section in the east side, respectively.

There is no big difference on unit weight among sections. These values are almost the same as those in Japanese environment.

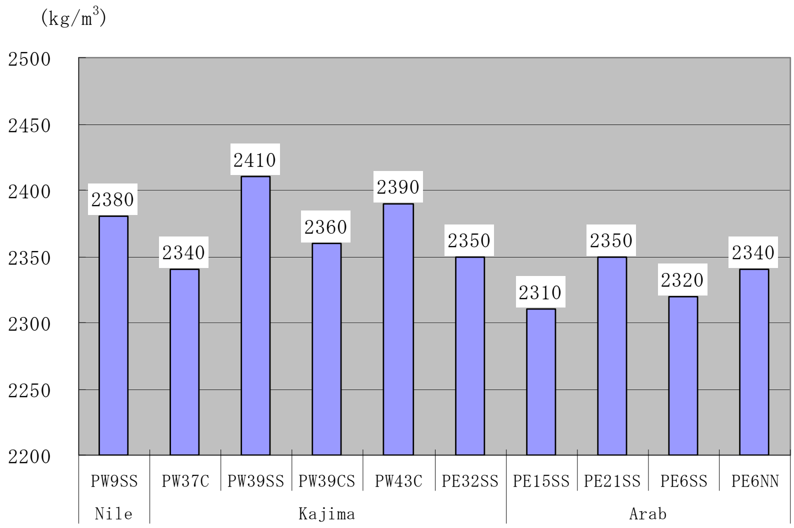


Figure 4 Average Unit Weight

(3) Water Content

Water content of PE32 is 2.87 %, which is around the half value of that in Japanese environment.

Relative water content is 40 %, which is the value having high corrosion resistance according to existing researches.

3.1.2 Compressive Strength and Static Modulus of Elasticity

(1) Compressive Strength

Compressive strengths vary from 26.9 to 65.7 N/mm^2, which are higher than 24.0 N/mm^2 of design compressive strength.

(2) Static Modulus of Elasticity

Static modulus of elasticity varies from 18.4 to 47.0 N/mm^2.

There is no particular disagreement on the relation between compressive strength and static modules of elasticity.

3.1.3 Carbonation Depth

(1) Carbonation Depth

Average carbonation depths are 15 mm, 17 mm, 21 mm and 13 mm for local section in the west side, Japanese section in the west side, Japanese section in the east side and local section in the east side, respectively.

Carbonation depths of Japanese section are slightly deeper than those of local section.

There is no clear difference in carbonation depth depending on heights or faces.

Maximum carbonation depth is 40 mm, which is found at the crack on the pile cap of PW43.

Predicted carbonation depth was calculated by following formula.

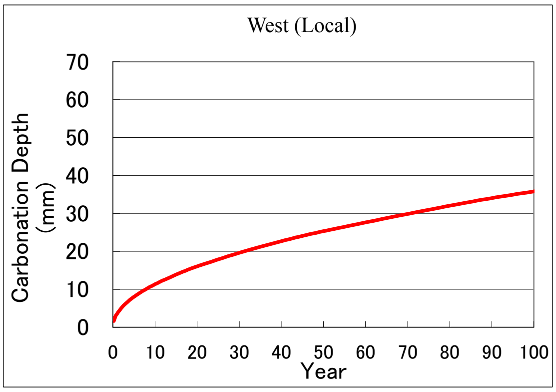
$$C = b\sqrt{t}$$

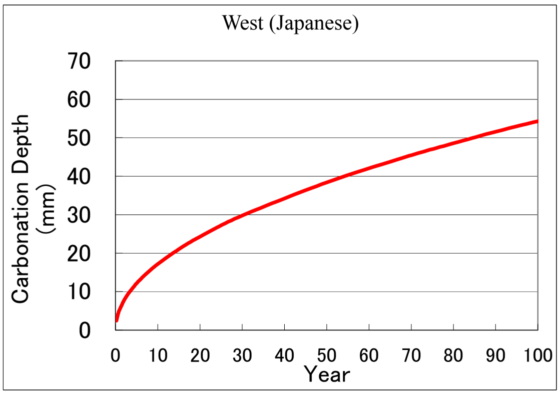
Where, C: Carbonation Depth (mm)

b: Rate of Carbonation (mm/√year)

t: Service Period

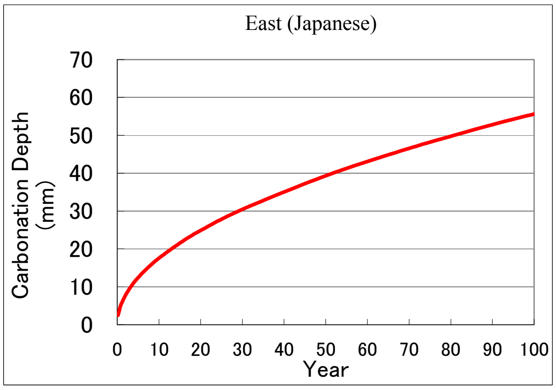
Relation between carbonation depth and service period is shown in Figure 5.

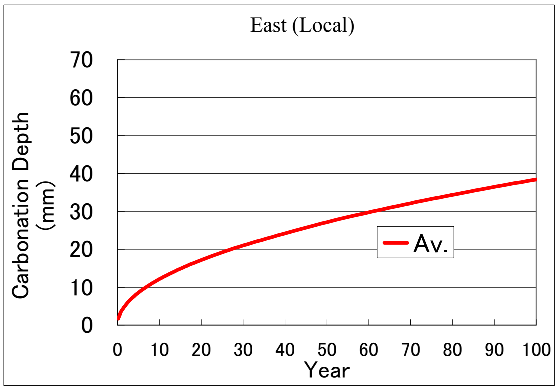




	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	16.0 mm	31.0 mm
20 year later	25.3 mm	40.3 mm
90 year later	35.8 mm	50.8 mm

	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	24.3 mm	39.3 mm
20 year later	38.4 mm	53.4 mm
90 year later	54.3 mm	69.3 mm





	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	24.9 mm	39.9 mm
20 year later	39.3 mm	54.3 mm
90 year later	55.6 mm	70.6 mm

	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	17.2 mm	32.2 mm
20 year later	27.2 mm	42.2 mm
90 year later	38.4 mm	53.4 mm

Figure 5 Relation between Carbonation Depth and Service Period

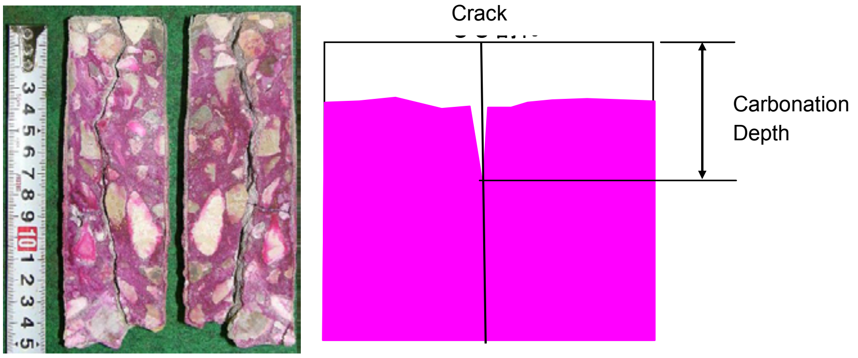


Figure 6 Sample of Carbonation at the Crack (Pile Cap of PW43)

(2) Rate of Carbonation

Average rate of carbonation is 3 to 10 times higher than that in Japanese environment.

Average rate of carbonation in Japanese section is 2 times higher than that in local section.

It will take 67 to 334 years for carbonation to reach as far as 55 mm[1] of concrete cover.

Section	Sample	Average Carbonation Depth	Maximum Carbonation Depth	Rate of Carbonation
West (Local)	PW9SS 0.5	16.8	19.5	4.63
	PW9SS 1.0	11.9	15.4	3.28
	PW9SS 1.5	15.2	19.2	4.18
West (Japanese)	PW39SS 0.5	20.2	23.3	6.11
	PW39SS 5.0	13.6	17.4	4.12
	PW39SS 10.0	15.8	19.8	4.79
	PW39SS 20.0	17.3	22.3	5.23
	PW39CS 0.5	16.2	19.8	4.89
East (Japanese)	PE32SS 0.5	21.7	26.8	6.25
	PE32SS 5.0	19.7	25.9	5.70
	PE32SS 10.0	23.3	26.3	6.72
	PE32SS 20.0	18.3	21.1	5.28
East (Local)	PE21SS 0.5	3.0	6.0	0.88
	PE15SS 0.5	11.6	15.3	3.38
	PE6 SS 0.5	14.3	15.9	4.04
	PE6 SS 1.0	12.6	16.0	3.56
	PE6 SS 1.5	13.9	18.8	3.91
	PE6 SS 5.0	12.4	14.8	3.50
	PE6 SS 10.0	13.8	21.4	3.89
	PE6 SS 20.0	11.5	13.2	3.25
	PE6 NN 0.5	10.7	13.6	3.01

[1] When Remaining carbonation depth (Concrete cover - Carbonation Depth) reaches 15 mm, corrosion of reinforcing bar may be commenced, where there is chloride in the concrete.

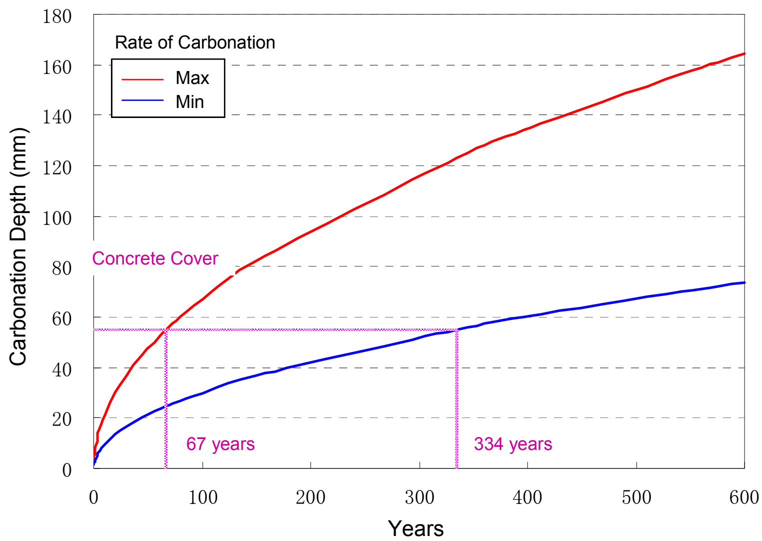


Figure 7 Rate of Carbonation

3.1.4 Chloride Content

(1) Chloride Content

The highest chloride content in deeper than 60 mm is approximately 1.5 kg/m^3 at PE21SS0.5[2]. In other locations, chloride contents were approximately 1.0 kg/m^3 in average.

There is no clear distinction on chloride content depending on heights or sections.

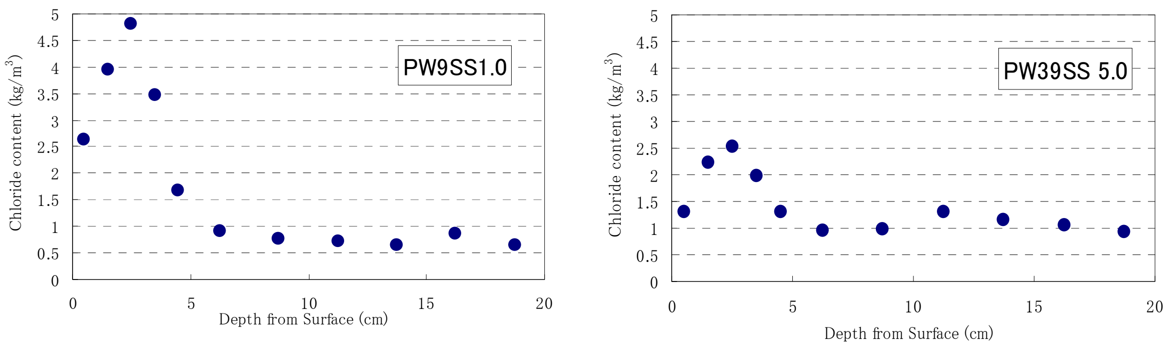


Figure 8 Chloride Contents by Depth

(2) Chloride Ionic Diffusion Coefficient

The value is quite variable since chloride content at surface, initial chloride content and chloride ionic diffusion coefficient are quite variable for each pier or concrete depth.

[2] PE21SS0.5 means P: Pier, E: East Section, 21: Pier Number 21, S: South Pier, S: South Face, and 0.5: Height from the ground is 0.5 m.

Table 4 Chloride Ionic Diffusion Coefficient

Section	Sample	Chloride Content at Surface C_0 (kg/m^3)	Initial Chloride Content C_i (kg/m^3)	Chloride Ionic Diffusion Coefficient D (cm^2/year)	Period for Chloride Content to reach 1.2 kg/m3 at Concrete Cover Depth (7 cm) (Year)
West (Local)	PW9SS 0.5	1.073	0.671	0.531	98.2
	PW9SS 1.0	3.750	0.551	1.489	8.9
	PW9SS 1.5	1.060	0.693	0.357	136.0
West (Japanese)	PW37C No.2	0.282	1.035	1.811	45.1
	PW39SS 0.5	0.370	0.849	16.477	311.9
	PW39SS 5.0	1.111	0.991	2.094	6.8
	PW39SS 10.0	0.164	1.016	1.513	not convergent
	PW39SS 20.0	0.296	0.954	1.788	293.9
	PW39CS 0.5	0.403	0.949	1.297	77.6
	PW43C No.5	0.542	0.827	1.273	119.0
East (Japanese)	PE32SS 0.5	0.484	0.860	5.380	31.2
	PE32SS 5.0	0.361	0.868	0.161	not convergent
	PE32SS 10.0	0.024	1.163	1.003	not convergent
	PE32SS 20.0	0.253	1.050	0.718	117.8
East (Local)	PE21SS 0.5	0.435	1.499	0.317	0.0
	PE15SS 0.5	1.063	0.738	1.027	38.9
	PE6 SS 0.5	1.532	0.798	0.247	78.9
	PE6 SS 1.0	0.455	0.799	0.722	1488.9
	PE6 SS 1.5	0.603	0.752	0.679	333.2
	PE6 SS 5.0	0.633	0.923	0.072	561.3
	PE6 SS 10.0	0.230	0.967	0.199	not convergent
	PE6 SS 20.0	0.547	0.795	0.038	5938.7
	PE6 NN 0.5	1.176	0.766	0.650	46.5

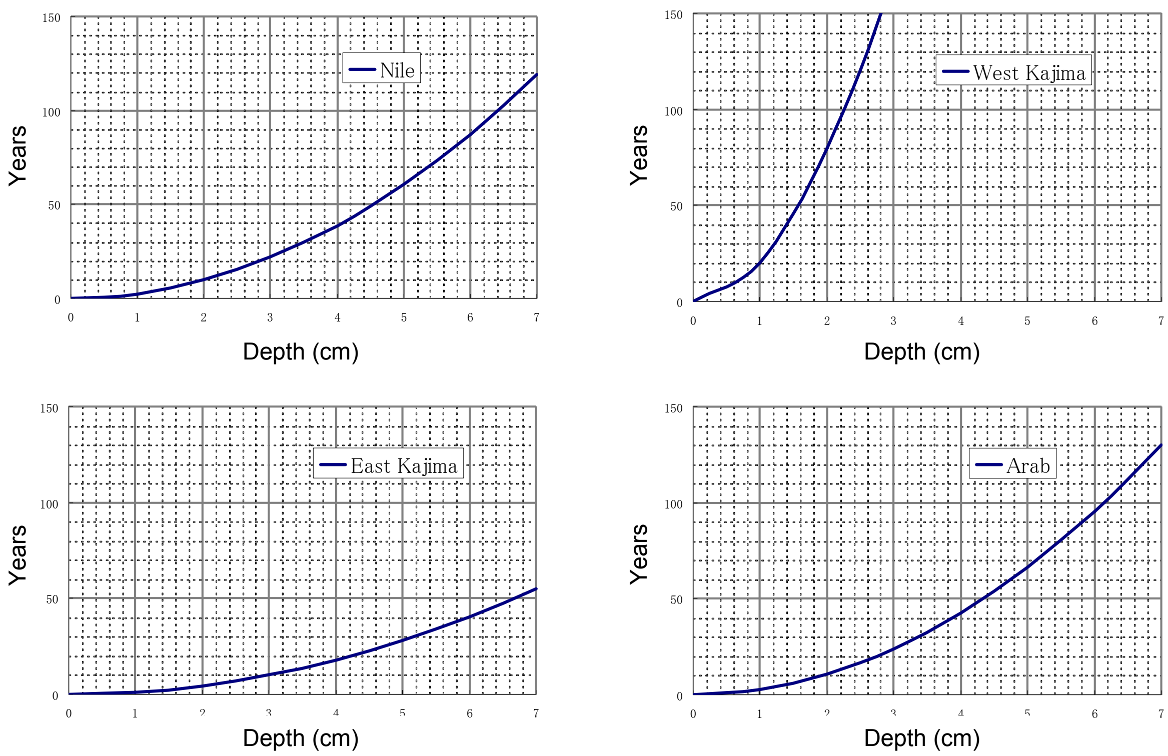


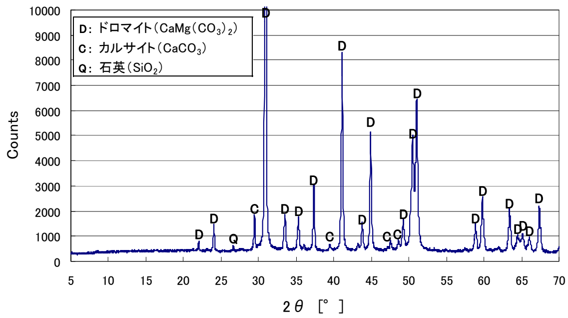
Figure 9 Period for Chloride Content to Reach 1.2 kg/m^3

3.1.5 Concrete Element Analysis

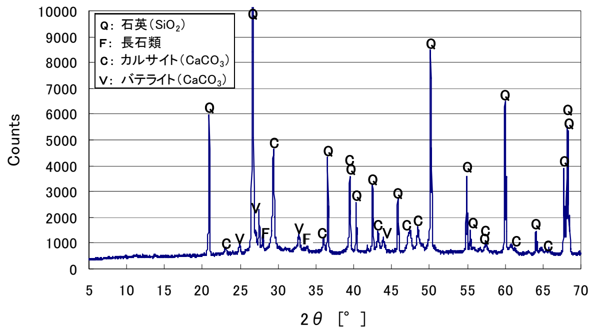
(1) XRD (X-Ray Diffraction)

Major component of aggregate is dolomite, and major components of mortar are quartz and calcite.

Ettringite and calcium sulfate, which are produced in case sulfate deterioration is made, were not found.



Aggregate



Mortar

Figure 10 XRD Result

(2) EPMA (Electron Probe Micro Analysis)

Concrete element analyses, whose target elements are Ca, Mg, S, Na, K, Cl and C, were executed by EPMA.

It was confirmed from one of the analyses that Cl penetrates from outside.

Some coarse aggregates have high chloride content, and chloride is widely distributed in mortar.

It is considered that chloride has been transferred from coarse aggregates since high chloride contents were found around some coarse aggregates.

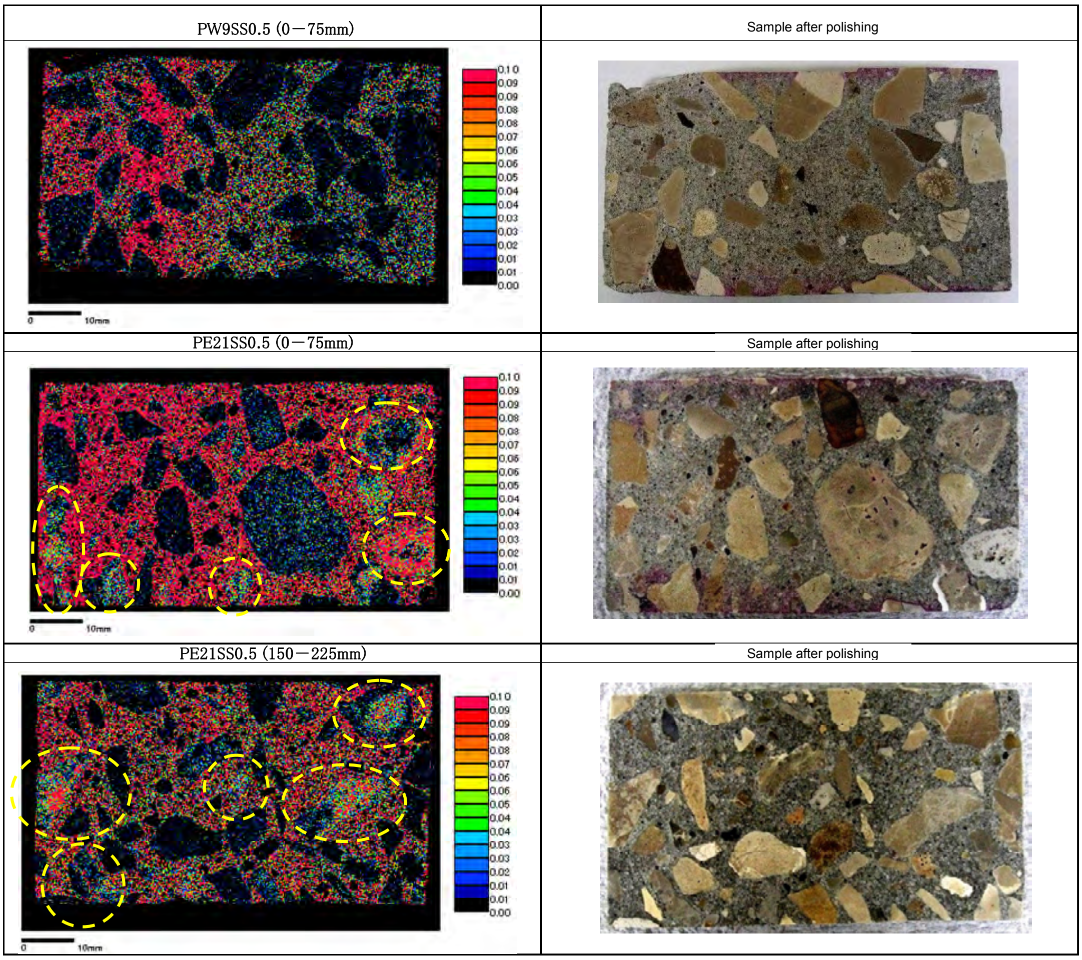


Figure 11 EPMA Result

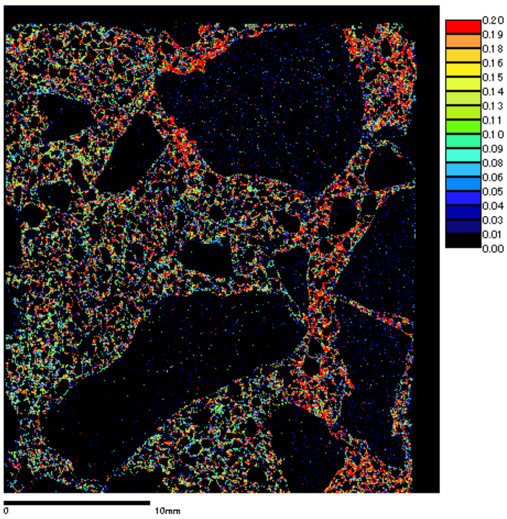


Figure 12 EPMA Result (Detail)

(3) Elemental Analysis

Elemental analysis was executed for concrete core sample of PE32SS20.

There is no big difference on concrete element between the sample (shown in Table 5) and limestone aggregate concrete in Japan.

Table 5 Elemental Analysis Result

Sample	PE32SS 20
ig.loss 1000 degree	25.26
insol.	35.51
SiO_2	2.89
Al_2O_3	1.12
Fe_2O_3	0.61
CaO	24.95
MgO	8.15
SO_3	0.17
Na_2O	0.14
K_2O	0.05

3.2 Cause of Deterioration and Evaluation of Structural Soundness

Cause of deterioration and evaluation of structural soundness are studied based on the site investigations and analysis of concrete core samples.

3.2.1 Cause of Deterioration

(1) Delamination on Pier and Pile Cap

1) Corrosion Environment

a) Chloride Content

There is 0.8 to 1.0 kg/m^3 of chloride content, which is coming from internal salt at the construction stage.

Chloride content on the concrete surface exceeds 1.2 kg/m^3 by chloride attack.

b) Carbonation Depth

Carbonation is observed near concrete surface (0 to 20 mm).

c) Concrete Cover

Concrete cover is approximately 70 mm in most piers and pile caps, but less than 50 mm in some piers and pile caps.

It is evaluated from above mentioned conditions that the reinforcing bars with thin concrete cover are under the corrosion environment.

2) Status of Delamination

Almost all the delamination occurred in the east side.

The difference of conditions between the west side and east side is regarding concrete cover.

Piers in the east side are directly touched to the soil, but (or whereas?) piers in the west side are not since the tops of pile caps are located above the ground surface.

3) Cause of Deterioration

It is considered that delaminations have occurred by chloride attack with water and oxygen supply from ground surface.

(2) Crack on Pile Cap

1) Crack Pattern and Depth

Cracks on upper surface have grillage-like regular pattern, namely, at orthogonal regular intervals (1 to 2 m).

Depth of crack exceeds 200 mm at the 0.5 mm width of crack.

2) Corrosion of Reinforcing Bar

Corrosion of reinforcing bar was not found, confirming by chipping during site investigations.

3) Cause of Deterioration

It is considered that cracks have occurred by not corrosion of reinforcing bar but thermal restraint with heat of cement hydration.

3.2.2 Evaluation of Structural Soundness

Structural soundness was evaluated using Japanese standards as reference.

(1) Delamination on Pier and Pile Cap

Structural soundness was evaluated for following three cases based on the site investigation results.

- A: No damage on concrete surface, and sufficient concrete cover
- B: No damage on concrete surface, but insufficient concrete cover
- C: Damage on concrete surface, and insufficient concrete cover

The relation between structural soundness and repair work is shown in Table 6.

Table 6 Necessity of Repair according to Structural Soundness

Soundness	Repair Work
Grade I	• Countermeasure for chloride attack is not necessary.
Grade II	• Preventive work is necessary to prevent damage generation.
Grade III	• Repair work is necessary to prevent further progress of existing damage or to maintain the existing performance.
Grade IV	• Urgent large-scale repair is necessary since deterioration caused by chloride attack is observed.

“A: No damage on concrete surface, and sufficient concrete cover” is evaluated as Grade I since countermeasure for chloride attack is not necessary.

“C: Damage on concrete surface, and insufficient concrete cover” is evaluated as Grade III since repair and preventive works are necessary for deterioration caused by chloride attack.

“B: No damage on concrete surface, but insufficient concrete cover” is evaluated as Grade I or II since degree of further deterioration caused by chloride attack will be different according to concrete cover at each place. It is required to determine the place to be required based on concrete cover, chloride content and carbonation depth for each pier.

(2) Crack on Pier and Pile Cap

Impact to soundness by crack is shown in Table 7.

Table 7 Impact to Soundness by Crack

Environment / Crack Width	Affected by salt attack or corrosion	General outdoor condition	Underground or indoor
0.5 < W	C (20-year durability)	C (20-year durability)	C (20-year durability)
0.4 < W ≤ 0.5	C (20-year durability)	C (20-year durability)	B (20-year durability)
0.3 < W ≤ 0.4	C (20-year durability)	B (20-year durability)	A (20-year durability)
0.2 < W ≤ 0.3	B (20-year durability)	A (20-year durability)	A (20-year durability)
W ≤ 0.2	A (20-year durability)	A (20-year durability)	A (20-year durability)

Note:
A: Structural soundness is maintained.
B: Structural soundness is maintained by small repair.
C: Structural soundness is not maintained.

* 20-year durability is reference only.

Applying “General outdoor condition” in Table 7,

- Structural soundness of piers is evaluated as “A”, since crack width is less than 0.3 mm.
- Structural soundness of pile caps with wider than 0.35 mm of cracks is evaluated as “B”

3.3 Place and Method of Repair

Place and method of repair are determined based on the cause of deterioration and evaluation of structural soundness.

3.3.1 Necessity of Repair and Place to be Repaired

(1) Delamination on Pier and Pile Cap

1) Necessity of Repair

Necessity of repair was determined as follows according to "3.2.2 Evaluation of Structural Soundness".

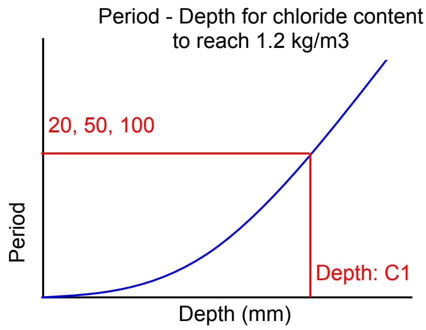
- A: No damage on concrete surface, and sufficient concrete cover
  => Repair work is not necessary.
- B: No damage on concrete surface, but insufficient concrete cover
  => Repair work is not necessary (for Grade I) or preventive work is necessary (for Grade II)
- C: Damage on concrete surface, and insufficient concrete cover
  => Repair and preventive works are necessary.

For "B: No damage on concrete surface, but insufficient concrete cover", place to be repaired will be determined based on concrete cover, predicted progress of chloride content and predicted progress of carbonation depth.

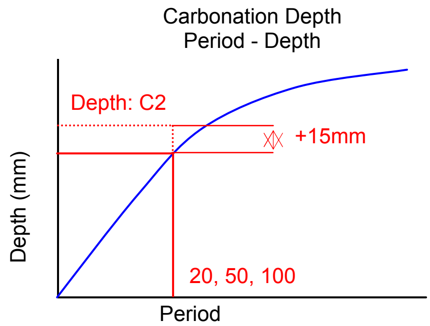
2) Place to be Repaired

For "B: No damage on concrete surface, but insufficient concrete cover", place to be repaired is determined based on the relation between concrete cover (C) and predicted progress of chloride content (C1), or concrete cover (C) and predicted progress of carbonation depth (C2), for each of C1 and C2 periods from completion of construction such as 20, 50 and 100 years being considered.

a) Predicted Progress of Chloride Content



b) Predicted Progress of Carbonation Depth



C < C1, C < C2 (including +15 mm) ···········	Shall be repaired
C < C1, C > C2 (including +15 mm) ···········	Follow-up observation
C > C1, C < C2 (including +15 mm) ···········	Follow-up observation
C > C1, C > C2 (including +15 mm) ···········	Follow-up observation

(2) Crack on Pier and Pile Cap

Table 8 Necessity of Repair according to Target Year

Impact to Soundness by Crack	Target Year		
	< 10 years	10 to 20 years	> 20 years
A (20-year durability)	• Repair work is not necessary	• Repair work is not necessary	• Repair work is not necessary (Periodic crack survey is necessary)
B (20-year durability)	• Repair work is not necessary	• Repair work is not necessary (Periodic crack survey is necessary)	• Repair work is necessary
C (20-year durability)	• Repair work is necessary	• Repair work is necessary	• Repair work is necessary

For piers, it is evaluated as “A”, therefore, repair work is not necessary (periodic crack survey is necessary).

For pile caps, it is evaluated as “B or C”, therefore, repair work is necessary for pile caps with wider than 0.35 mm of cracks.

3.3.2 Method of Repair

Following repair works shall be carried out.

- Refill of repair material as repair work for delamination
- Protection to concrete surface as preventive work for insufficient concrete cover
- Refill of filling material for cracks on pile caps

(1) Refill of Repair Material

Repair work shall be carried out based on the following work procedure.

In case the area of repair is larger than 300 mm x 300 mm, grout material shall be applied to refill repair material by form.

Incase the area of repair is smaller than 300 mm x 300 mm, polymer cement mortar shall be applied to refill repair material by plastering.

Comparison of repair material is shown in Table 9.

Table 9 Comparison of Repair Material

Material		Alt 1: Polymer Cement Mortal	Alt 2: Epoxy Resin Mortar	Alt 3: Cement Mortar
Work Procedure		• Remove concrete without damage reinforcing bar. • Remove corrosion on the reinforcing bar surface • Coat reinforcing bar with corrosion inhibitor. • Refill the polymer cement mortal material.	• Remove concrete without damage reinforcing bar. • Remove corrosion on the reinforcing bar surface • Coat reinforcing bar with corrosion inhibitor. • Refill the epoxy resin mortar material.	• Remove concrete without damage reinforcing bar. • Remove corrosion on the reinforcing bar surface • Coat reinforcing bar with corrosion inhibitor. • Install the form • Refill the cement mortar material.
Refill Method	Plaster	Suitable	Suitable	Suitable
	Spray	Suitable	Not applicable	Not applicable
	Form	Not suitable but applicable	Not suitable but applicable	Suitable
Feature		• Quick development of strength after the repair work • High durability for crack and delaminaion • No specific work method • Not suitable for large area	• Low specific gravity (0.75) • High adhesive • Expensive • Not suitable for large area • Difficult work procedure	• Cheap • Suitable for large area
Cost		190,000 JPY/m^3	580,000 JPY/m^3	90,000 JPY/m^3
Evaluation		• Good quality and workability for small area. • More expensive than Alt 3 which is not suitable for small area, but cheaper than Alt 2. **Recommended (for small area)**	• Good quality but most expensive.	• Good quality and workability for large area, which is repaired by form. • Cheapest **Recommended (for large area)**

(2) Protection to Concrete Surface

Protection material to concrete surface is selected from following alternatives.

- Coating Material (Organic)
- Coating Material (Inorganic)
- Impregnation material (Silane)
- Impregnation material (Sodium silicate)

Impregnation material (silane) is applied for protection material to concrete surface from the following aspects

- Damage such as crack can be checked easily in the further maintenance work since it is colorless and transparent.
- It can keep out water which is a cause of corrosion.

The height of protection is set as 4 m from the top of pile cap from the following aspects.

- Protection will be provided for the bottom of piers since insufficient concrete cover is mainly located there.
- First lift height is 4 m in local section.
- Lift height by slip form is 7 m in Japanese section, however the height of the fixing point of longitudinal reinforcing bar is 2.2 m.
- Damage has occurred mainly near the ground surface.
- Sufficient concrete cover is secured at 5 m in height.

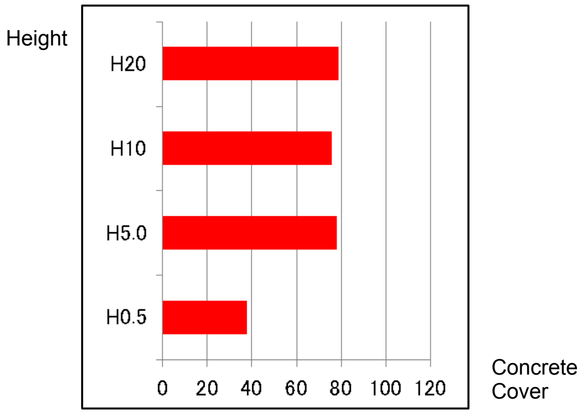


Figure 13 Concrete Cover

The number of piers to be protected is calculated according to target year, namely 20, 50 and 100 years from completion of construction (10, 40 and 90 years from today).

- Option 1 (20 years): 50 piers out of 180 piers
- Option 2 (50 years): 71 piers out of 180 piers
- Option 3 (100 years): 101 piers out of 180 piers
- Option 4 (all piers with insufficient concrete cover): 172 piers out of 180 piers

Option 2 is selected as the appropriate option from following points of view.

- Target of Option 1 is only the piers which is expected to be damaged within 20 years from completion of construction (10 years from today), and therefore another repair work might be required in 10 years.
- Target of Option 3 is the piers which are expected to be damaged within 100 years from completion of construction (90 years from today). This 100 year is much longer than the effect duration of concrete surface protection material (around 20 years), and therefore it is not cost effective.
- Target of Option 4 is almost all the piers. It is not cost effective from same reason of Option 3.

Comparison of protection material is shown in Table 10.

Table 10 Comparison of Protection Material

Material	Coating Material		Impregnation material	
	Alt 1: Organic	**Alt 2: Inorganic**	**Alt 3: Silane**	**Alt 4: Sodium silicate**
Feature	• Organic coating material consisting primarily of epoxy resin or polyurethane resin, etc.	• Inorganic coating material consisting primarily of polymer cement	• Polymer resin is produced by chemical reaction between OH- in the cement and silane solvent.	• Gel (crystal) is produced by chemical reaction between Ca(OH)2 in the cement and Sodium silicate solvent.
Barrier against Cause of Deterioration	• High barrier properties	• High barrier properties, but lower than organic material	• High barrier properties • Anti-corrosion effect	• High barrier properties • Performance degradation by ultraviolet degradation
	(Good)	(Moderate)	(Good)	(Moderate)
Moisture Permeability	• Low moisture permeability	• Low moisture permeability	• High moisture permeability	• Low moisture permeability
	(Poor)	(Poor)	(Good)	(Poor)
Maintenance	• Damage can not be checked easily since it is not colorless and transparent.	• Damage can not be checked easily since it is not colorless and transparent.	• Damage can be checked easily since it is colorless and transparent.	• Damage can be checked easily since it is colorless and transparent.
	(Poor)	(Poor)	(Good)	(Good)
Workability	• Long work period	• Shorter work period	• Short work period	• Shorter work period
	(Poor)	(Moderate)	(Good)	(Moderate)
Cost	5,000 JPY/m^2	4,000 JPY/m^2	9,000 JPY/m^2	11,000 JPY/m^2
	(Good)	(Good)	(Poor)	(Poor)
Evaluation	• Not good workability • Difficult maintenance work since the material is not transparent.	• Not good workability • Difficult maintenance work since the material is not transparent.	• Easy maintenance work since the material is transparent. • Good moisture permeability and workability **Recommended**	• Easy maintenance work since the material is transparent. • Poor moisture permeability • More expensive than Alt 3

(3) Refill of Filling Material for Cracks

Filling material shall be refilled in cracks on pile cap since crack depth and width for pile cap are deep and wide (0.5 mm).

(4) Place to be Repaired

The number of columns or pile caps to be repaired in Option 2 is shown below.

- Refill of Repair Material: 46 columns
- Protection to Concrete Surface: 71 columns
- Repair of Crack: 10 pile caps

CHAPTER 4 CONSTRUCTION SCHEDULE

Construction schedule of the repair work is shown in Figure 14. Construction period is 5.0 months.

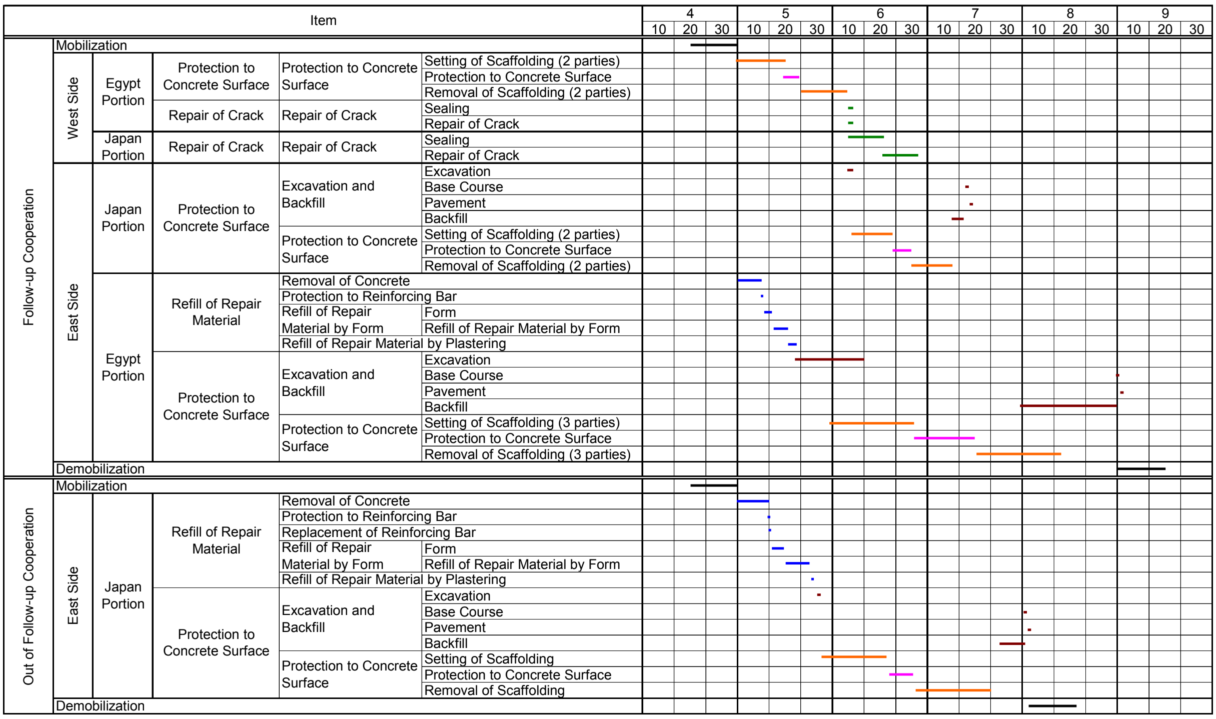


Figure 14 Construction Schedule

CHAPTER 5 COST ESTIMATES

5.1 Implementing Organization for Repair

The responsibility for the damage and implementing organization for further repair work for each section were discussed in the site survey report meeting held on August 17, 2011.

In the meeting, it was concluded that the contractor who implemented original construction has no responsibility to repair the damages, for the following reasons. However, the contractor proposed to implement the repair work by his own expense in the sections which were originally implemented by the contractor.

- According to the record, chloride content tests for cement and aggregate were carried out periodically, and the value satisfied the criteria.
- Concrete cover is insufficient at some piers, but 10 years have passed since the construction was completed and there is no critical impact on structural soundness.
- Defects liability period (1 year for grant aid project) was expired.

As shown in Table 11, Implementing organization for local section, Japanese section in west side and local section, a part of Japanese section in east side is JICA, that for a part of Japanese section in east side is the contractor who implemented original construction.

The section implemented by the contractor is out of scope of the follow-up cooperation.

Table 11 Implementing Organization for Repair

Follow-up Cooperation	Follow-up Cooperation				Out of F/U Cooperation
Section	West Side		East Side		East Side
	Local Section	Japanese Section	Japanese Section	Local Section	Japanese Section
Implementing Organization	JICA				Contractor
Refill of Repair Material	0 column	0 column	0 column	36 columns	10 columns
Protection to Concrete Surface	12 columns	0 column	11 columns	38 columns	10 columns
Repair of Crack	1 pile caps	9 pile caps	0 pile cap	0 pile cap	0 pile cap

5.2 Cost Estimates

5.2.1 Cost Estimates for Follow-up Cooperation

Construction cost for the repair work in the follow-up cooperation is 59,210 thousand Japanese Yen (4,314 thousand EGP) as shown in Table 12.

Table 12 Construction cost for the Follow-up Cooperation

Item	Class	Unit	Quantity	Unit Price			Amount			JPY Equivalent
				JPY	EGP	USD	JPY	EGP	USD	
Repair Work										
Removal of Concrete		m2	9.175		225			2,064		28,332
Protection to Reinforcing Bar		m	63.870		85			5,429		74,507
Replacement of Reinforcing Bar		m	-	-	-	-	-	-	-	-
Refill of Repair Material by Form		m3	0.629		16,000			10,064		138,119
Refill of Repair Material by Plastering		m3	0.290		13,500			3,915		53,730
Protection to Concrete Surface		m2	#######		630			2,489,760		34,169,546
Excavation and Backfill		m3	#######		330			1,699,599		23,325,351
Repair of Crack		m	647.200		160			103,552		1,421,151
Total								4,314,383		59,210,735

5.2.2 Cost Estimates for out of Follow-up Cooperation

Construction cost for the repair work out of the follow-up cooperation is 7,031 thousand Japanese Yen (512 thousand EGP) as shown in Table 13.

Table 13 Construction cost for out of the Follow-up Cooperation

Item	Class	Unit	Quantity	Unit Price			Amount			JPY Equivalent
				JPY	EGP	USD	JPY	EGP	USD	
Repair Work										
Removal of Concrete		m2	11.650		225			2,621		35,974
Protection to Reinforcing Bar		m	78.200		85			6,647		91,224
Replacement of Reinforcing Bar		m	9.000		90			810		11,116
Refill of Repair Material by Form		m3	1.304		16,000			20,864		286,338
Refill of Repair Material by Plastering		m3	0.024		13,500			324		4,447
Protection to Concrete Surface		m2	664.000		630			418,320		5,741,037
Excavation and Backfill		m3	190.300		330			62,799		861,855
Repair of Crack		m	-		160			-		-
Total								512,385		7,031,992

CHAPTER 6 IMPLEMENTATION PLAN

Implementation schedule for the project is shown in Table 14.

Table 14 Implementation Schedule

Item	Period	2011					2012											
		8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Follow-up Cooperation Study	Detailed Design	—	—	—	—													
	Preparation of Tender Document			—	—													
Procurement of Consultant	TA / CS					—	—											
Tender Assistance / Construction Supervision	Tender Assistance						—	—	—	—								
	Construction Supervision									—	—	—	—	—	—			
Tender Process	Approval of Tender Document						—											
	Tender Notice						★											
	Provision of Tender Document							—										
	Opening of Tender								★									
	Evaluation of Tender									—								
	Signing of Contract									★								
Construction	Mobilization									—								
	Refill of Repair Material										—							
	Protection to Concrete Surface										—	—	—	—				
	Repair of Crack											—						
	Demobilization														—			

CHAPTER 7 OPERATION AND MAINTENANCE PLAN

7.1 Existing Maintenance

Maintenance of Suez Canal Bridge has been carried out based on the "Operation and Maintenance Manual" prepared by Kajima - NKK Nippon Steel Consortium in July 2001.

Existing inspection item is shown in Table 15 and 16.

Table 15 Inspection Item for Main Bridge (Steel)

Object	To be inspected	Method of Inspection	Maintenance period
Steel box girder	abnormal deformation deterioration of painting	side walk from the ground inspection walkway	Routine (daily) General (every year)
	crack on welding joint abnormal sound looseness of bolts	inspection walkway inspection vehicle maintenance platform	General (every year)
Survey of Girder profile	girder elevation temperature of girder inclination of pylon	road surface inspection walkway from ground	Principal (every five years)
Bearing	looseness of setting bolt/nut surface crack of rubber / grouting damage of bearing plate deterioration of painting crack on welding joint abnormal sound of bearing plate	through manhole of pylon side walk lower cross beam through inspection walkway manhole of girder platform on pier	General (every year)
Cable	abnormal sag damage of sheathing	side walk	Routine (daily)
	measured by vibration method abnormal slip of zinc-copper alloy	side walk inspection vehicle gondola lifted by crane	Principal (when cable has abnormal sag)
Cable damper	looseness of setting bolt abnormal crack on rubber material coming out of anchor bolt	inspection vehicle gondola lifted by crane	Principal (when cable has abnormal vibration)
Pavement	deterioration	by the car	Routine (daily)
Drainage system	abnormal drainage	side walk	Routine (daily)
	leakage of water at joint part looseness of setting bolt/nut corrosion of pipe	through inspection walkway manhole of girder	General (every year)
Guard fence/ Net fence	damage of deformation	side walk	Routine (daily)
	looseness of setting bolt/nut	side walk	General (every year)
Expansion joint	abnormal sound excess gap of finger joint	side walk	Routine (daily)
	looseness of setting bolt/nut corrosion of finger/basement	through manhole of end diaphram	General (every year)
	distance of expansion joint between fixed finger and moved finger temperature of girder	manhole of end diaphram	Principal (every five years)
Inspection vehicle	looseness of setting bolt/nut breaking system moving system	on the inspection vehicle	General (every year)
Anemometer	irregularity	side walk	Routine (daily)
	looseness of setting bolt/nut	side walk	General (every year)
Navigation light	irregularity burn-out	side walk	Routine (daily)
	looseness of setting bolt/nut	side walk	General (every year)

Table 16 Inspection Item for Approach Bridge (Concrete)

Object	To be inspected	Method of Inspection	Maintenance period
Bearings	cleanliness protective coating wearing surface PTFE disc seals fixings for corrosion	Not mentioned	Principal (every five years)
Expansion joints	cleanliness side seam sealing condition concrete condition	Not mentioned	General (every six months)
	after any road repaving after any sandstorm	Not mentioned	Special
Gully grates	abnormal drainage	Not mentioned	Routine (every week)
	condition of the grilles condition of the drain body	Not mentioned	General (every six months)
Pylon lightning protection system	check the earth resistance check the copper tape conductor	Not mentioned	General (every year)
Pylon	condition of the ladders condition of the hand rails condition of the man holes	Not mentioned	General (every year)
Aviation warning lighta system	check all electrical power connections	Not mentioned	General (every six months)
Seismic sensor system	check all electrical power connections check the recording meter	Not mentioned	General (every six months)
Electrical power system	measure the insulation between the cable ends and earthing	Not mentioned	General (every six months)
	check the riser attachment to the supporting wires checking all connections	Not mentioned	(every three months)
	testing the boards earth leakage breaker	Not mentioned	General (every year)
	checking for signs of rodents	Not mentioned	(every month)
Asphalt paving	inspecting any changes	Not mentioned	Routine (every week)
	check the cracks…etc	Not mentioned	General (every six months)
Road markings & Curb painting	checking for signs of wear	Not mentioned	General (every year)

7.2 Maintenance Plan on Pier and Pile Cap

7.2.1 Inspection Method

It was evaluated that deterioration on piers was caused by chloride attack and crack on pile caps was caused by heat of cement hydration.

Inspection item to be executed for piers and pile cap was determined by reference to Japanese standard since it is not stated in "Operation and Maintenance Manual".

Inspection item for piers and pile cap is shown in Table 17.

Table 17 Inspection Item for Piers and Pile Caps

Object	To be inspected	Method of Inspection	Maintenance period
Concrete (Damage, Deterioration)	Efflorescence	Visual inspection	Daily/Periodical (every year) ※1
	Delamination	Test hammering	Periodical (every five year) ※1
	Carbonation	Chipping	Periodical (every five year) ※1
	Chloride content	Drilling, Coring	Periodical (every five year) ※2
	Generation of cracks	Crack scale	Periodical (every five year) ※2
Reinforcement (Corrosion)	Rate of corrosion	Chipping, Half-cell potential	Special/Emergency ※3

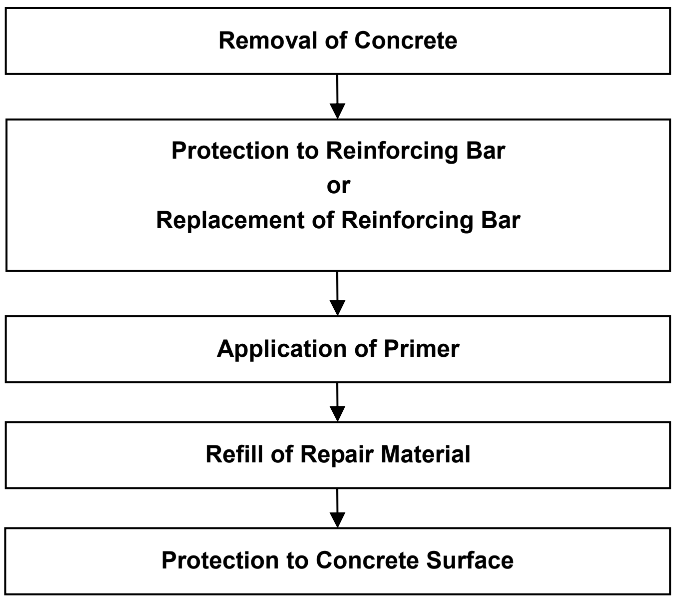
※1 Maintenance period was determined by Japanese standard.
※2 Maintenance period was determined considering follow-up observation, since chloride attack and carbonation were found in the site investigations.
※3 Corrosion of reinforcement is checked when delamination and crack on concrete are observed.

7.2.2 Repair Work

(1) Refill of Repair Material

In case the area of repair is larger than 300 mm x 300 mm, grout material shall be applied to refill repair material by form.

In case the area of repair is smaller than 300 mm x 300 mm, polymer cement mortar shall be applied to refill repair material by plastering.



(2) Repair of Crack

Filling material shall be refilled in cracks on pile cap since crack depth and width for pile cap are deep and wide (0.5 mm).

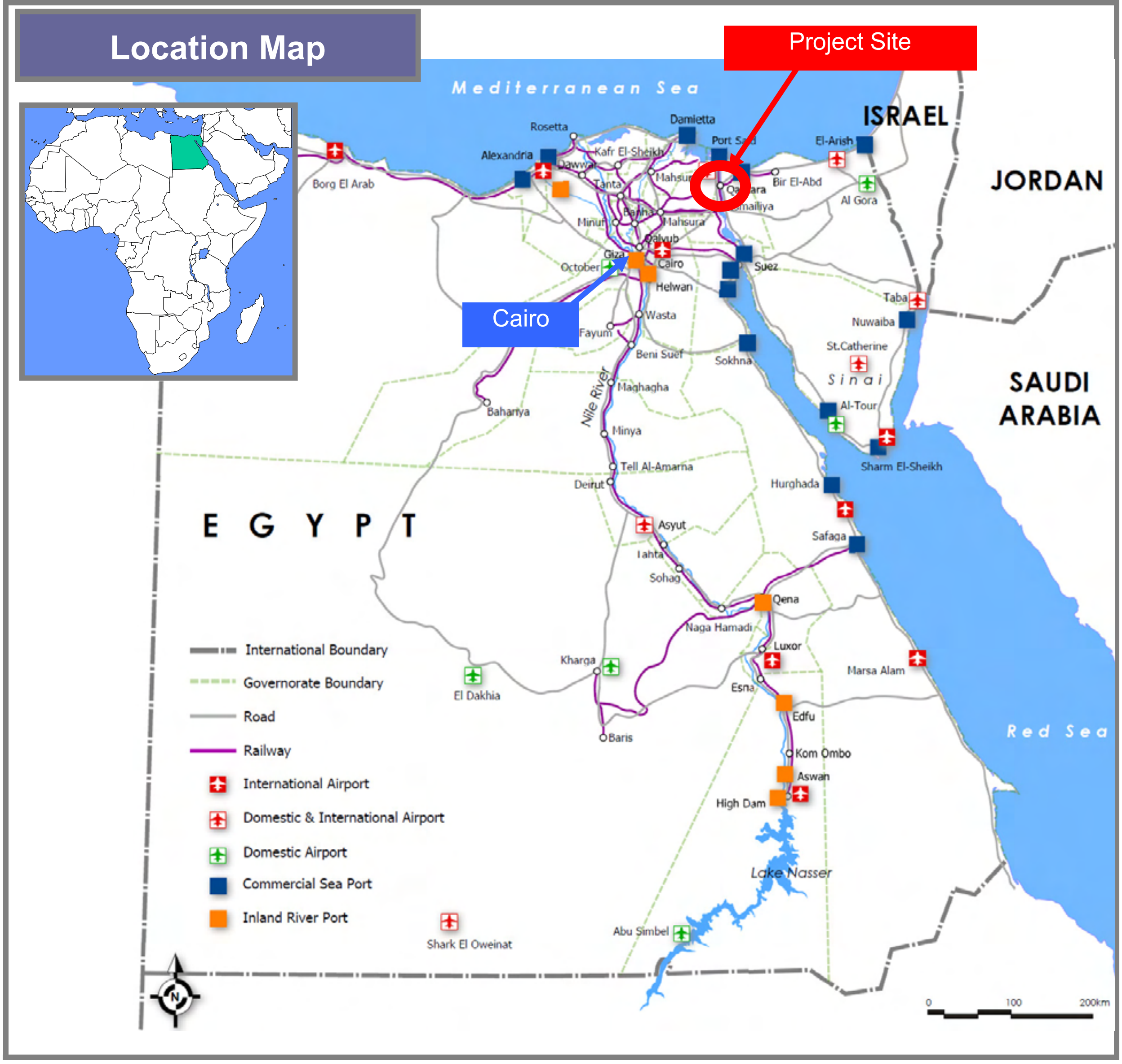
Cracks will not make substantial progress since the cause of cracks is dry shrinkage and temperature stress, and therefore, polymer cement mortar is applied as the filling material.

Contents

Appendices

1. Member List of the Study Team
2. Study Schedule
3. List of Parties Concerned in the Recipient Country
4. Minutes of Discussions
5. Material for Meeting

Arab Republic of Egypt



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Abbreviations

EPMA	Electron Probe Micro Analyzer
GARBLT	General Authority for Roads, Bridge and Land Transport
JICA	Japan International Cooperation Agency
JIS	Japan Industrial Standards Committee
PE	Pier in East Side
PW	Pier in West Side

CHAPTER 1 SUMMARY OF THE SITE SURVEY

1.1 Objectives of the Study

The Suez Canal Bridge, being a symbol of the friendship between Egypt and Japan, was constructed by cooperative works of both the countries with Japan's Grant Aid.

The bridge was handed over in September 2001 and the Authority for Roads, Bridges and Land Transport (hereinafter called GARBLT), the implementation agency in Egypt, notified the Embassy of Japan in March 2010 that the Suez Canal Bridge was found to display damage in the Japanese constructed section. The Japanese contractor in cooperation with GARBLT immediately carried out the first investigation and reported that delaminations of the concrete were found in the piers located on the Sinai Peninsula side, the east bank of the Canal. Inside the concrete, having removed the delaminations, rust was also found on the surface of the reinforcing steel.

Soon after this report, JICA executed a monitoring survey of the current situation for 13 days after the incidents from 16th April 2010. The objective of the survey was to investigate the damage to the concrete in the piers of the Suez Canal Bridge, to estimate the extent of the areas affected by the damage and to discuss with the concerned parties of Egypt about investigations, analyses and measures needed to be taken in the future. As a result, the survey team presented the following.

- The degrees of the damages in the piers were quite different in the west bank and the east bank of the Canal, the damage in the east bank side being much greater. This tendency was the same throughout the Japanese constructed section and the Egyptian constructed sections.
- A total of I7 core drilled samples were taken for detail testing in Japan to analyze chloride content, degree of carbonation, compressive strength and so on.
- Hammer tests were carried out to detect delaminations of the concrete and the rusting of the reinforcing steel having been exposed by chipping of the surface concrete during the previous (first) investigation was reconfirmed.
- Since a permit from the Army to enter the site was not issued, no further chippings of the surface concrete were possible during this most recent investigation and thus the visual confirmation of the concrete cover to the reinforcing steel was also not possible.
- Reports and data regarding the inspections during construction and the testing results were obtained.
- Lack of issuance of the entrance permit to the eastern section of the site hindered the survey. It shall be absolutely necessary to obtain the permit from the Army before the site investigations in the next survey.

The analyses of the 17 core drilled samples were carried out from June to July 2010 have obtained the following results.

- The compressive strengths ranged between 26.9 and 65.7 N/mm^2, all exceeding the specified design strength of 24 N/mm^2.
- The static elastic moduli ranged between 18.4 and 47.0 KN/mm^2. Notwithstanding the presence of small values no particular problems were considered to exist in the relationship between the compressive strength and the static elastic modulus.
- The depths of the carbonation in the concrete ranged between 11.0 and 20.2 mm (16.6 mm in average) except for few samples with small values. For concrete 10 years of age with a 45 % water cement ratio, such progress of the carbonation is 3 times faster than that in Japanese environment.
- It was found that the chloride contents in the core test results were greater than the expected from the site test records during construction obtained using Quantab. There was no correlation between the chloride ion density and the location of the sampling.

Under these circumstances a follow-up cooperation Study is executed to investigate in detail all the piers including those in the Egyptian constructed sections. The objectives of the Study based on the detailed investigations shall be to infer the causes of the deterioration and evaluate the degree of the soundness so as to determine the extent of the necessary repairs and also to study the repair and maintenance plan and finally to suggest to the implementation agency in Egypt a method of repair as well as a method of maintenance in the future.

1.2 Summary of the Study

1.2.1 Study Schedule

The schedule of the Study is shown in Figure 1.2.1.

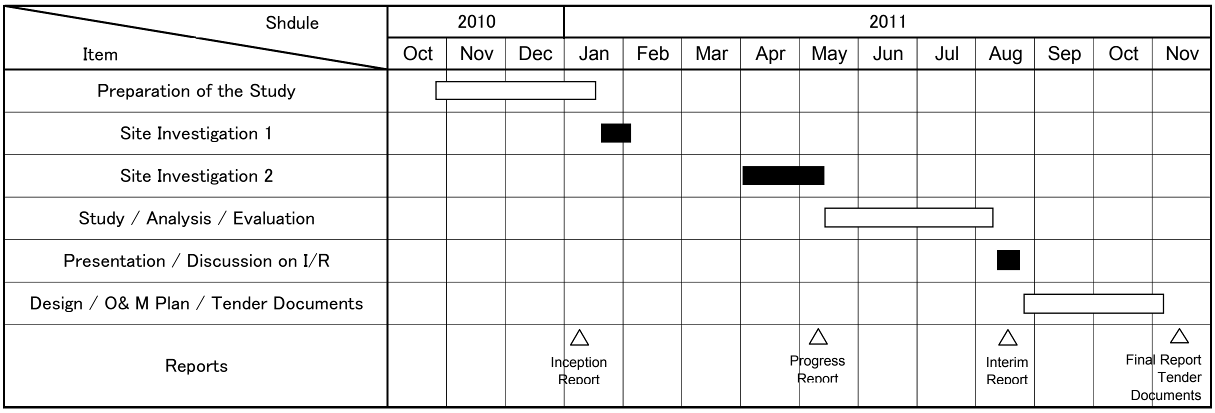


Figure 1.2.1 Study Schedule

It was originally scheduled to execute the site investigation for 45 days from January 22nd to March 7th, 2011. However, it was terminated on February 4th, 2011 due to the massive demonstration begun from January 28th.

Site investigation 2 was executed for 38 days from April 4th to May 11th, 2011 since the situation in Egypt had been settled down.

This report states the results of site investigation 1 and 2, and results of study/analysis/evaluation carried out based on the site investigations.

1.2.2 Study Items

Study items in the follow-up cooperation study are shown in Table 1.2.1.

Table 1.2.1 Study Item

	Study Item
Site Investigations	1. Investigation on Concrete Pier - Hammer Test - Crack Survey - Infrared Thermo Graphic Camera Survey - Concrete Cover Survey by RC Rader - Chipping Survey - Chloride Content Survey by Drilling - Half-cell Potential Survey 2. Site Investigation - Underground Water Level - Chloride and Sulfate Contents of Underground Water - Soil Survey - Meteorological Condition Survey 3. Analysis of Concrete Material - Analysis of Aggregate
Study / Analysis / Evaluation	1. Observation of Concrete Core Sample - Visual Investigation - Unit Weight - Water Content 2. Compressive Strength and Static Modulus of Elasticity - Compressive Strength - Static Modulus of Elasticity 3. Carbonation Depth - Carbonation Depth - Rate of Carbonation 4. Chloride Content - Chloride Content - Chloride Ionic Diffusion Coefficient 5. Concrete Element Analysis - XRD (X-Ray Diffraction) - EPMA (Electron Probe Micro Analysis) - Elemental Analysis

1.2.3 Study Area

Study area is shown in Figure 1.2.2.

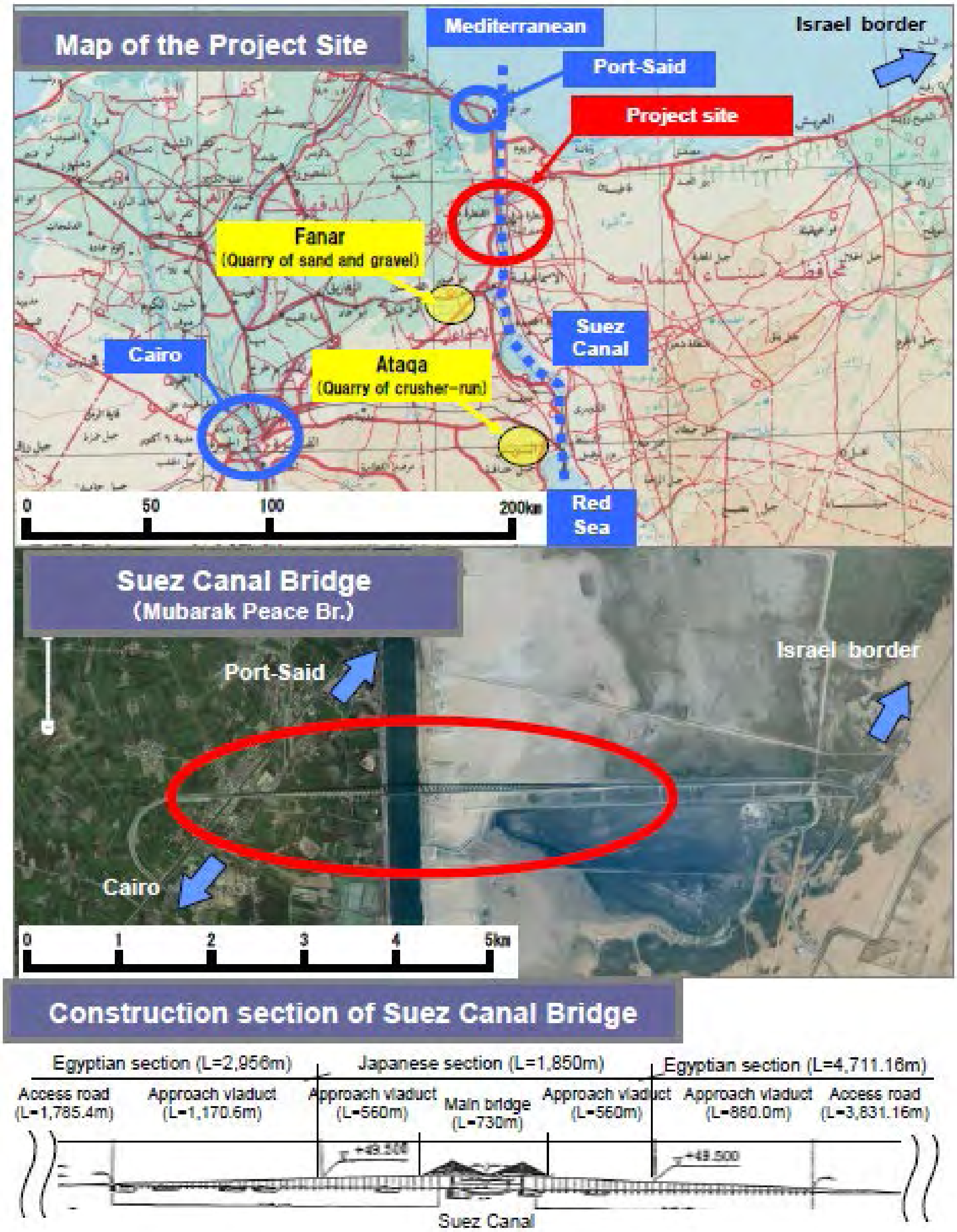


Figure 1.2.2 Study Area

CHAPTER 2 SITE INVESTIGATION

2.1 Investigation on Concrete Pier

2.1.1 Hammer Test

(1) Survey Targets

- All of Columns, and Pile Caps in the West Side

(2) Number of Damaged Faces

Column

	Faces (a)	Faces with Delamination and/or Spalling (b)	Damaged Faces (c)	Ratio	
				b/a	c/a
West Column (Local)	240	8	0	3%	0%
West Column (Japanese)	136	40	0	29%	0%
East Column (Japanese)	136	16	11	12%	8%
East Column (Local)	208	5	52	2%	25%

Pile Cap

	Faces (a)	Faces with Delamination and/or Spalling (b)	Damaged Faces (c)	Ratio	
				b/a	c/a
West Pile Cap (Local)	98	22	1	22%	1%
West Pile Cap(Japanese)	68	6	0	0%	0%

(3) Comments

- Number of damaged faces (column and pile cap) in the east side, 63 is greater than the west side, 1.
- In faces with delamination and/or spalling, damaged faces to be repaired were determined by further hammer test or chipping, and delamination of thin surface layer was judged as non-damage (refer to Photo 2.1.1, 2.1.2).
- Cause of damages is assumed to be chloride attack from the damage pattern, chloride content and carbonation depth.

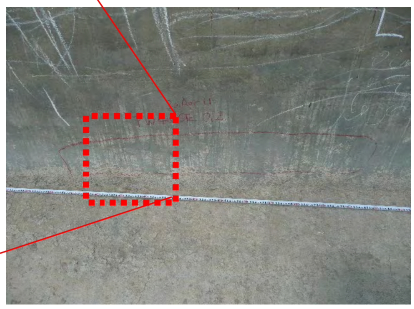
No.	Picture	Comments
1		・ PW40SE ・ 0.2m ・ Center ・ Delamination
2		・ After Chipping 
3		・ Thickness 1.5mm 

Photo 2.1.1 Delamination near Ground Surface at PW40SE

No.	Picture	Comments
1		・ PE35NS ・ 0.2m ・ Delamination
2		・ After Chipping

Photo 2.1.2 Delamination near Corner at PE35NS

2.1.2 Crack Survey

(1) Survey Targets

- All of Columns, and Pile Caps in the West Side

(2) Number of Cracked Faces

Column

	Faces	Cracked Faces	Ratio
West Column (Local)	240	0	0%
West Column (Japanese)	136	0	0%
East Column (Japanese)	136	0	0%
East Column (Local)	208	0	0%

Pile Cap

	Faces	Cracked Faces	Ratio
West Pile Cap (Local)	128	2	2%
West Pile Cap(Japanese)	85	27	32%

(3) Comments

- Definition of crack to be repaired is the crack with 0.35 mm width and more.
- Cracks to be repaired were found on only pile caps in the west side.
- Crack was not found from pile caps in the east side, which was confirmed by excavation for 3 pile caps.

Photo 2.1.3 Upper Surface of Pile Cap in the East Side (Confirmed by Excavation)

- Cause of cracks on the pile cap is assumed to be thermal restraint from crack patterns and the depth of 200 mm and more at the largest.

Photo 2.1.4 Crack on Pile Cap (Upper and Side Surface)

2.1.3 Infrared Thermo Graphic Camera Survey

(1) Survey Targets

- All of Columns at Higher Position (2-10 m)

(2) Number of Damaged Faces

Column

	Faces	Suspected Faces	Damaged Faces
West Column (Local)	240	3	0
West Column (Japanese)	136	1	0
East Column (Japanese)	136	8	0
East Column (Local)	208	6	0

(3) Comments

- In faces with delamination and/or spalling, damaged faces to be repaired were determined by further hammer test or chipping, and delamination of thin surface layer was judged as non-damage.

2.1.4 Concrete Cover Survey by RC Radar

(1) Survey Targets

- All of Columns at lower position (0.5-1.5 m), and pile Caps in the West Side

(2) Number of faces with insufficient Concrete Cover

Column

	Faces	Faces with Insufficient Concrete Cover		Ratio
		50 mm - 69 mm	Less than 50 mm	
West Column (Local)	240	86	22	45%
West Column (Japanese)	136	83	13	71%
East Column (Japanese)	136	44	1	33%
East Column (Local)	208	83	9	44%

Pile Cap

	Faces	Faces with Insufficient Concrete Cover		Ratio
		50 mm - 99 mm	Less than 50 mm	
West Pile Cap (Local)	84	72	1	87%
West Pile Cap(Japanese)	63	13	0	21%

(3) Comments

- Concrete cover was measured on 3 vertical lines (left, right and center).
- Number of faces was counted based on average cover depth on the center line.
- Corrosion of reinforcing bar was not found by the chipping at PW2 (25 mm) and PE17 (33 mm) which are minimum cover depth points.

2.1.5 Chipping Survey

(1) Survey Targets

- Sampled columns, and pile caps in the west side

(2) Concrete Cover

1) Number of points with insufficient Concrete Cover

Column

	Points	Points with Insufficient Concrete Cover		Ratio
		50 mm - 69 mm	Less than 50 mm	
West Column (Local)	7	3	2	71%
West Column (Japanese)	7	2	1	43%
East Column (Japanese)	7	1	1	29%
East Column (Local)	15	3	1	27%

Pile Cap

	Points	Points with Insufficient Concrete Cover		Ratio
		50 mm - 99 mm	Less than 50 mm	
West Pile Cap (Local)	2	2	0	100%
West Pile Cap(Japanese)	2	2	0	100%

2) Comments

- Concrete cover by visual checking was measured at only few chipping points, therefore evaluation of concrete cover will be made by the result of survey by RC Radar.
- Corrosion of reinforcing bar was not found at all points despite the insufficient concrete cover.

(3) Carbonation Depth

1) Average Carbonation Depth

Column

	Points	Average Depth (mm)	Maximum Depth (mm)
West Column (Local)	7	12	15
West Column (Japanese)	7	19	24
East Column (Japanese)	7	18	23
East Column (Local)	15	14	20

Pile Cap

	Points	Average Depth (mm)	Maximum Depth (mm)
West Pile Cap (Local)	2	8	10
West Pile Cap(Japanese)	2	14	16

2) Comments

- Carbonation depth was measured by phenolphthalein method at the chipping points.
- Carbonation depth in Japanese section is deeper than that in local section.

(4) Reinforcing Bar Condition

1) Number of Corrosion of Reinforcing Bar

Column

	Points	Points with Corrosion	Ratio
West Column (Local)	7	0	0%
West Column (Japanese)	7	0	0%
East Column (Japanese)	7	0	0%
East Column (Local)	15	0	0%

Pile Cap

	Points	Points with Corrosion	Ratio
West Pile Cap (Local)	2	0	0%
West Pile Cap(Japanese)	2	0	0%

2) Comments

- Condition of reinforcing bar was visually checked at the chipping points.
- All the reinforcing bars were sound with no corrosion.

2.1.6 Chloride Content Survey by Drilling

(1) Survey Targets

- Sampled columns, and pile caps in the west side

(2) Chloride Content

Column

	0 – 20 mm (kg/m^3)	60 – 80 mm (kg/m^3)	170 – 200 mm (kg/m^3)
West Column (Local)	0.91	0.58	0.47
West Column (Japanese)	1.07	0.86	0.79
East Column (Japanese)	0.95	0.73	0.75
East Column (Local)	1.61	0.81	0.95

Pile Cap

	0 – 20 mm (kg/m^3)	60 – 80 mm (kg/m^3)	170 – 200 mm (kg/m^3)
West Pile Cap (Local)	-	-	-
West Pile Cap(Japanese)	1.20	0.93	0.82

(3) Comments

- Chloride contents in the depth of 60 mm and deeper were less than 1.0 kg/m^3.
- Chloride contents in the east side are greater than that in the west side.
- Evaluation of chloride contents will be made together with the analysis for sampled cores.

2.1.7 Half-cell Potential Survey

(1) Survey Targets

- Sampled columns at lower position (0-1.5 m), and pile caps in the west side

(2) Natural Potential of Reinforcing Bar

Column

	Faces	Potential in Average (mV)
West Column (Local)	6	-067
West Column (Japanese)	4	-125
East Column (Japanese)	14	-138
East Column (Local)	22	-143

Pile Cap

	Faces	Potential in Average (mV)
West Pile Cap (Local)	6	-186
West Pile Cap(Japanese)	8	-208

(3) Comments

- Natural potentials of east column and west pile cap are lower since they are near ground surface.
- Minimum natural potential of reinforcing bar was around -420 mV near ground surface.
- Corrosion of reinforcing bar was not found by chipping at 5 points despite low natural potential (-360 to -420) measured there.
- According to BS 7361, reinforcing bar with natural potential lower than -350 mV may be corroded at 95 % probability.

2.2 Site Investigation

2.2.1 Underground Water Level

(1) Survey Results

Underground water level is shown in Table 2.2.1 and Figure 2.2.1.

Table 2.2.1 Underground Water Level

Pier No.		Depth of Underground Water Level from Ground Surface	Depth of Underground Water Level from Bottom Level of Pile Cap	Measurement Date
PW9	West Side	-1.95	-0.15	2011/04/27
PW39		-2.10	-0.40	2011/04/27
PE6	East Side	-5.65	0.35	2011/04/26
PE32		-4.95	-1.45	2011/04/26

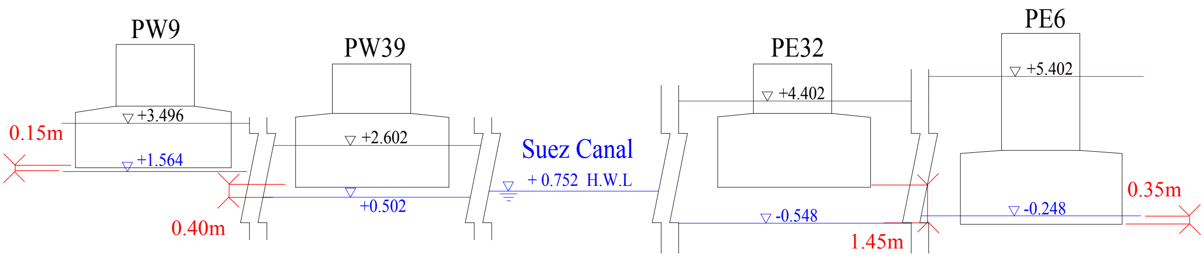


Figure 2.2.1 Relationship between Underground Water Level and Suez Canal Water Level

(2) Comments

- Underground water level in the west side is high, although it is lower than the bottom level of pile cap (-0.15 to -0.40 m).
- Underground water level in the east side is lower than the bottom level of pile cap (-1.45 m) at most positions, however it is higher than the bottom level of pile cap (0.35 m) at some positions (PE6).

2.2.2 Chloride and Sulfate Contents of Underground Water

(1) Survey Results

Chloride and sulfate contents of underground water are shown in Table 2.2.2.

Table 2.2.2 Chloride and Sulfate Contents of Underground Water

No.	Pier	Depth (m)	SO_3 (ppm)	CL (ppm)
1	PW 9	-1.95	420	1,170
2	PW 9	-6.95	532	1,697
3	PW 39	-2.1	545	1,287
4	PW 39	-7.1	703	1,170
5	PE 32	-4.95	1,655	22,815
6	PE 32	-9.95	1,204	8,483
7	PE 6	-5.65	1,060	7,020
8	PE 6	-10.65	1,362	9,653

1ppm = 0.0001 %

(2) Comments

- Chloride content of underground water in the west side is low, which is classified as brackish water (Cl: 0.05% - 3.5 %).
- High chloride content was found at PE 32 although it is lower than that of seawater.

2.2.3 Soil Survey

(1) Survey Results

Chloride contents of fill materials obtained near the piers are shown in Figure 2.2.2.

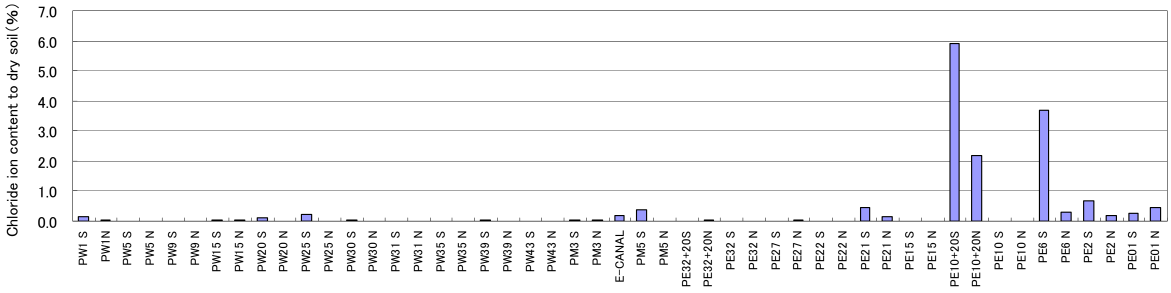


Figure 2.2.2 Chloride Contents of Fill Materials

Laboratory test results of chloride and sulfate contents of fill materials and aggregates are shown in Figure 2.2.3 and 2.2.4.

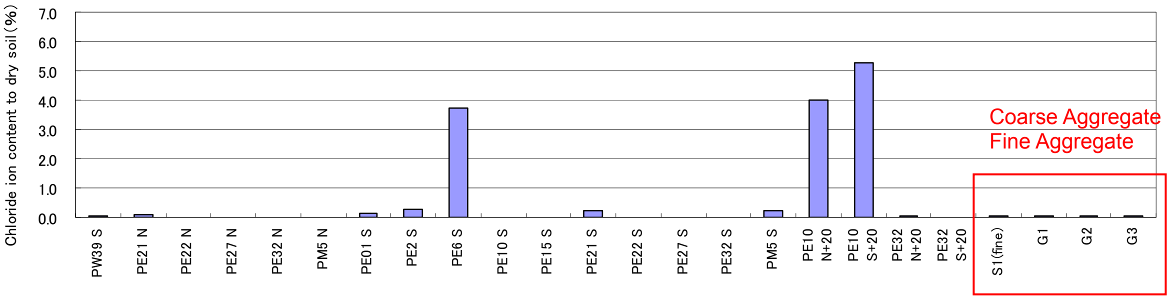


Figure 2.2.3 Chloride Contents of Fill Materials and Aggregates

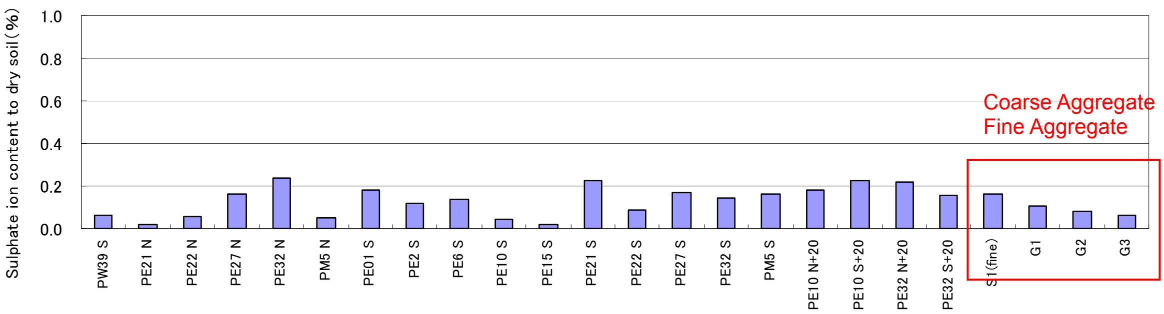


Figure 2.2.4 Sulfate Contents of Fill Materials and Aggregates

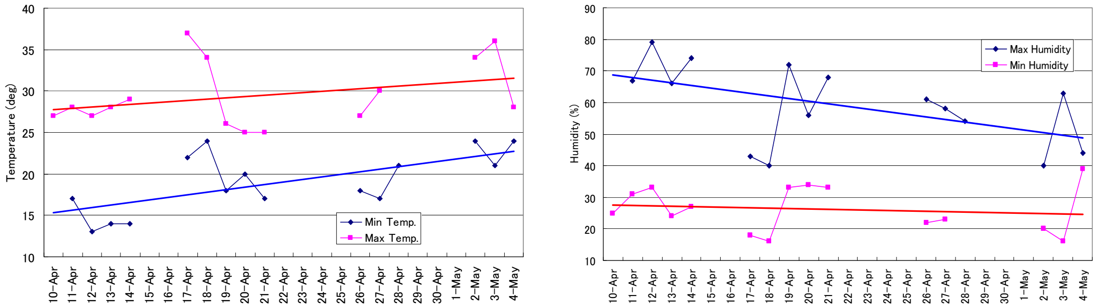
(2) Comments

- Chloride contents of fill materials at 20 m south from the bridge are high since salt lake used to exist there before.
- Chloride contents of fill materials in some areas of east side are high.
- Chloride contents of fill materials in the west side are low.
- Chloride contents of coarse and fine aggregates obtained from quarry site meet the criteria.

2.2.4 Meteorological Conditions Survey

(1) Survey Results

Temperature and humidity measured during the site investigations (April 10 to May 4, 2010) are shown in Figure 2.2.5.



Temperature Humidity

Figure 2.2.5 Meteorological Condition at Site

(2) Comments

- Few rain-fall was observed. It should be the same as the whole country.
- Large daily temperature range observed is shown in Figure 2.2.5.
- High temperature and low humidity observed are shown in Figure 2.2.5.

2.3 Analysis of Concrete Material

2.3.1 Analysis of Fine Aggregate from Quarry Site

Element analysis was carried out by Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDX).

As a result, higher concentration of chloride (Cl) was found.

In addition, rock salt was found by microscope observation. Therefore, there is a possibility that rock salt did not dissolve by washing during construction, and then it has become a supply source of chloride in the concrete.

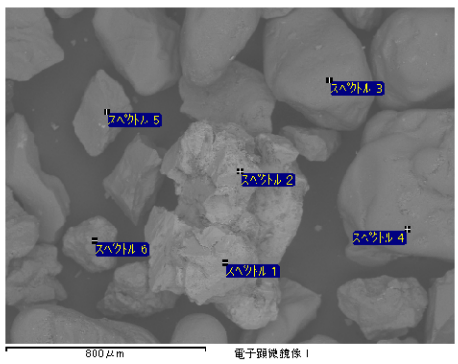


Figure 2.3.1 SEM Image

Figure 2.3.2 Microscope Image

Table 2.3.1 Analysis of SEM Image

Sample	C	Na	Mg	Al	Si	Cl	K	Ca	Fe	O	トータル
Sample1		*12.60*		*0.71*	*6.48*	*67.82*				*12.39*	*100.00*
Sample2	*9.23*	*8.05*		*0.45*	*4.22*	*44.67*		*0.54*		*32.83*	*100.00*
Sample3	3.27				41.15					55.58	100.00
Sample4	6.64			1.04	34.46					57.86	100.00
Sample5	11.82	1.94	0.69	5.12	16.07	2.13	0.28	2.95	1.77	57.22	100.00
Sample6	7.76	0.90	0.57	3.08	19.44	0.97		9.08	1.59	56.61	100.00
Max.	11.82	12.60	0.69	5.12	41.15	67.82	0.28	8.40	1.77	57.86	
Min.	3.27	0.83	0.53	0.45	4.22	0.90	0.28	0.54	1.47	12.39	

2.3.2 Analysis of Coarse Aggregate from Concrete Core

Chloride ion contents of coarse aggregates vary from 0.015 to 0.064 wt%, and the average is 0.035 wt%.

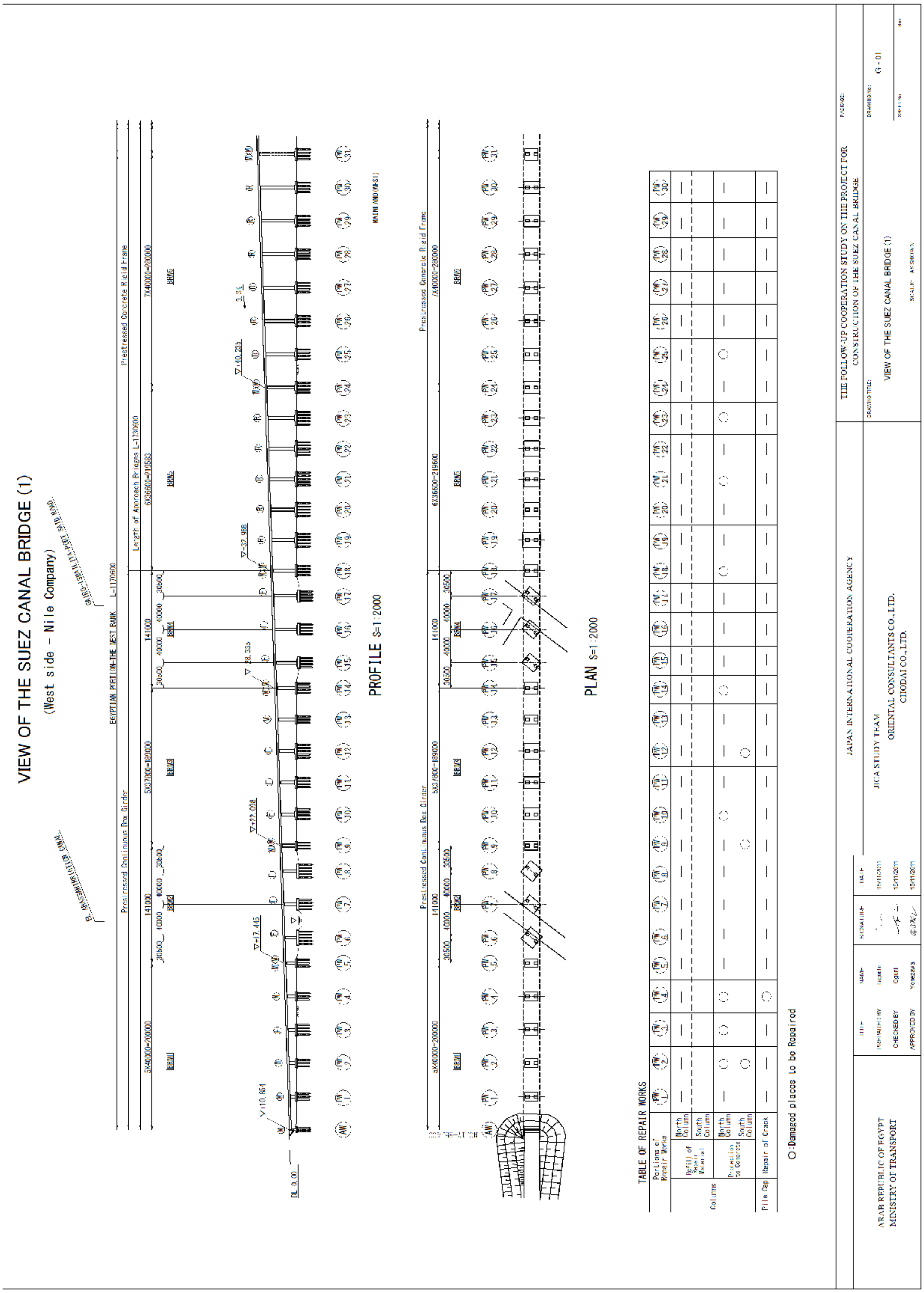
Table 2.3.2 Chloride Ion Contents of Coarse Aggregate

Sample	Cl- wt%
1	0.034
2	0.040
3	0.032
4	0.015
5	0.024
6	0.028
7	0.047
8	0.016
9	0.027
10	0.053
11	0.064

Figure 2.3.3 Sample

2.4 Drawing Preparation

General view of the bridge was prepared based on the as-built drawing and measurement at site.


VIEW OF THE SUEZ CANAL BRIDGE (1)
(West side - Nile Company)
PROFILE S=1:2000
PLAN S=1:2000
TABLE OF REPAIR WORKS
○:Damaged places to be Repaired
THE FOLLOW-UP COOPERATION STUDY ON THE PROJECT FOR CONSTRUCTION OF THE SUEZ CANAL BRIDGE
VIEW OF THE SUEZ CANAL BRIDGE (1)
JAPAN INTERNATIONAL COOPERATION AGENCY
JICA STUDY TEAM
ORIENTAL CONSULTANTS CO., LTD.
CHODAI CO., LTD.
ARAB REPUBLIC OF EGYPT
MINISTRY OF TRANSPORT

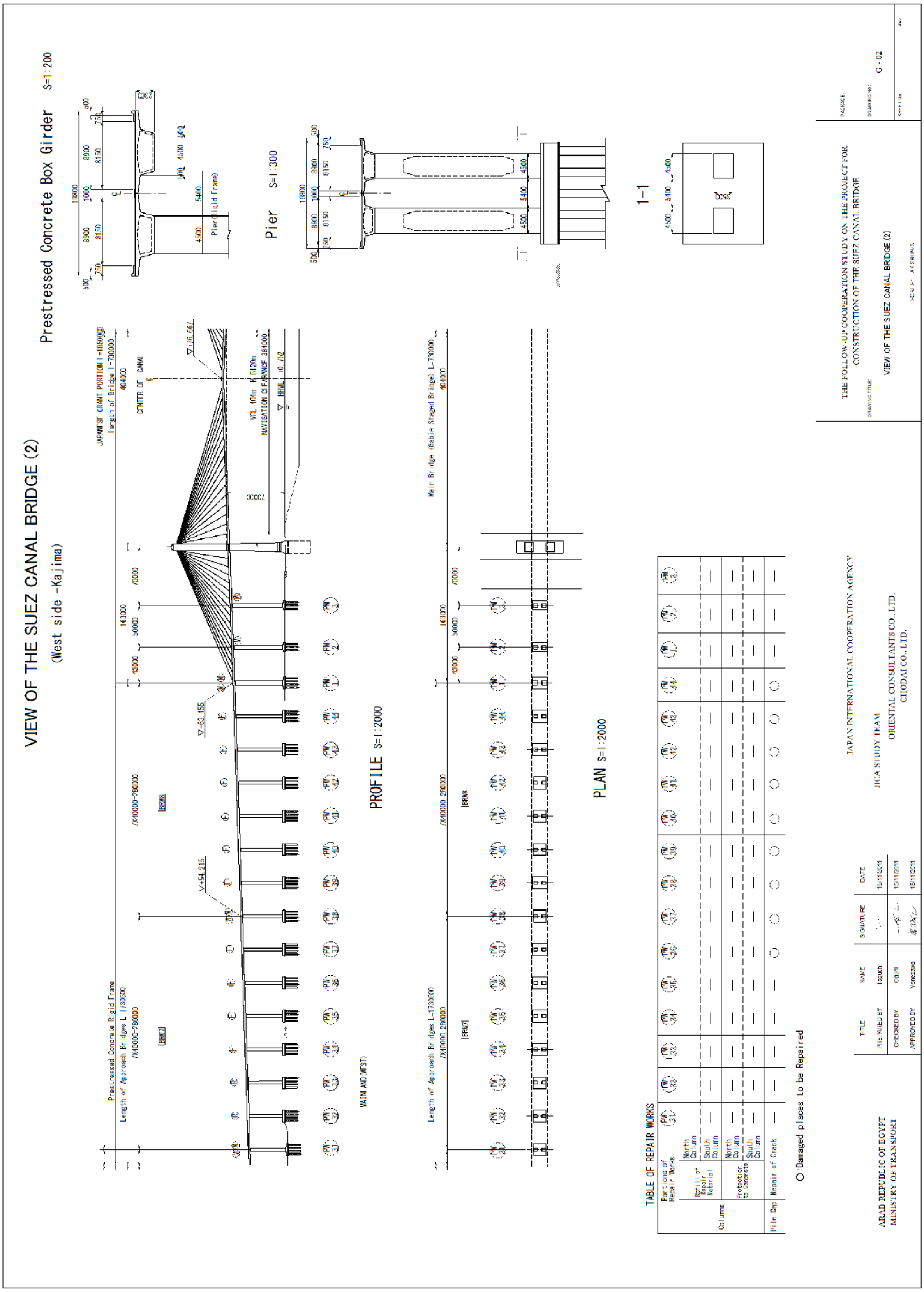
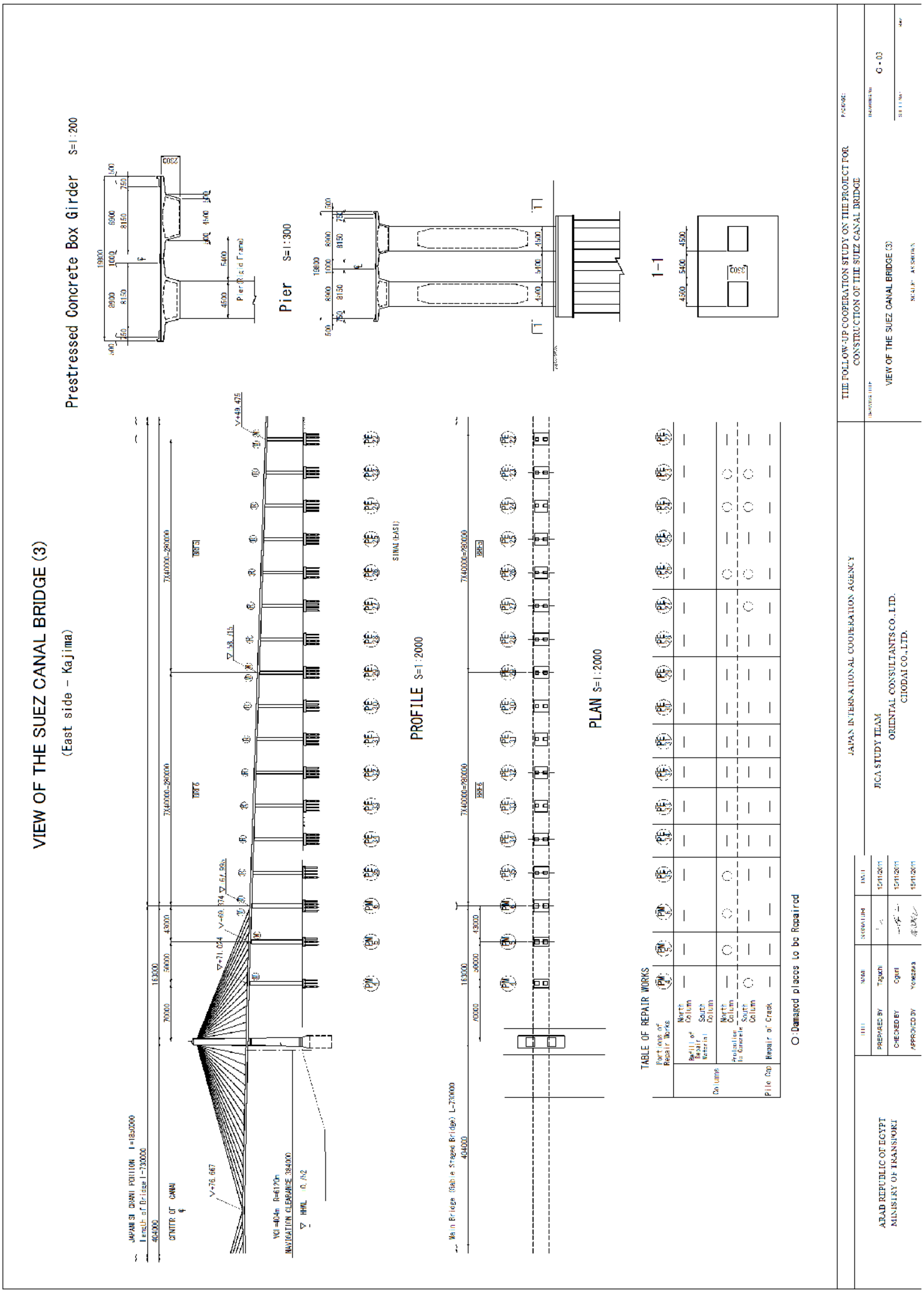
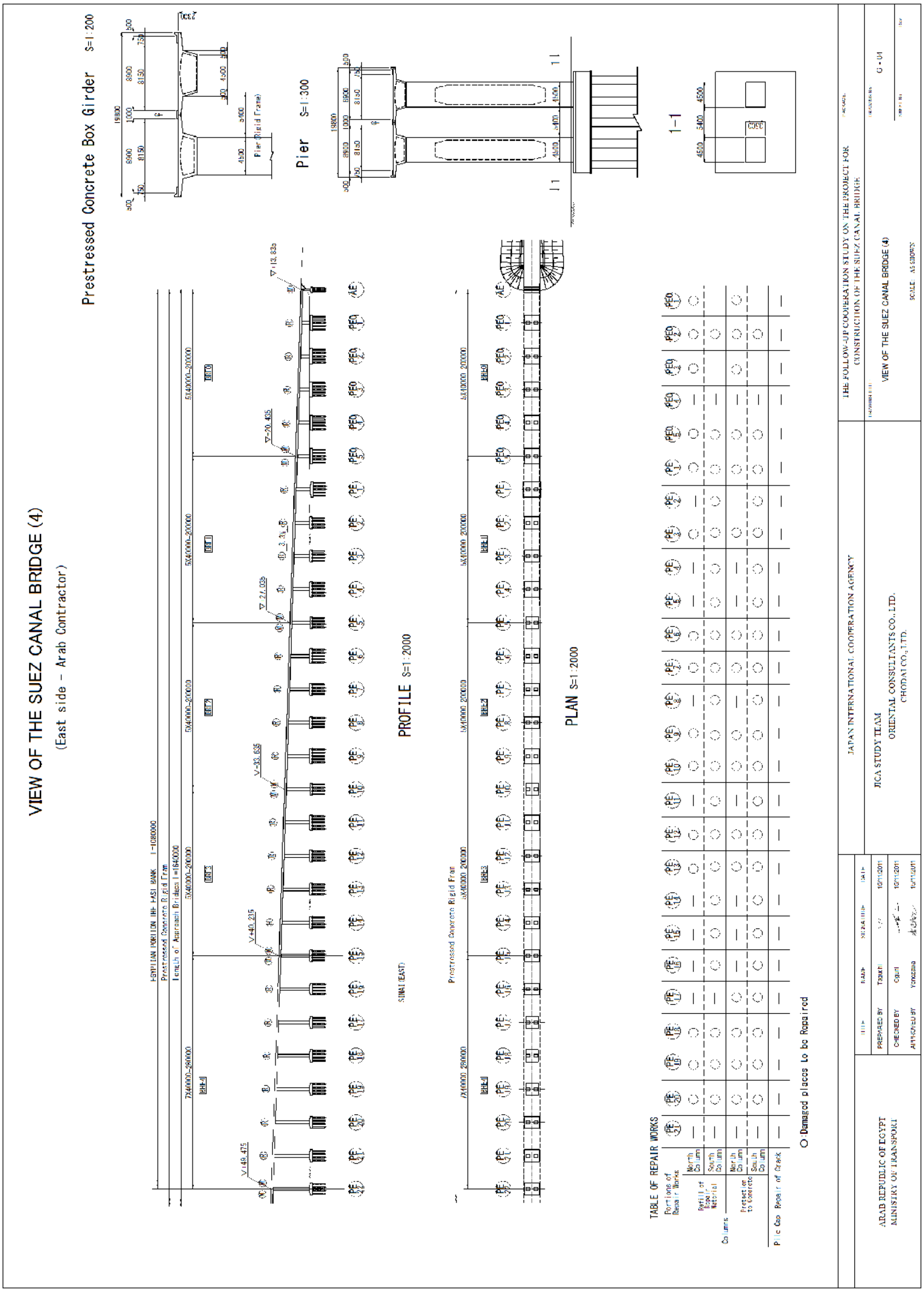


TABLE OF REPAIR WORKS

Portions of Repair Works			PW 31	PW 32	PW 33	PW 34	PW 35	PW 36	PW 37	PW 38	PW 39	PW 40	PW 41	PW 42	PW 43	PW 44	PM 1	PM 2	PM 3
Columns	Refill of Repair Material	North Column																	
		South Column	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Protection to Concrete	North Column	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		South Column	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pile Cap	Repair of Crack		—	—	—	—	—	○	○	○	○	○	○	○	○	○	—	—	—

○:Damaged places to be Repaired


VIEW OF THE SUEZ CANAL BRIDGE (3)
(East side - Kajima)
Prestressed Concrete Box Girder S=1:200
Pier S=1:300
PROFILE S=1:2000
PLAN S=1:2000
TABLE OF REPAIR WORKS
○:Damaged places to be Repaired
JAPAN INTERNATIONAL COOPERATION AGENCY
JICA STUDY TEAM
ORIENTAL CONSULTANTS CO., LTD.
CHODAI CO., LTD.
ARAB REPUBLIC OF EGYPT
MINISTRY OF TRANSPORT
THE FOLLOW-UP COOPERATION STUDY ON THE PROJECT FOR CONSTRUCTION OF THE SUEZ CANAL BRIDGE
VIEW OF THE SUEZ CANAL BRIDGE (3)


VIEW OF THE SUEZ CANAL BRIDGE (4)
(East side - Arab Contractor)
Prestressed Concrete Box Girder S=1:200
Pier S=1:300
1-1
PROFILE S=1:2000
PLAN S=1:2000
TABLE OF REPAIR WORKS
○:Damaged places to be Repaired
JAPAN INTERNATIONAL COOPERATION AGENCY
JICA STUDY TEAM
ORIENTAL CONSULTANTS CO., LTD.
CHODAI CO., LTD.
ARAB REPUBLIC OF EGYPT
MINISTRY OF TRANSPORT
VIEW OF THE SUEZ CANAL BRIDGE (4)

CHAPTER 3 STUDY, ANALYSIS AND EVALUATION

3.1 Analysis of Concrete Core Sample

The following analyses were carried out for 32 concrete core samples.

3.1.1 Observation of Concrete Core Sample

(1) Visual Investigation

Negative conditions such as gel deposition around aggregates, expansion of aggregates and unusual crack were not found in all concrete core samples.

More voids in concrete cores from the Japanese section are observed than in those from the local section.

Figure 3.1.1 Core Sample in Local Section in the West Side (PW1SS0.5)

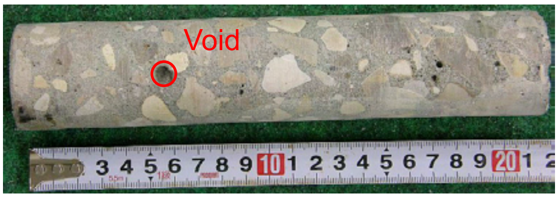


Figure 3.1.2 Core Sample in Japanese Section in the West Side (PW39CS0.5)

Figure 3.1.3 Core Sample in Japanese Section in the East Side (PE32SS0.5)

Figure 3.1.4 Core Sample in Local Section in the East Side (PE6SS0.5)

(2) Unit Weight

Average unit weights of piers are 2,380 kg/m^3 for local section in the west side, 2,410 kg/m^3 for Japanese section in the west side, 2,350 kg/m^3 for Japanese section in the east side and 2,330 kg/m^3 for local section in the east side, respectively.

There is no big difference on unit weight among sections. These values are almost the same as those in Japanese environment.

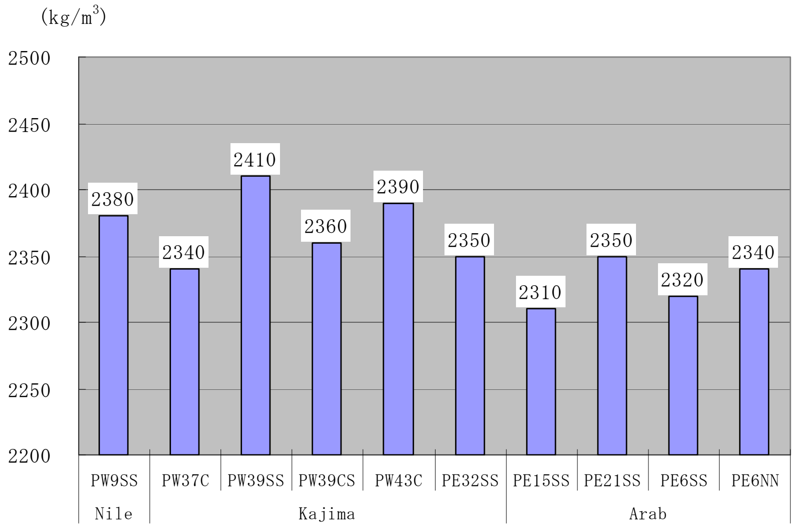


Figure 3.1.5 Average Unit Weight

(3) Water Content

Water content of PE32 is 2.87 %, which is around the half value of that in Japanese environment.

Relative water content is 40 %, which is the value having high corrosion resistance according to existing researches.

3.1.2 Compressive Strength and Static Modulus of Elasticity

(1) Compressive Strength

Compressive strengths vary from 26.9 to 65.7 N/mm^2, which are higher than 24.0 N/mm^2 of design compressive strength.

(2) Static Modulus of Elasticity

Static modulus of elasticity varies from 18.4 to 47.0 N/mm^2.

There is no particular disagreement on the relation between compressive strength and static modules of elasticity.

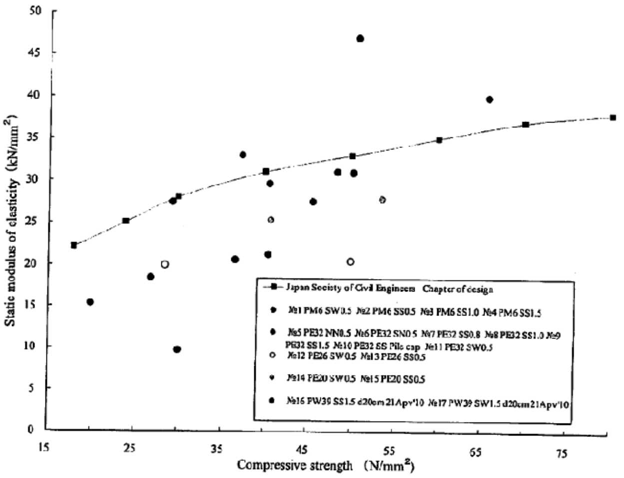


Figure 3.1.6 Relation between Compressive Strength and Static Modulus of Elasticity

3.1.3 Carbonation Depth

(1) Carbonation Depth

Average carbonation depths are 15 mm, 17 mm, 21 mm and 13 mm for local section in the west side, Japanese section in the west side, Japanese section in the east side and local section in the east side, respectively.

Carbonation depths of Japanese section are slightly deeper than those of local section.

There is no clear difference in carbonation depth depending on heights or faces.

Maximum carbonation depth is 40 mm, which is found at the crack on the pile cap of PW43.

Predicted carbonation depth was calculated by following formula.

$C = b\sqrt{t}$

Where, C: Carbonation Depth (mm)

b: Rate of Carbonation (mm/√year)

t: Service Period

Relation between carbonation depth and service period is shown in Figure 3.1.8.

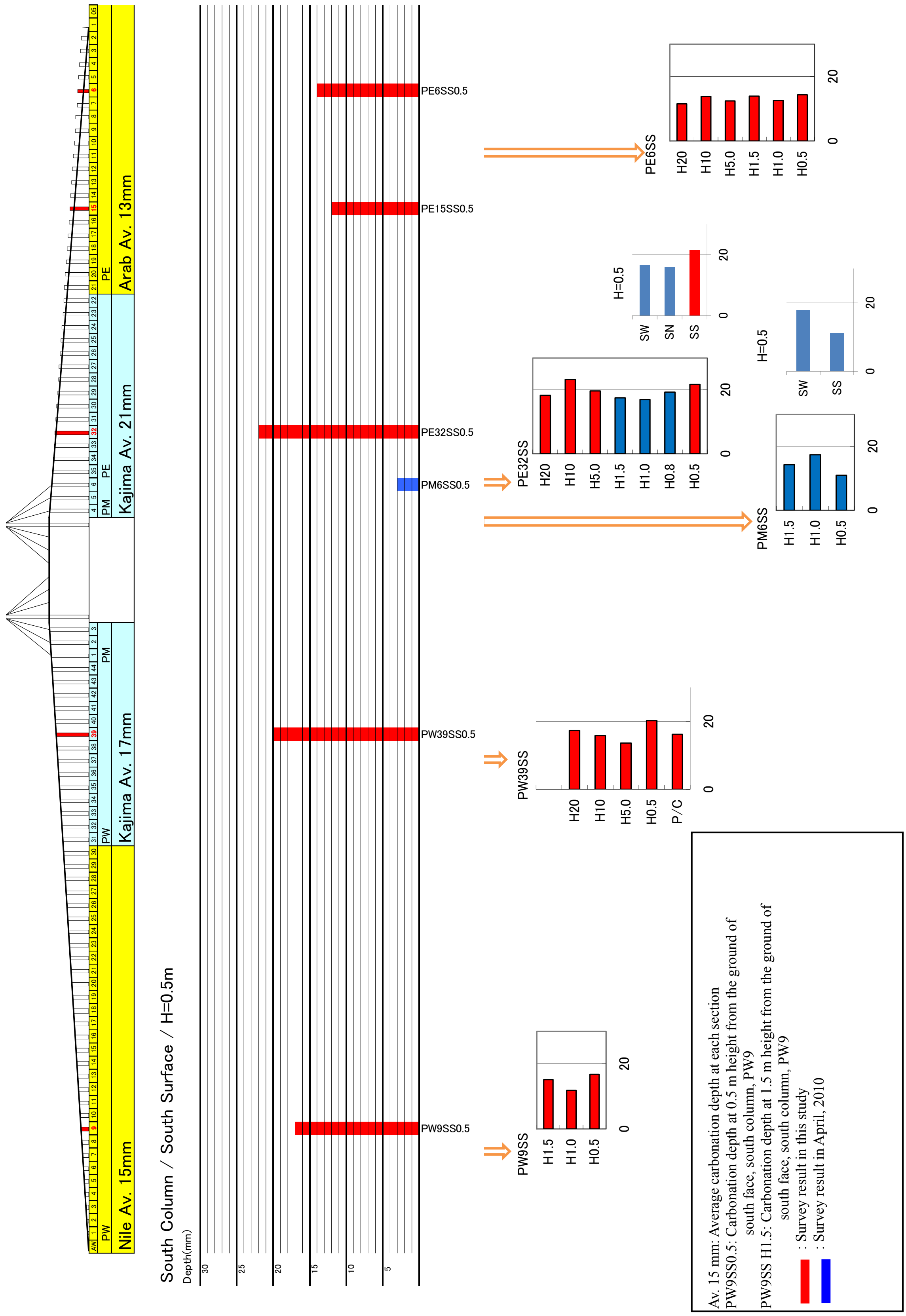
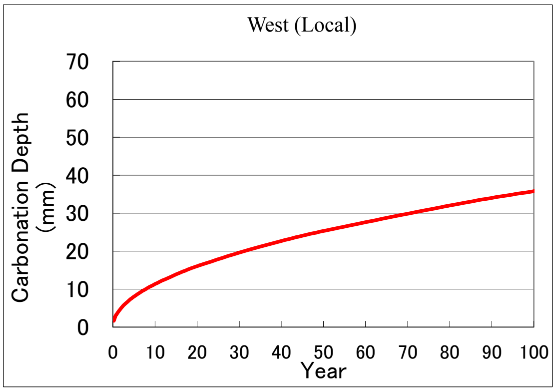
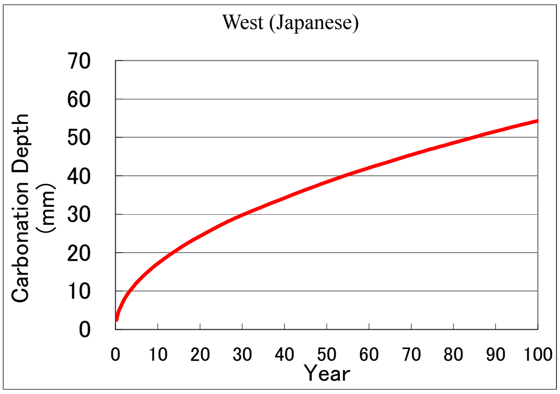


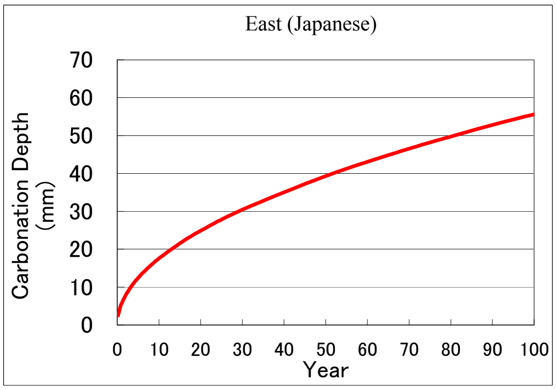
Figure 3.1.7 Carbonation Depth



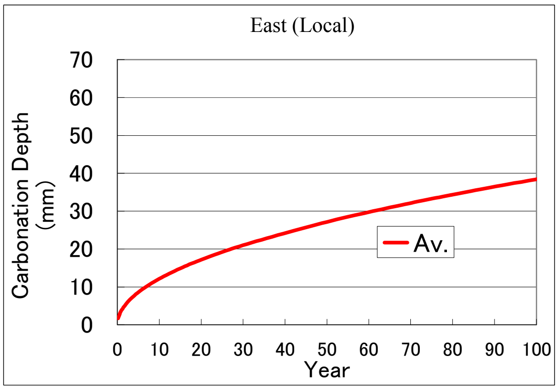
	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	16.0 mm	31.0 mm
20 year later	25.3 mm	40.3 mm
90 year later	35.8 mm	50.8 mm



	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	24.3 mm	39.3 mm
20 year later	38.4 mm	53.4 mm
90 year later	54.3 mm	69.3 mm



	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	24.9 mm	39.9 mm
20 year later	39.3 mm	54.3 mm
90 year later	55.6 mm	70.6 mm



	Carbonation Depth	Carbonation Depth + 15 mm
10 year later	17.2 mm	32.2 mm
20 year later	27.2 mm	42.2 mm
90 year later	38.4 mm	53.4 mm

Figure 3.1.8 Relation between Carbonation Depth and Service Period

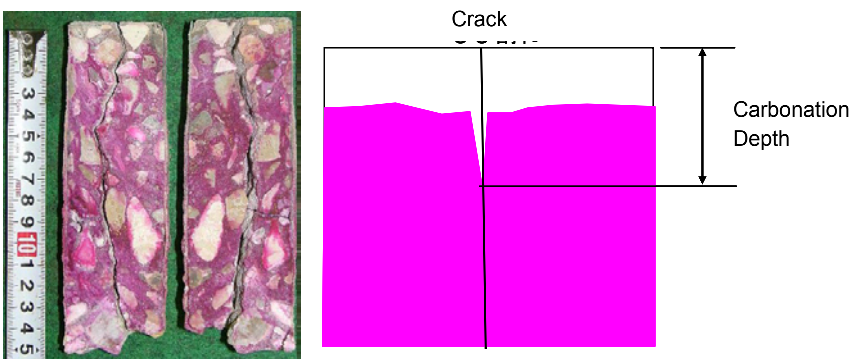


Figure 3.1.9 Carbonation at the Crack on the Pile Cap of PW43

(2) Rate of Carbonation

Average rate of carbonation is 3 to 10 times higher than that in Japanese environment.

Average rate of carbonation in Japanese section is 2 times higher than that in local section.

It will take 67 to 334 years for carbonation to reach as far as 55 mm[1] of concrete cover.

Table 3.1.1 Rate of Carbonation

Section	Sample	Average Carbonation Depth	Maximum Carbonation Depth	Rate of Carbonation
West (Local)	PW9SS 0.5	16.8	19.5	4.63
	PW9SS 1.0	11.9	15.4	3.28
	PW9SS 1.5	15.2	19.2	4.18
West (Japanese)	PW39SS 0.5	20.2	23.3	6.11
	PW39SS 5.0	13.6	17.4	4.12
	PW39SS 10.0	15.8	19.8	4.79
	PW39SS 20.0	17.3	22.3	5.23
	PW39CS 0.5	16.2	19.8	4.89
East (Japanese)	PE32SS 0.5	21.7	26.8	6.25
	PE32SS 5.0	19.7	25.9	5.70
	PE32SS 10.0	23.3	26.3	6.72
	PE32SS 20.0	18.3	21.1	5.28
East (Local)	PE21SS 0.5	3.0	6.0	0.88
	PE15SS 0.5	11.6	15.3	3.38
	PE6 SS 0.5	14.3	15.9	4.04
	PE6 SS 1.0	12.6	16.0	3.56
	PE6 SS 1.5	13.9	18.8	3.91
	PE6 SS 5.0	12.4	14.8	3.50
	PE6 SS 10.0	13.8	21.4	3.89
	PE6 SS 20.0	11.5	13.2	3.25
	PE6 NN 0.5	10.7	13.6	3.01

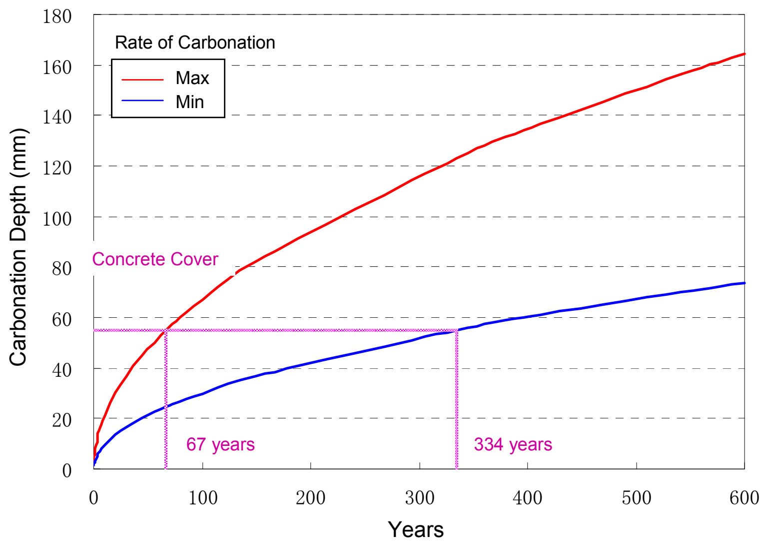


Figure 3.1.10 Rate of Carbonation

[1] When Remaining carbonation depth (Concrete cover - Carbonation Depth) reaches 15 mm, corrosion of reinforcing bar may be commenced, where there is chloride in the concrete.

3.1.4 Chloride Content

(1) Chloride Content

The highest chloride content in deeper than 60 mm is approximately 1.5 kg/m^3 at PE21SS0.5[2]. In other locations, chloride contents were approximately 1.0 kg/m^3 in average.

There is no clear distinction on chloride content depending on heights or sections.

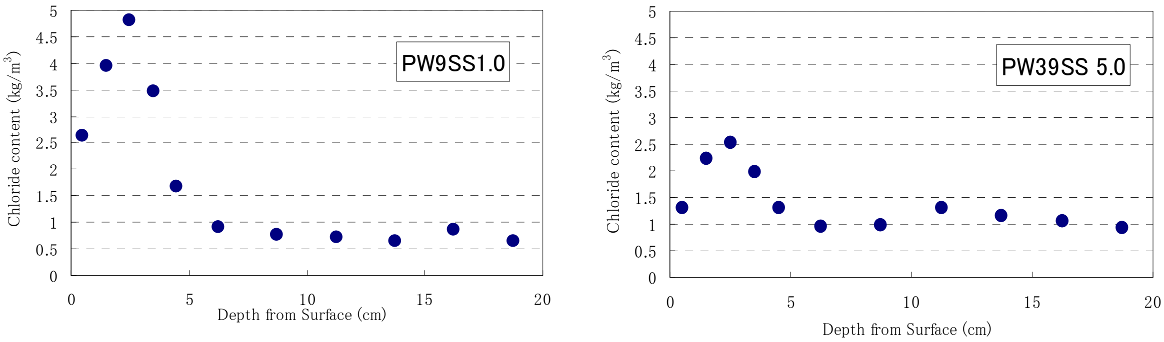


Figure 3.1.11 Chloride Contents by Depth

2 PE21SS0.5 means P: Pier, E: East Section, 21: Pier Number 21, S: South Pier, S: South Face, and 0.5: Height from the ground is 0.5 m.

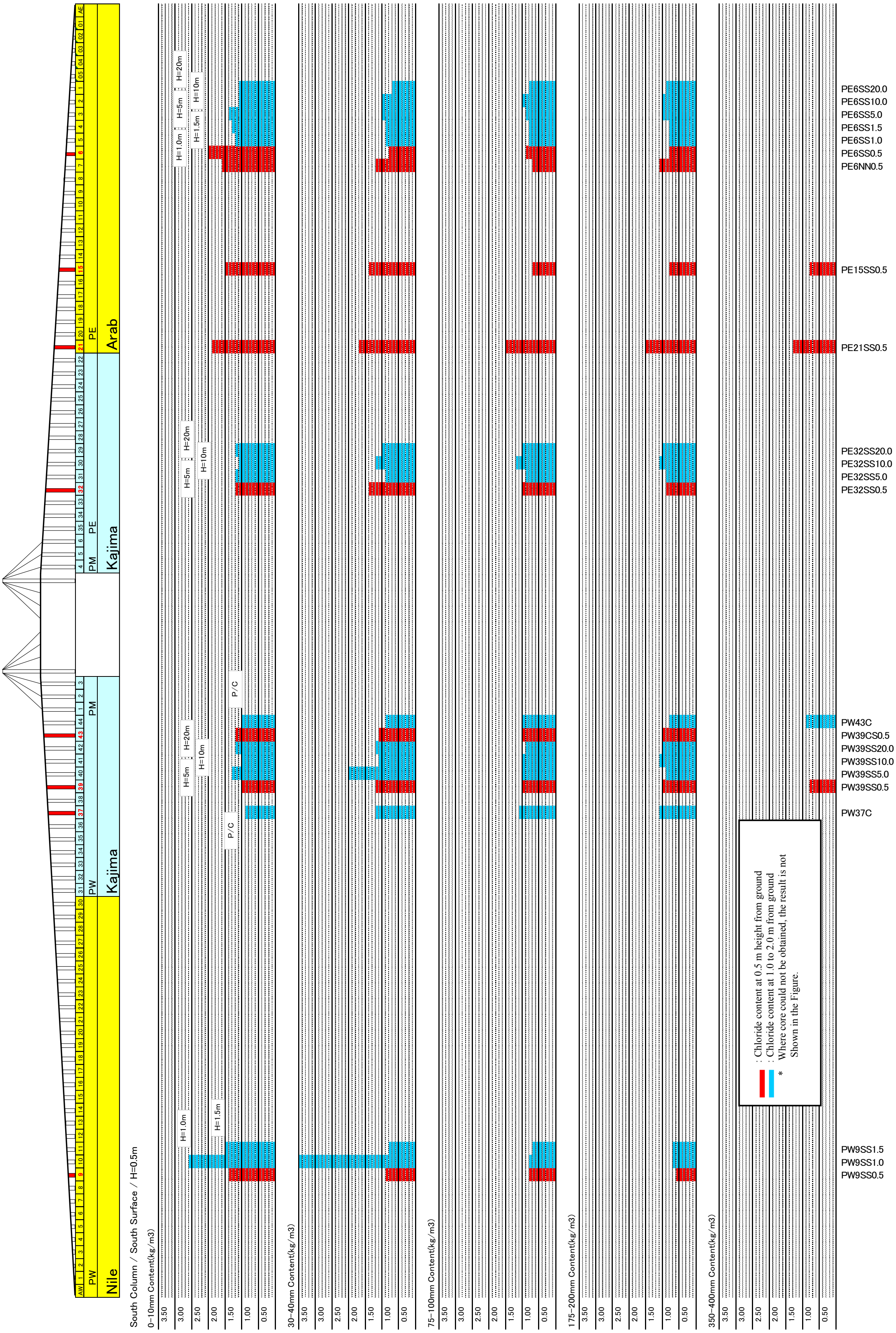


Figure 3.1.12 Chloride Content

(2) Chloride Ionic Diffusion Coefficient

Chloride ionic diffusion coefficient was calculated by following formula.

(Formula)

$$C(x,y) = C_0\left(1 - erf\left(\frac{x}{2\sqrt{D\cdot t}}\right)\right) + C_i$$

(Approximation Formula)

$$C(x,y) = C_0\left(1 - erf\left(\frac{x}{2\sqrt{D\cdot t}}\right)\right) + C_i$$

$$y = P1(1 - erf(x/P2)) + P3$$

C(x,y): Chloride Content (Cl- kg/m^3) at depth x(cm), time t(year)
C_0: Chloride Content at Surface (Cl- kg/m^3)
C_i: Initial Chloride Content (Cl- kg/m^3)
D: Chloride Ionic Diffusion Coefficient

The period for chloride content to reach 1.2 kg/m^3 was calculated for each concrete depth.

The value is quite variable since chloride content at surface, initial chloride content and chloride ionic diffusion coefficient are quite variable for each pier or concrete depth.

Table 3.1.2 Chloride Ionic Diffusion Coefficient

Section	Sample	Chloride Content at Surface C_0 (kg/m^3)	Initial Chloride Content C_i (kg/m^3)	Chloride Ionic Diffusion Coefficient D (cm^2/year)	Period for Chloride Content to reach 1.2 kg/m^3 at Concrete Cover Depth (7 cm) (Year)
West (Local)	PW9SS 0.5	1.073	0.671	0.531	98.2
	PW9SS 1.0	3.750	0.551	1.489	8.9
	PW9SS 1.5	1.060	0.693	0.357	136.0
West (Japanese)	PW37C No.2	0.282	1.035	1.811	45.1
	PW39SS 0.5	0.370	0.849	16.477	311.9
	PW39SS 5.0	1.111	0.991	2.094	6.8
	PW39SS 10.0	0.164	1.016	1.513	not convergent
	PW39SS 20.0	0.296	0.954	1.788	293.9
	PW39CS 0.5	0.403	0.949	1.297	77.6
	PW43C No.5	0.542	0.827	1.273	119.0
East (Japanese)	PE32SS 0.5	0.484	0.860	5.380	31.2
	PE32SS 5.0	0.361	0.868	0.161	not convergent
	PE32SS 10.0	0.024	1.163	1.003	not convergent
	PE32SS 20.0	0.253	1.050	0.718	117.8
East (Local)	PE21SS 0.5	0.435	1.499	0.317	0.0
	PE15SS 0.5	1.063	0.738	1.027	38.9
	PE6 SS 0.5	1.532	0.798	0.247	78.9
	PE6 SS 1.0	0.455	0.799	0.722	1488.9
	PE6 SS 1.5	0.603	0.752	0.679	333.2
	PE6 SS 5.0	0.633	0.923	0.072	561.3
	PE6 SS 10.0	0.230	0.967	0.199	not convergent
	PE6 SS 20.0	0.547	0.795	0.038	5938.7
	PE6 NN 0.5	1.176	0.766	0.650	46.5

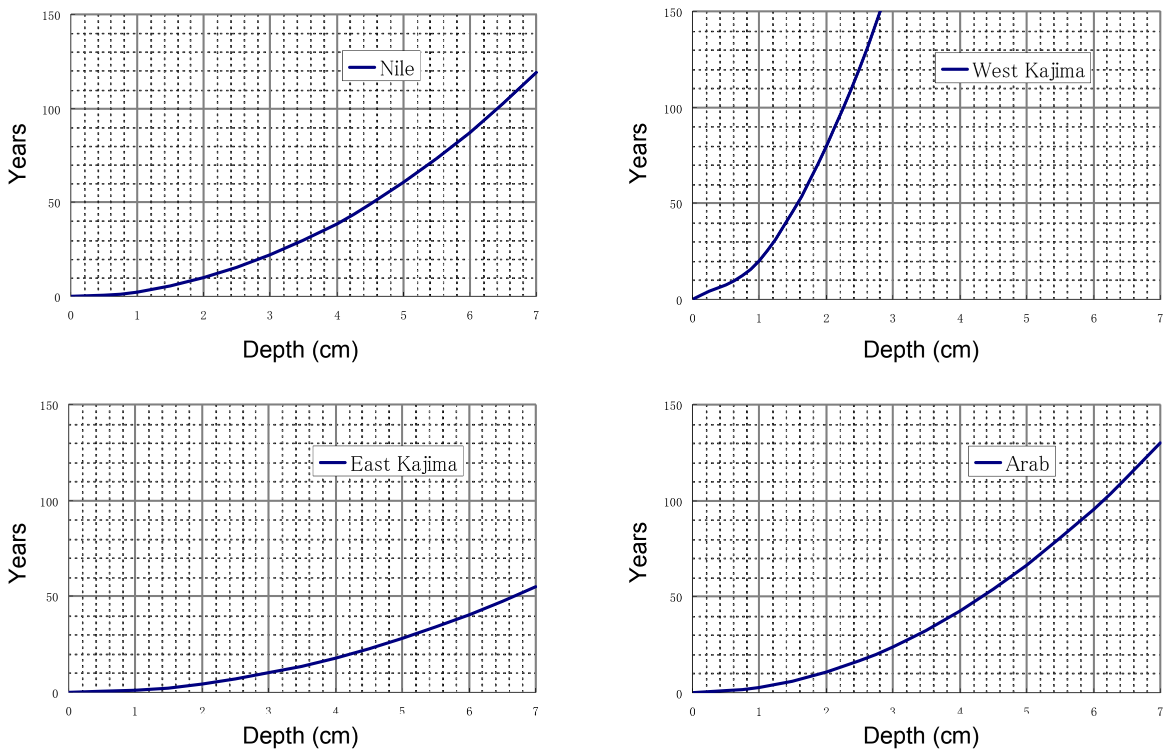


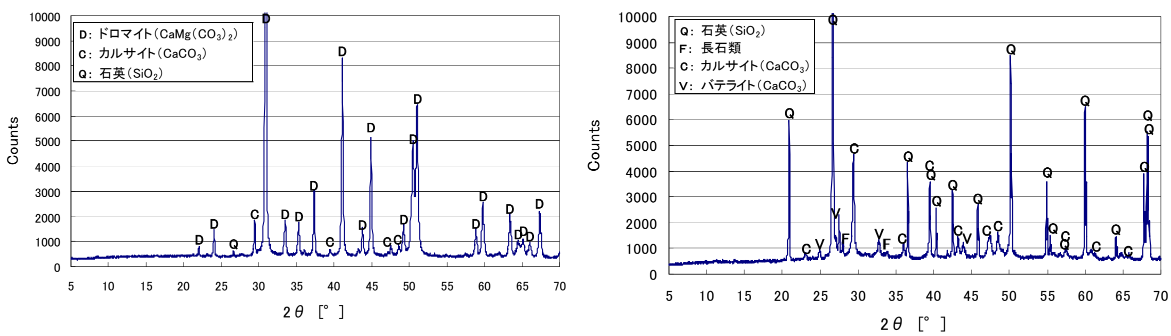
Figure 3.1.13 Period for Chloride Content to Reach 1.2 kg/m^3

3.1.5 Concrete Element Analysis

(1) XRD (X-Ray Diffraction)

Major component of aggregate is dolomite, and major components of mortar are quartz and calcite.

Ettringite and calcium sulfate, which are produced in case sulfate deterioration is made, were not found.



Aggregate Mortar

Figure 3.1.14 XRD Result

(2) EPMA (Electron Probe Micro Analysis)

Concrete element analyses, whose target elements are Ca, Mg, S, Na, K, Cl and C, were executed by EPMA.

It was confirmed from one of the analyses that Cl penetrates from outside.

Some coarse aggregates have high chloride content, and chloride is widely distributed in mortar.

It is considered that chloride has been transferred from coarse aggregates since high chloride contents were found around some coarse aggregates.

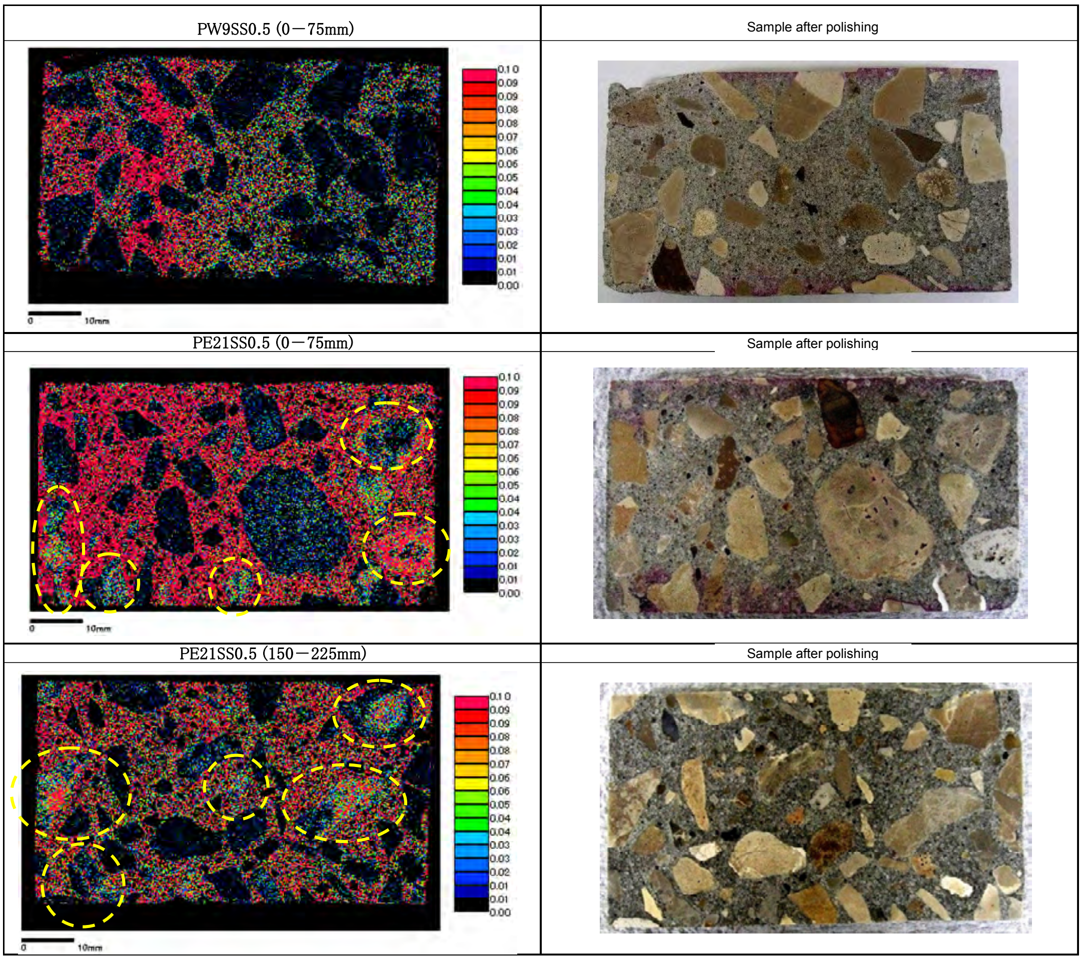


Figure 3.1.15 EPMA Result

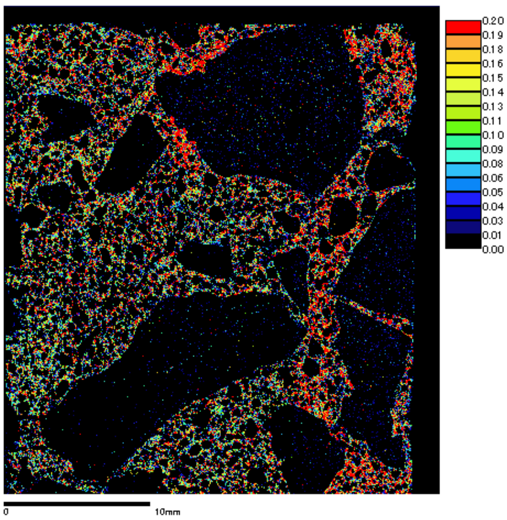


Figure 3.1.16 EPMA Result (Detail)

(3) Elemental Analysis

Elemental analysis was executed for concrete core sample of PE32SS20.

There is no big difference on concrete element between the sample (shown in Table 3.1.3) and limestone aggregate concrete in Japan.

Table 3.1.3 Elemental Analysis Result

Sample	PE32SS 20
ig.loss 1000 degree	25.26
insol.	35.51
SiO_2	2.89
Al_2O_3	1.12
Fe_2O_3	0.61
CaO	24.95
MgO	8.15
SO_3	0.17
Na_2O	0.14
K_2O	0.05

3.2 Cause of Deterioration and Evaluation of Structural Soundness

Cause of deterioration and evaluation of structural soundness are studied based on the site investigations and analysis of concrete core samples.

3.2.1 Cause of Deterioration

(1) Delamination on Pier and Pile Cap

1) Corrosion Environment

a) Chloride Content

There is 0.8 to 1.0 kg/m^3 of chloride content, which is coming from internal salt at the construction stage.

Chloride content on the concrete surface exceeds 1.2 kg/m^3 by chloride attack.

b) Carbonation Depth

Carbonation is observed near concrete surface (0 to 20 mm).

c) Concrete Cover

Concrete cover is approximately 70 mm in most piers and pile caps, but less than 50 mm in some piers and pile caps.

It is evaluated from above mentioned conditions that the reinforcing bars with thin concrete cover are under the corrosion environment.

2) Status of Delamination

Almost all the delamination occurred in the east side.

The difference of conditions between the west side and east side is regarding concrete cover.

Piers in the east side are directly touched to the soil, but (or whereas?) piers in the west side are not since the tops of pile caps are located above the ground surface.

3) Cause of Deterioration

It is considered that delaminations have occurred by chloride attack with water and oxygen supply from ground surface.

(2) Crack on Pile Cap

1) Crack Pattern and Depth

Cracks on upper surface have grillage-like regular pattern, namely, at orthogonal regular intervals (1 to 2 m).

Depth of crack exceeds 200 mm at the 0.5 mm width of crack.

2) Corrosion of Reinforcing Bar

Corrosion of reinforcing bar was not found, confirming by chipping during site investigations.

3) Cause of Deterioration

It is considered that cracks have occurred by not corrosion of reinforcing bar but thermal restraint with heat of cement hydration.

3.2.2 Evaluation of Structural Soundness

Structural soundness was evaluated using Japanese standards as reference.

(1) Delamination on Pier and Pile Cap

Structural soundness was evaluated for following three cases based on the site investigation results.

- A: No damage on concrete surface, and sufficient concrete cover
- B: No damage on concrete surface, but insufficient concrete cover
- C: Damage on concrete surface, and insufficient concrete cover

The relation between structural soundness and repair work is shown in Table 3.2.1.

Table 3.2.1 Necessity of Repair according to Structural Soundness

Soundness	Repair Work
Grade I	• Countermeasure for chloride attack is not necessary.
Grade II	• Preventive work is necessary to prevent damage generation.
Grade III	• Repair work is necessary to prevent further progress of existing damage or to maintain the existing performance.
Grade IV	• Urgent large-scale repair is necessary since deterioration caused by chloride attack is observed.

"A: No damage on concrete surface, and sufficient concrete cover" is evaluated as Grade I since countermeasure for chloride attack is not necessary.

"C: Damage on concrete surface, and insufficient concrete cover" is evaluated as Grade III since repair and preventive works are necessary for deterioration caused by chloride attack.

"B: No damage on concrete surface, but insufficient concrete cover" is evaluated as Grade I or II since degree of further deterioration caused by chloride attack will be different according to concrete cover at each place. It is required to determine the place to be required based on concrete cover, chloride content and carbonation depth for each pier.

(2) Crack on Pier and Pile Cap

Impact to soundness by crack is shown in Table 3.2.2.

Table 3.2.2 Impact to Soundness by Crack

Environment / Crack Width	Affected by salt attack or corrosion	General outdoor condition	Underground or indoor
$0.5 < W$	C (20-year durability)	C (20-year durability)	C (20-year durability)
$0.4 < W \leq 0.5$	C (20-year durability)	C (20-year durability)	B (20-year durability)
$0.3 < W \leq 0.4$	C (20-year durability)	B (20-year durability)	A (20-year durability)
$0.2 < W \leq 0.3$	B (20-year durability)	A (20-year durability)	A (20-year durability)
$W \leq 0.2$	A (20-year durability)	A (20-year durability)	A (20-year durability)

Note:
A: Structural soundness is maintained.
B: Structural soundness is maintained by small repair.
C: Structural soundness is not maintained.

* 20-year durability is reference only.

Applying "General outdoor condition" in Table 3.2.2,

- Structural soundness of piers is evaluated as "A", since crack width is less than 0.3 mm.
- Structural soundness of pile caps with wider than 0.35 mm of cracks is evaluated as "B"

3.3 Place and Method of Repair

Place and method of repair are determined based on the cause of deterioration and evaluation of structural soundness.

3.3.1 Necessity of Repair and Place to be Repaired

(1) Delamination on Pier and Pile Cap

1) Necessity of Repair

Necessity of repair was determined as follows according to "3.2.2 Evaluation of Structural Soundness".

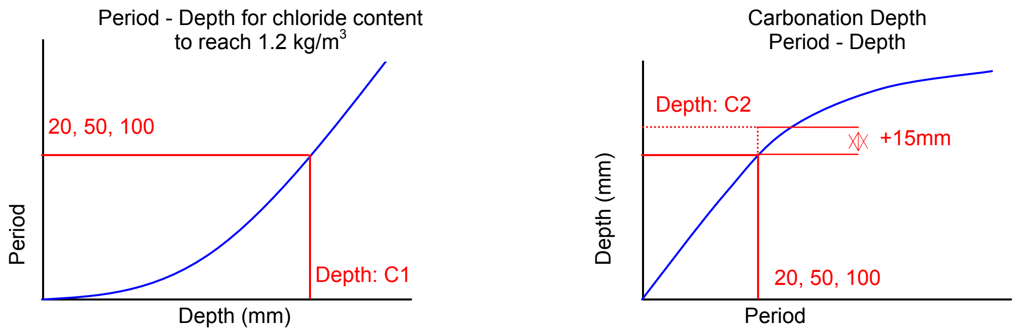
- A: No damage on concrete surface, and sufficient concrete cover
  => Repair work is not necessary.
- B: No damage on concrete surface, but insufficient concrete cover
  => Repair work is not necessary (for Grade I) or preventive work is necessary (for Grade II)
- C: Damage on concrete surface, and insufficient concrete cover
  => Repair and preventive works are necessary.

For "B: No damage on concrete surface, but insufficient concrete cover", place to be repaired will be determined based on concrete cover, predicted progress of chloride content and predicted progress of carbonation depth.

2) Place to be Repaired

For "B: No damage on concrete surface, but insufficient concrete cover", place to be repaired is determined based on the relation between concrete cover (C) and predicted progress of chloride content (C1), or concrete cover (C) and predicted progress of carbonation depth (C2), for each of C1 and C2 periods from completion of construction such as 20, 50 and 100 years being considered.

a) Predicted Progress of Chloride Content   b) Predicted Progress of Carbonation Depth



C < C1, C < C2 (including +15 mm) ···········	Shall be repaired
C < C1, C > C2 (including +15 mm) ···········	Follow-up observation
C > C1, C < C2 (including +15 mm) ···········	Follow-up observation
C > C1, C > C2 (including +15 mm) ···········	Follow-up observation

(2) Crack on Pier and Pile Cap

Table 3.3.1 Necessity of Repair according to Target Year

Impact to Soundness by Crack	Target Year		
	< 10 years	10 to 20 years	> 20 years
A (20-year durability)	• Repair work is not necessary	• Repair work is not necessary	• Repair work is not necessary (Periodic crack survey is necessary)
B (20-year durability)	• Repair work is not necessary	• Repair work is not necessary (Periodic crack survey is necessary)	• Repair work is necessary
C (20-year durability)	• Repair work is necessary	• Repair work is necessary	• Repair work is necessary

For piers, it is evaluated as “A”, therefore, repair work is not necessary (periodic crack survey is necessary).

For pile caps, it is evaluated as “B or C”, therefore, repair work is necessary for pile caps with wider than 0.35 mm of cracks.

3.3.2 Method of Repair

Following repair works shall be carried out.

- Refill of repair material as repair work for delamination
- Protection to concrete surface as preventive work for insufficient concrete cover
- Refill of filling material for cracks on pile caps

(1) Refill of Repair Material

Repair work shall be carried out based on the following work procedure.

In case the area of repair is larger than 300 mm x 300 mm, grout material shall be applied to refill repair material by form.

Incase the area of repair is smaller than 300 mm x 300 mm, polymer cement mortar shall be applied to refill repair material by plastering.

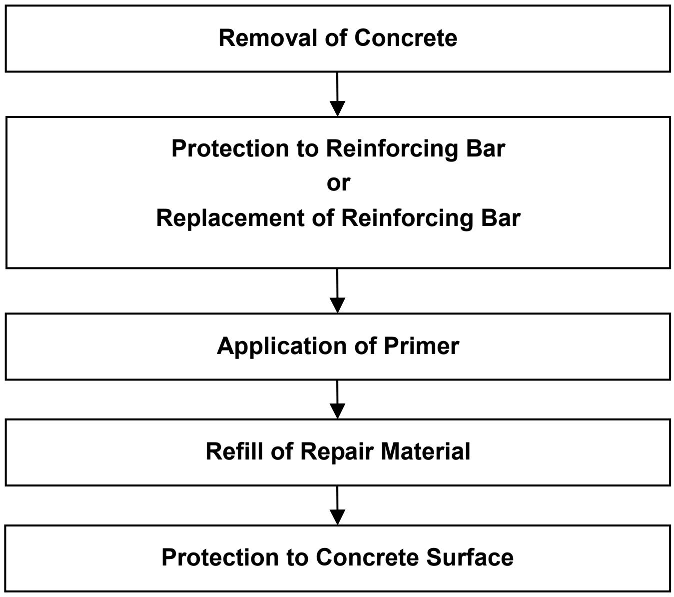


Figure 3.3.1 Repair Work Procedure

Comparison of repair material is shown in Table 3.3.2.

Table 3.3.2 Comparison of Repair Material

Material		Polymer Cement Mortal	Epoxy Resin Mortar	Cement Mortar
Work Procedure		• Remove concrete without damage reinforcing bar. • Remove corrosion on the reinforcing bar surface • Coat reinforcing bar with corrosion inhibitor. • Refill the polymer cement mortal material.	• Remove concrete without damage reinforcing bar. • Remove corrosion on the reinforcing bar surface • Coat reinforcing bar with corrosion inhibitor. • Refill the epoxy resin mortar material.	• Remove concrete without damage reinforcing bar. • Remove corrosion on the reinforcing bar surface • Coat reinforcing bar with corrosion inhibitor. • Install the form • Refill the cement mortar material.
Refill Method	Plaster	Suitable	Suitable	Suitable
	Spray	Suitable	Not applicable	Not applicable
	Form	Not suitable but applicable	Not suitable but applicable	Suitable
Feature		• Quick development of strength after the repair work • High durability for crack and delaminaion • No specific work method • Not suitable for large area	• Low specific gravity (0.75) • High adhesive • Expensive • Not suitable for large area • Difficult work procedure	• Cheap • Suitable for large area
Cost		190,000 JPY/m^3	580,000 JPY/m^3	90,000 JPY/m^3
Evaluation		• Good quality and workability for small area. • More expensive than Alt 3 which is not suitable for small area, but cheaper than Alt 2. **Recommended (for small area)**	• Good quality but most expensive.	• Good quality and workability for large area, which is repaired by form. • Cheapest **Recommended (for large area)**

(2) Protection to Concrete Surface

Protection material to concrete surface is selected from following alternatives.

- Coating Material (Organic)
- Coating Material (Inorganic)
- Impregnation material (Silane)
- Impregnation material (Sodium silicate)

Impregnation material (silane) is applied for protection material to concrete surface from the following aspects

- Damage such as crack can be checked easily in the further maintenance work since it is colorless and transparent.
- It can keep out water which is a cause of corrosion.

The height of protection is set as 4 m from the following aspects.

- Protection will be provided for the bottom of piers since insufficient concrete cover is mainly located there.
- First lift height is 4 m in local section.
- Lift height by slip form is 7 m in Japanese section, however the height of the fixing point of longitudinal reinforcing bar is 2.2 m.
- Damage has occurred mainly near the ground surface.
- Sufficient concrete cover is secured at 5 m in height.

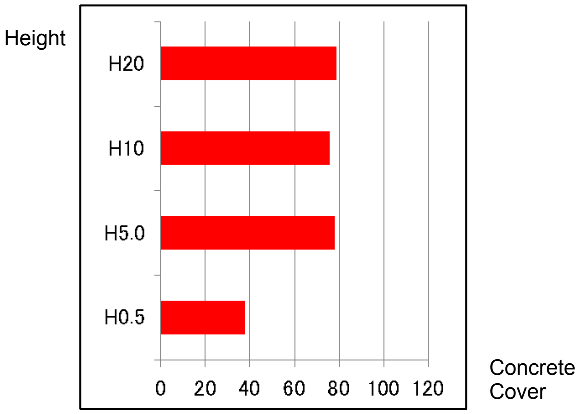


Figure 3.3.2 Concrete Cover

The number of piers to be protected is calculated according to target year, namely 20, 50 and 100 years from completion of construction (10, 40 and 90 years from today).

- Option 1 (20 years): 50 piers out of 180 piers
- Option 2 (50 years): 71 piers out of 180 piers
- Option 3 (100 years): 101 piers out of 180 piers
- Option 4 (all piers with insufficient concrete cover): 172 piers out of 180 piers

Option 2 is selected as the appropriate option from following points of view.

- Target of Option 1 is only the piers which is expected to be damaged within 20 years from completion of construction (10 years from today), and therefore another repair work might be required in 10 years.
- Target of Option 3 is the piers which are expected to be damaged within 100 years from completion of construction (90 years from today). This 100 year is much longer than the effect duration of concrete surface protection material (around 20 years), and therefore it is not cost effective.
- Target of Option 4 is almost all the piers. It is not cost effective from same reason of Option 3.

PKG	Pier	Column	Concrete Cover	Chloride Content: Reach to 1.2kg/m3			Carbonation Depth (+15mm)			Evaluation						Necessity of Repair			
				20 years	50 years	100 years	20 years	50 years	100 years	C>C1			C>C2			20 years	50 years	100 years	Insufficient Cover
			C (mm)	C1_10	C1_50	C1_100	C2_10	C2_50	C2_100	>C1_10	>C1_50	>C1_100	>C1_10	>C1_50	>C1_100				
Nile	PW1	N	41	31	45	64	31	40	51	○	×	×	○	○	×				
		S	52	31	45	64	31	40	51	○	○	×	○	○	○				
	PW2	N	38	31	45	64	31	40	51	○	×	×	○	×	×				
		S	25	31	45	64	31	40	51	×	×	×	×	×	×				
	PW3	N	36	31	45	64	31	40	51	○	×	×	○	×	×				
		S	46	31	45	64	31	40	51	○	○	×	○	○	×				
	PW4	N	38	31	45	64	31	40	51	○	×	×	○	×	×				
		S	50	31	45	64	31	40	51	○	○	×	○	○	×				
	PW5	N	47	31	45	64	31	40	51	○	○	×	○	○	×				
		S	54	31	45	64	31	40	51	○	○	×	○	○	○				
	PW6	N	55	31	45	64	31	40	51	○	○	×	○	○	○				
		S	59	31	45	64	31	40	51	○	○	×	○	○	○				
	PW7	N	60	31	45	64	31	40	51	○	○	×	○	○	○				
		S	51	31	45	64	31	40	51	○	○	×	○	○	○				
	PW8	N	58	31	45	64	31	40	51	○	○	×	○	○	○				
		S	42	31	45	64	31	40	51	○	×	×	○	○	×				
	PW9	N	47	31	45	64	31	40	51	○	○	×	○	○	×				
		S	32	31	45	64	31	40	51	○	×	×	○	×	×				
	PW10	N	36	31	45	64	31	40	51	○	×	×	○	×	×				
		S	54	31	45	64	31	40	51	○	○	×	○	○	○				
	PW11	N	53	31	45	64	31	40	51	○	○	×	○	○	○				
		S	56	31	45	64	31	40	51	○	○	×	○	○	○				
	PW12	N	65	31	45	64	31	40	51	○	○	○	○	○	○				
		S	38	31	45	64	31	40	51	○	×	×	○	×	×				
	PW13	N	51	31	45	64	31	40	51	○	○	×	○	○	○				
		S	67	31	45	64	31	40	51	○	○	○	○	○	○				
	PW14	N	31	31	45	64	31	40	51	×	×	×	×	×	×				
		S	43	31	45	64	31	40	51	○	×	×	○	○	×				
	PW15	N	72	31	45	64	31	40	51	○	○	○	○	○	○				
		S	41	31	45	64	31	40	51	○	×	×	○	○	×				
	PW16	N	57	31	45	64	31	40	51	○	○	×	○	○	○				
		S	72	31	45	64	31	40	51	○	○	○	○	○	○				
	PW17	N	57	31	45	64	31	40	51	○	○	×	○	○	○				
		S	65	31	45	64	31	40	51	○	○	○	○	○	○				
	PW18	N	36	31	45	64	31	40	51	○	×	×	○	×	×				
		S	50	31	45	64	31	40	51	○	○	×	○	○	×				
	PW19	N	43	31	45	64	31	40	51	○	×	×	○	○	×				
		S	49	31	45	64	31	40	51	○	○	×	○	○	×				
	PW20	N	50	31	45	64	31	40	51	○	○	×	○	○	×				
		S	50	31	45	64	31	40	51	○	○	×	○	○	×				
	PW21	N	37	31	45	64	31	40	51	○	×	×	○	×	×				
		S	57	31	45	64	31	40	51	○	○	×	○	○	○				
	PW22	N	53	31	45	64	31	40	51	○	○	×	○	○	○				
		S	52	31	45	64	31	40	51	○	○	×	○	○	○				
	PW23	N	40	31	45	64	31	40	51	○	×	×	○	×	×				
		S	49	31	45	64	31	40	51	○	○	×	○	○	×				
	PW24	N	48	31	45	64	31	40	51	○	○	×	○	○	×				
		S	54	31	45	64	31	40	51	○	○	×	○	○	○				
	PW25	N	38	31	45	64	31	40	51	○	×	×	○	×	×				
		S	64	31	45	64	31	40	51	○	○	×	○	○	○				
	PW26	N	54	31	45	64	31	40	51	○	○	×	○	○	○				
		S	55	31	45	64	31	40	51	○	○	×	○	○	○				
	PW27	N	72	31	45	64	31	40	51	○	○	○	○	○	○				
		S	62	31	45	64	31	40	51	○	○	×	○	○	○				
	PW28	N	65	31	45	64	31	40	51	○	○	○	○	○	○				
		S	47	31	45	64	31	40	51	○	○	×	○	○	×				
	PW29	N	50	31	45	64	31	40	51	○	○	×	○	○	×				
		S	69	31	45	64	31	40	51	○	○	○	○	○	○				
	PW30	N	62	31	45	64	31	40	51	○	○	×	○	○	○				
		S	49	31	45	64	31	40	51	○	○	×	○	○	×				
W_Kajima	PW31	N	51	10	16	23	39	53	69	○	○	○	○	×	×				
		S	53	10	16	23	39	53	69	○	○	○	○	×	×				
	PW32	N	41	10	16	23	39	53	69	○	○	○	○	×	×				
		S	50	10	16	23	39	53	69	○	○	○	○	×	×				
	PW33	N	47	10	16	23	39	53	69	○	○	○	○	×	×				
		S	43	10	16	23	39	53	69	○	○	○	○	×	×				
	PW34	N	47	10	16	23	39	53	69	○	○	○	○	×	×				
		S	57	10	16	23	39	53	69	○	○	○	○	○	×				
	PW35	N	53	10	16	23	39	53	69	○	○	○	○	×	×				
		S	57	10	16	23	39	53	69	○	○	○	○	○	×				
	PW36	N	53	10	16	23	39	53	69	○	○	○	○	×	×				
		S	57	10	16	23	39	53	69	○	○	○	○	○	×				
	PW37	N	47	10	16	23	39	53	69	○	○	○	○	×	×				
		S	37	10	16	23	39	53	69	○	○	○	×	×	×				
	PW38	N	53	10	16	23	39	53	69	○	○	○	○	×	×				
		S	57	10	16	23	39	53	69	○	○	○	○	○	×				
	PW39	N	43	10	16	23	39	53	69	○	○	○	○	×	×				
		S	48	10	16	23	39	53	69	○	○	○	○	×	×				
	PW40	N	54	10	16	23	39	53	69	○	○	○	○	○	×				
		S	38	10	16	23	39	53	69	○	○	○	×	×	×				
	PW41	N	43	10	16	23	39	53	69	○	○	○	○	×	×				
		S	42	10	16	23	39	53	69	○	○	○	○	×	×				
	PW42	N	50	10	16	23	39	53	69	○	○	○	○	×	×				
		S	44	10	16	23	39	53	69	○	○	○	○	×	×				
	PW43	N	54	10	16	23	39	53	69	○	○	○	○	○	×				
		S	54	10	16	23	39	53	69	○	○	○	○	○	×				
	PW44	N	54	10	16	23	39	53	69	○	○	○	○	○	×				
		S	49	10	16	23	39	53	69	○	○	○	○	×	×				
	PM1	N	44	10	16	23	39	53	69	○	○	○	○	×	×				
		S	36	10	16	23	39	53	69	○	○	○	×	×	×				
	PM2	N	49	10	16	23	39	53	69	○	○	○	○	×	×				
		S	44	10	16	23	39	53	69	○	○	○	○	×	×				
	PM3	N	44	10	16	23	39	53	69	○	○	○	○	×	×				
		S	34	10	16	23	39	53	69	○	○	○	×	×	×				

PKG	Pier	Column	Concrete Cover	Chloride Content: Reach to 1.2kg/m3			Carbonation Depth (＋15mm)			Evaluation						Necessity of Repair			
				20 years	50 years	100 years	20 years	50 years	100 years	C>C1			C>C2			20 years	50 years	100 years	Insufficient Cover
			C (mm)	C1_10	C1_50	C1_100	C2_10	C2_50	C2_100	>C1_10	>C1_50	>C1_100	>C1_10	>C1_50	>C1_100				
E_Kajima	PM4	N	62	44	66	100	40	54	71	○	×	×	○	○	×				
		S	52	44	66	100	40	54	71	○	×	×	○	×	×				
	PM5	N	52	44	66	100	40	54	71	○	×	×	○	×	×				
		S	58	44	66	100	40	54	71	○	×	×	○	○	×				
	PM6	N	43	44	66	100	40	54	71	×	×	×	○	×	×				
		S	49	44	66	100	40	54	71	○	×	×	○	×	×				
	PE35	N	50	44	66	100	40	54	71	○	×	×	○	×	×				
		S	52	44	66	100	40	54	71	○	×	×	○	×	×				
	PE34	N	56	44	66	100	40	54	71	○	×	×	○	○	×				
		S	53	44	66	100	40	54	71	○	×	×	○	×	×				
	PE33	N	57	44	66	100	40	54	71	○	×	×	○	○	×				
		S	46	44	66	100	40	54	71	○	×	×	○	×	×				
	PE32	N	56	44	66	100	40	54	71	○	×	×	○	○	×				
		S	53	44	66	100	40	54	71	○	×	×	○	×	×				
	PE31	N	56	44	66	100	40	54	71	○	×	×	○	○	×				
		S	53	44	66	100	40	54	71	○	×	×	○	×	×				
	PE30	N	61	44	66	100	40	54	71	○	×	×	○	○	×				
		S	53	44	66	100	40	54	71	○	×	×	○	×	×				
	PE29	N	61	44	66	100	40	54	71	○	×	×	○	○	×				
		S	62	44	66	100	40	54	71	○	×	×	○	○	×				
	PE28	N	61	44	66	100	40	54	71	○	×	×	○	○	×				
		S	45	44	66	100	40	54	71	○	×	×	○	×	×				
	PE27	N	80	44	66	100	40	54	71	○	○	×	○	○	○				
		S	48	44	66	100	40	54	71	○	×	×	○	×	×				
	PE26	N	45	44	66	100	40	54	71	○	×	×	○	×	×				
		S	37	44	66	100	40	54	71	×	×	×	×	×	×				
	PE25	N	81	44	66	100	40	54	71	○	○	×	○	○	○				
		S	40	44	66	100	40	54	71	×	×	×	○	×	×				
	PE24	N	33	44	66	100	40	54	71	×	×	×	×	×	×				
		S	43	44	66	100	40	54	71	×	×	×	○	×	×				
	PE23	N	46	44	66	100	40	54	71	○	×	×	○	×	×				
		S	41	44	66	100	40	54	71	×	×	×	○	×	×				
	PE22	N	93	44	66	100	40	54	71	○	○	×	○	○	○				
		S	89	44	66	100	40	54	71	○	○	×	○	○	○				
Arab	PE21	N	70	29	43	61	32	42	53	○	○	○	○	○	○				
		S	48	29	43	61	32	42	53	○	○	×	○	○	×				
	PE20	N	42	29	43	61	32	42	53	○	×	×	○	×	×				
		S	39	29	43	61	32	42	53	○	×	×	○	×	×				
	PE19	N	44	29	43	61	32	42	53	○	○	×	○	○	×				
		S	35	29	43	61	32	42	53	○	×	×	○	×	×				
	PE18	N	29	29	43	61	32	42	53	×	×	×	×	×	×				
		S	36	29	43	61	32	42	53	○	×	×	○	×	×				
	PE17	N	35	29	43	61	32	42	53	○	×	×	○	×	×				
		S	41	29	43	61	32	42	53	○	×	×	○	×	×				
	PE16	N	65	29	43	61	32	42	53	○	○	○	○	○	○				
		S	59	29	43	61	32	42	53	○	○	×	○	○	○				
	PE15	N	64	29	43	61	32	42	53	○	○	○	○	○	○				
		S	55	29	43	61	32	42	53	○	○	×	○	○	○				
	PE14	N	51	29	43	61	32	42	53	○	○	×	○	○	×				
		S	66	29	43	61	32	42	53	○	○	○	○	○	○				
	PE13	N	63	29	43	61	32	42	53	○	○	○	○	○	○				
		S	61	29	43	61	32	42	53	○	○	×	○	○	○				
	PE12	N	66	29	43	61	32	42	53	○	○	○	○	○	○				
		S	59	29	43	61	32	42	53	○	○	×	○	○	○				
	PE11	N	62	29	43	61	32	42	53	○	○	○	○	○	○				
		S	42	29	43	61	32	42	53	○	×	×	○	×	×				
	PE10	N	57	29	43	61	32	42	53	○	○	×	○	○	○				
		S	63	29	43	61	32	42	53	○	○	○	○	○	○				
	PE9	N	51	29	43	61	32	42	53	○	○	×	○	○	×				
		S	57	29	43	61	32	42	53	○	○	×	○	○	○				
	PE8	N	58	29	43	61	32	42	53	○	○	×	○	○	○				
		S	65	29	43	61	32	42	53	○	○	○	○	○	○				
	PE7	N	56	29	43	61	32	42	53	○	○	×	○	○	○				
		S	48	29	43	61	32	42	53	○	○	×	○	○	×				
	PE6	N	64	29	43	61	32	42	53	○	○	○	○	○	○				
		S	71	29	43	61	32	42	53	○	○	○	○	○	○				
	PE5	N	54	29	43	61	32	42	53	○	○	×	○	○	○				
		S	67	29	43	61	32	42	53	○	○	○	○	○	○				
	PE4	N	55	29	43	61	32	42	53	○	○	×	○	○	○				
		S	54	29	43	61	32	42	53	○	○	×	○	○	○				
	PE3	N	59	29	43	61	32	42	53	○	○	×	○	○	○				
		S	50	29	43	61	32	42	53	○	○	×	○	○	×				
	PE2	N	58	29	43	61	32	42	53	○	○	×	○	○	○				
		S	58	29	43	61	32	42	53	○	○	×	○	○	○				
	PE1	N	52	29	43	61	32	42	53	○	○	×	○	○	×				
		S	49	29	43	61	32	42	53	○	○	×	○	○	×				
	PE05	N	52	29	43	61	32	42	53	○	○	×	○	○	×				
		S	49	29	43	61	32	42	53	○	○	×	○	○	×				
	PE04	N	61	29	43	61	32	42	53	○	○	×	○	○	○				
		S	50	29	43	61	32	42	53	○	○	×	○	○	×				
	PE03	N	52	29	43	61	32	42	53	○	○	×	○	○	×				
		S	68	29	43	61	32	42	53	○	○	○	○	○	○				
	PE02	N	53	29	43	61	32	42	53	○	○	×	○	○	×				
		S	44	29	43	61	32	42	53	○	○	×	○	○	×				
	PE01	N	65	29	43	61	32	42	53	○	○	○	○	○	○				
		S	55	29	43	61	32	42	53	○	○	×	○	○	○				

Legend
: No Protection
: No Protection
: Protection

		20 years	50 years	100 years	InsufficientCover
Total		167	99	22	9
		8	41	76	0
		5	40	82	171
	total	180	180	180	180

Nile	20 years	50 years	100 years	InsufficientCover
	58	43	8	3
	0	5	22	0
	2	12	30	57

Kajima	20 years	50 years	100 years	InsufficientCover
	58	12	0	4
	8	36	38	0
	2	20	30	64

Arab	20 years	50 years	100 years	InsufficientCover
	51	44	14	2
	0	0	16	0
	1	8	22	50

Figure 3.3.3 Necessity of Repair for Each Option

Comparison of protection material is shown in Table 3.3.3.

Table 3.3.3 Comparison of Protection Material

Material	Coating Material		Impregnation material	
	Organic	Inorganic	Silane	Sodium silicate
Feature	• Organic coating material consisting primarily of epoxy resin or polyurethane resin, etc.	• Inorganic coating material consisting primarily of polymer cement	• Polymer resin is produced by chemical reaction between OH- in the cement and silane solvent.	• Gel (crystal) is produced by chemical reaction between Ca(OH)2 in the cement and Sodium silicate solvent.
Barrier against Cause of Deterioration	• High barrier properties	• High barrier properties, but lower than organic material	• High barrier properties • Anti-corrosion effect	• High barrier properties • Performance degradation by ultraviolet degradation
	(Good)	(Moderate)	(Good)	(Moderate)
Moisture Permeability	• Low moisture permeability	• Low moisture permeability	• High moisture permeability	• Low moisture permeability
	(Poor)	(Poor)	(Good)	(Poor)
Maintenance	• Damage can not be checked easily since it is not colorless and transparent.	• Damage can not be checked easily since it is not colorless and transparent.	• Damage can be checked easily since it is colorless and transparent.	• Damage can be checked easily since it is colorless and transparent.
	(Poor)	(Poor)	(Good)	(Good)
Workability	• Long work period	• Shorter work period	• Short work period	• Shorter work period
	(Poor)	(Moderate)	(Good)	(Moderate)
Cost	5,000 JPY/m^2	4,000 JPY/m^2	9,000 JPY/m^2	11,000 JPY/m^2
	(Good)	(Good)	(Poor)	(Poor)
Evaluation	• Not good workability • Difficult maintenance work since the material is not transparent.	• Not good workability • Difficult maintenance work since the material is not transparent.	• Easy maintenance work since the material is transparent. • Good moisture permeability and workability **Recommended**	• Easy maintenance work since the material is transparent. • Poor moisture permeability • More expensive than Alt 3

(3) Refill of Filling Material for Cracks

Filling material shall be refilled in cracks on pile cap since crack depth and width for pile cap are deep and wide (0.5 mm).

(4) Place to be Repaired

Place to be repaired for each option is shown in Figure 3.3.3 to 3.3.6.

The number of columns or pile caps to be repaired in Option 2 is shown below.

- Refill of Repair Material: 46 columns
- Protection to Concrete Surface: 71 columns
- Repair of Crack: 10 pile caps

Figure 3.3.4 Place to be Repaired (Option 1)

Figure 3.3.5 Place to be Repaired (Option 2)

Figure 3.3.6 Place to be Repaired (Option 3)

Figure 3.3.7 Place to be Repaired (Option 4)

3.4 Detailed Design

Detailed design was carried out according to “3.3 Place and Method of Repair”. Samples of detailed design drawings for refill of repair material, protection to concrete surface and repair of crack are shown in Figure 3.4.1 to 3.4.3, respectively. Drawings for whole repair works are shown in separate volume “Drawings”.

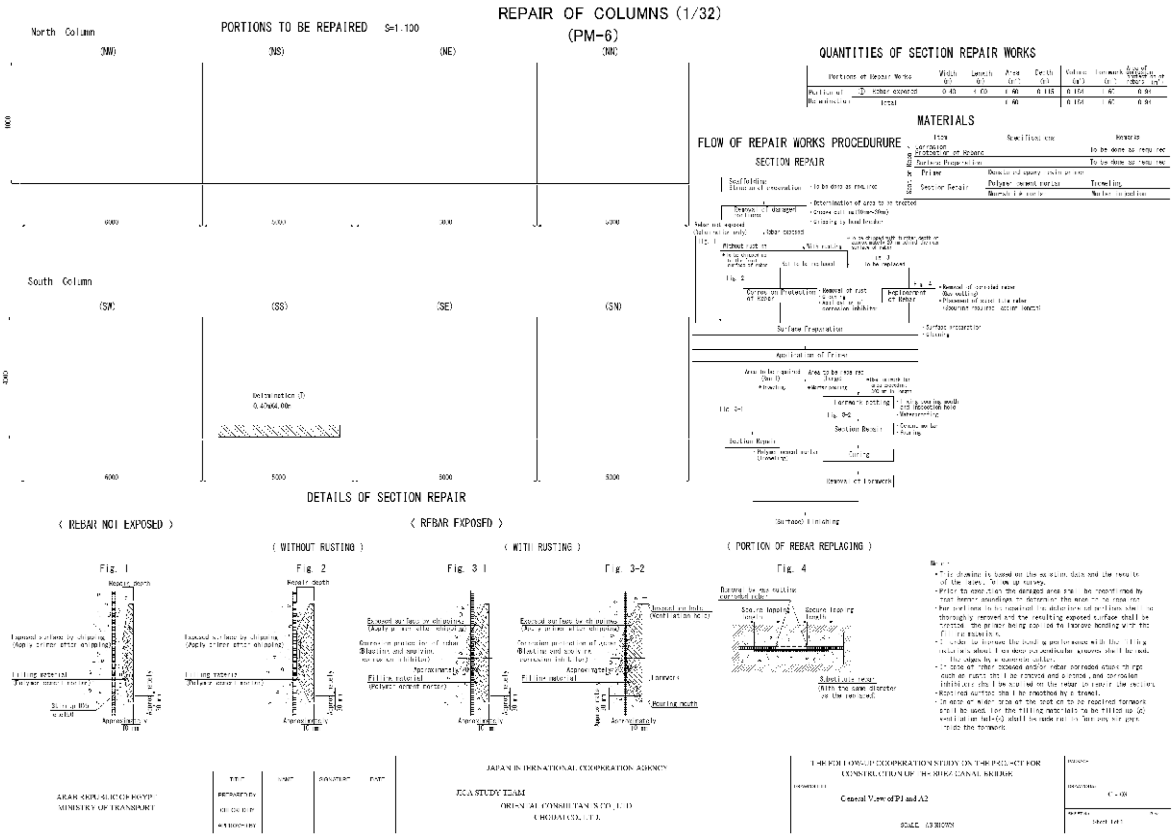


Figure 3.4.1 Refill of Repair Material

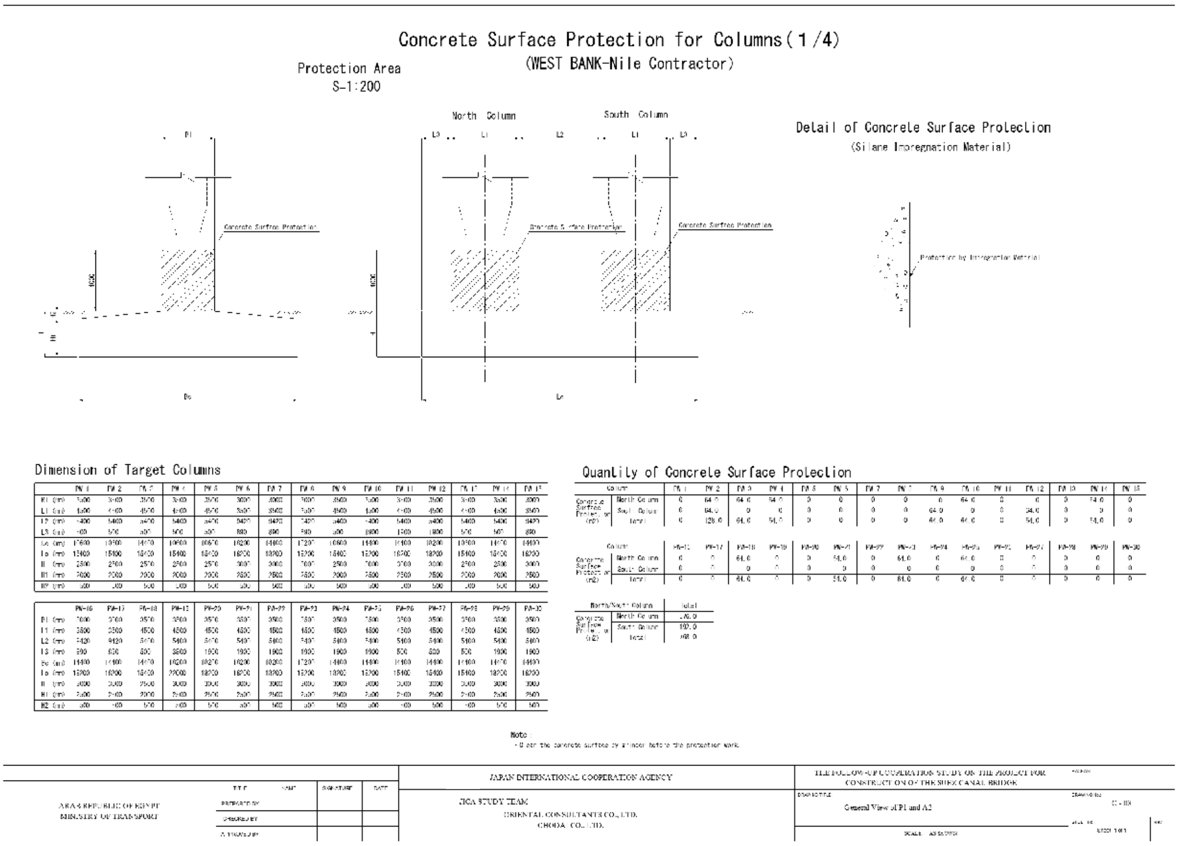


Figure 3.4.2 Protection to Concrete Surface

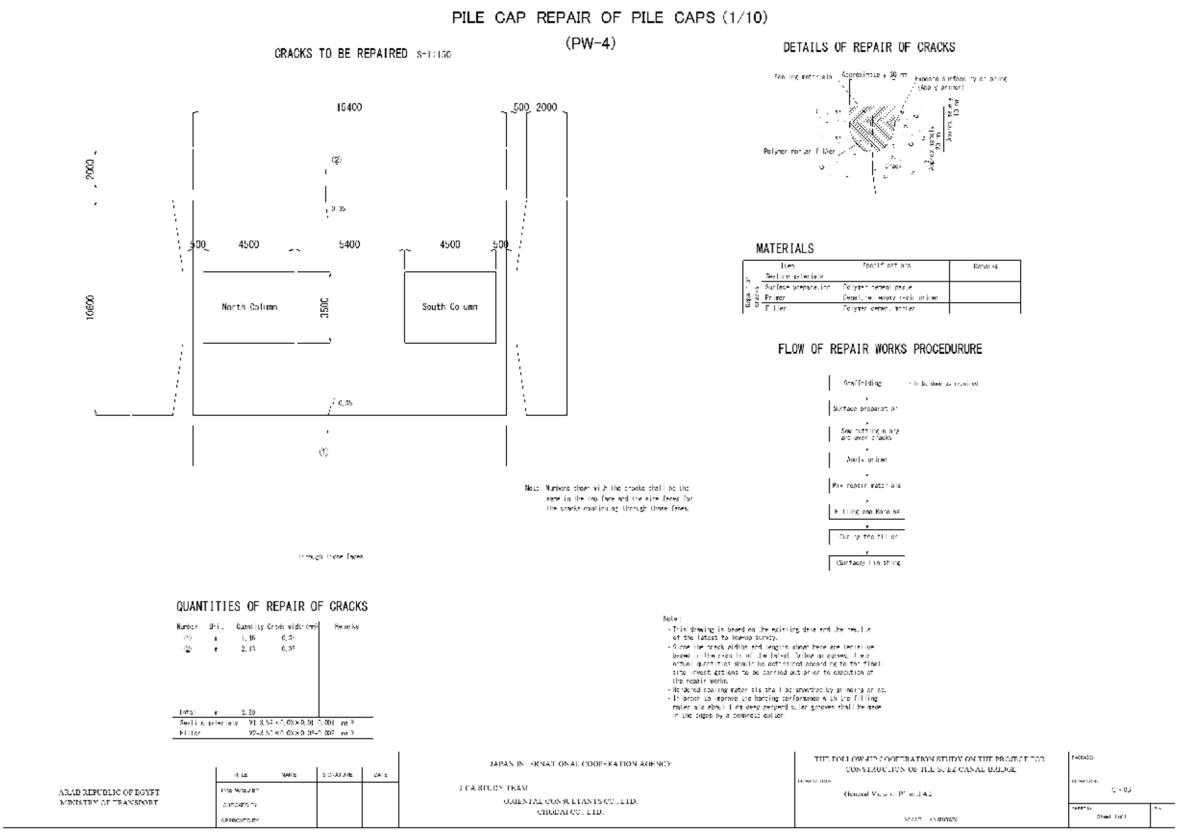


Figure 3.4.3 Repair of Crack

CHAPTER 4 CONSTRUCTION AND PROCUREMENT PLAN

4.1 Construction Plan

4.1.1 Refill of Repair Material

(1) General

Refill of repair material will be executed as a repair work for delamination or spalling on piers under the corrosion environment.

(2) Removal of Concrete

1) Objectives

Concrete will be removed in order to protect or replace reinforcing bar at delamination or spalling points.

2) Procedure

a) Identification of the Location to be Repaired

- Identify the location of delamination or spalling by hammer sounding under the direction of the Engineer.

b) Preparation of Surface Repair Boundaries

- Prepare surface repair boundaries by cutting with disc cutter to prevent feather edged conditions before chipping.
- Depth of cutting shall be around 30mm not to cut reinforcing bar.

c) Chipping

- Remove deteriorated concrete in the boundaries by hand breaker.
- Depth of chipping will be around 100mm in order to expose reinforcing bar.
- Chipping shall be carried out without damage of reinforcing bar.

(3) Protection to Reinforcing Bar

1) Objectives

Reinforcing bar will be coated with corrosion Inhibitor in order to prevent deterioration of concrete structure.

2) Procedure

a) Removal of Corrosion

- Remove corrosion on the reinforcing bar surface by abrasive blast cleaning or wire brushing.

b) High Pressure Water Cleaning

- Clean reinforcing bar surface by high pressure water.

c) Coating with Corrosion Inhibitor

- Coat reinforcing bar with corrosion inhibitor.

(4) Replacement of Reinforcing Bar

1) Objectives

Reinforcing bar will be replaced where it is pretty rusty.

2) Procedure

a) Removal of Reinforcing Bar

- Cut and remove the lost section of reinforcing bar.
- Reinforcing bar shall be cut by gas cutting, etc.

b) Replacement of Reinforcing Bar

- Splice new reinforcing bar to the existing reinforcing bar.
- New and existing reinforcing bar shall be spliced with required lap.

(5) Refill of Repair Material by Form

1) Objectives

Repair material will be refilled by form after protection or replacement of reinforcing bar.

2) Procedure

a) Surface Preparation

- Smooth the concrete surface by hand breaker.
- Clean the concrete surface by high pressure water.

b) Installation of Form

- Install the form.
- Install 2 tubes which are utilized for refilling the repair material and confirming the completion of refill.

c) Refill of Repair Material

- Refill the repair material by a tube.
- Confirm whether the refill is completed by another tube.
- Remove the form.

(6) Refill of Repair Material by Plastering (Hand Applied)

1) Objectives

Repair material will be refilled by plastering after protection or replacement of reinforcing bar.

2) Procedure

a) Surface Preparation

- Smooth the concrete surface by hand breaker.
- Clean the concrete surface by high pressure water.

b) Refill of Repair Material

- Refill the repair material by plastering (hand applied).

4.1.2 Protection to Concrete Surface

(1) General

Protection of concrete surface is effective to protect concrete structure from chloride attack with water and oxygen supply.

In the east side, embankment will be excavated before protection to concrete surface since the bottom of pier is under the ground in the east side.

(2) Excavation and Backfill

1) Objectives

Embankment will be excavated to expose bottom of piers, and be backfilled after protection work.

2) Procedure

a) Excavation

- Excavate the embankment to expose whole column.
- Cut slope gradient shall be 1 to 1.0 - 2.0.

b) Backfill

- After the protection work for pier, make backfill.

c) Repair of Side Road

- Repair the side road which was collapsed by the excavation.

(3) Protection to Concrete Surface

1) Objectives

Concrete surface will be protected from chloride attack

2) Procedure

a) Surface Preparation

- Smooth the concrete surface by grinder.
- Clean the concrete surface by high pressure water.

b) Protection of Concrete Surface

- Paint the protection material to the concrete surface, which protects reinforcing bar from chloride attack.

4.1.3 Repair of Crack

1) Objectives

Filling material will be refilled on cracks to prevent ingress of water into the concrete structure.

2) Procedure

a) Identification of crack to be repaired

- Identify the crack to be repaired by crack scale under the direction of the Engineer.

b) U-shape Cut of the Crack

- Make U-shape cut along the crack by disc cutter.

c) Surface Preparation

- Smooth the U-shape cut surface by wire brushing.

d) Refill of filling Material

- Refill the filing material to U-shape cut.

4.2 Procurement Plan

4.2.1 Local Contractor

Contractors are classified into 7 classes by the scale and performance. The condition of each class is shown in Table 4.2.1.

Table 4.2.1 Condition of Classification

Class	1	2	3	4	5	6	7
Capital paid-up (in million EGP)	10	5	2	1.5	0.5	0.1	0.1
Contractor's period of experience, not less than (year)	20	12	8	5	3	1	—
Technical agency, not less than	25 (6*)	15 (4**)	10 (3***)	7	2	1	1
Financial agency	Integral under a financial director			Account and assistants		—	—
Administrative and legal agency	Integral			—	—	—	—
Higher value of works prosecuted in any of the last 5 years (in million EGP)	40	20	15	6	2	0.4	—
Value of the biggest contractual agreement prosecuted successfully during the five years preceding the submission of the application (in million EGP)	25	12	7	4	2	0.4	—
Ceiling of the adjudication amount allowed to submit the tender therefore (in million EGP)	Without Ceiling	37.5	22.5	12	6	3	0.75

* International Projects Management Association (IPMA) Certificate, Level (B)
** International Projects Management Association (IPMA) Certificate, Level (C)
*** International Projects Management Association (IPMA) Certificate, Level (D)

Source: The Egyptian Federation of Construction and Building Contractors

The number of contractors classified as class 1 and having experience of road/bridge work is 13, and class 2 and having experience of road/bridge work is 3.

4.2.2 Labor

Skilled labors will be procured from class 1 contractors.

4.2.3 Materials

Major materials for the repair work are as follows.

- Corrosion inhibitor
- Cement mortar for form
- Cement mortar for plastering
- Concrete protection material
- Filling material for crack
- Reinforcing bar

These materials will be procured from Cairo branch of global chemical companies.

4.2.4 Equipments

Equipments required for the repair wok such as hand breaker, grinder and backhoe will be procured from class 1 contractors.

4.3 Construction Schedule

Construction schedule of the repair work is shown in Figure 4.3.1. Construction period is 5.0 months.

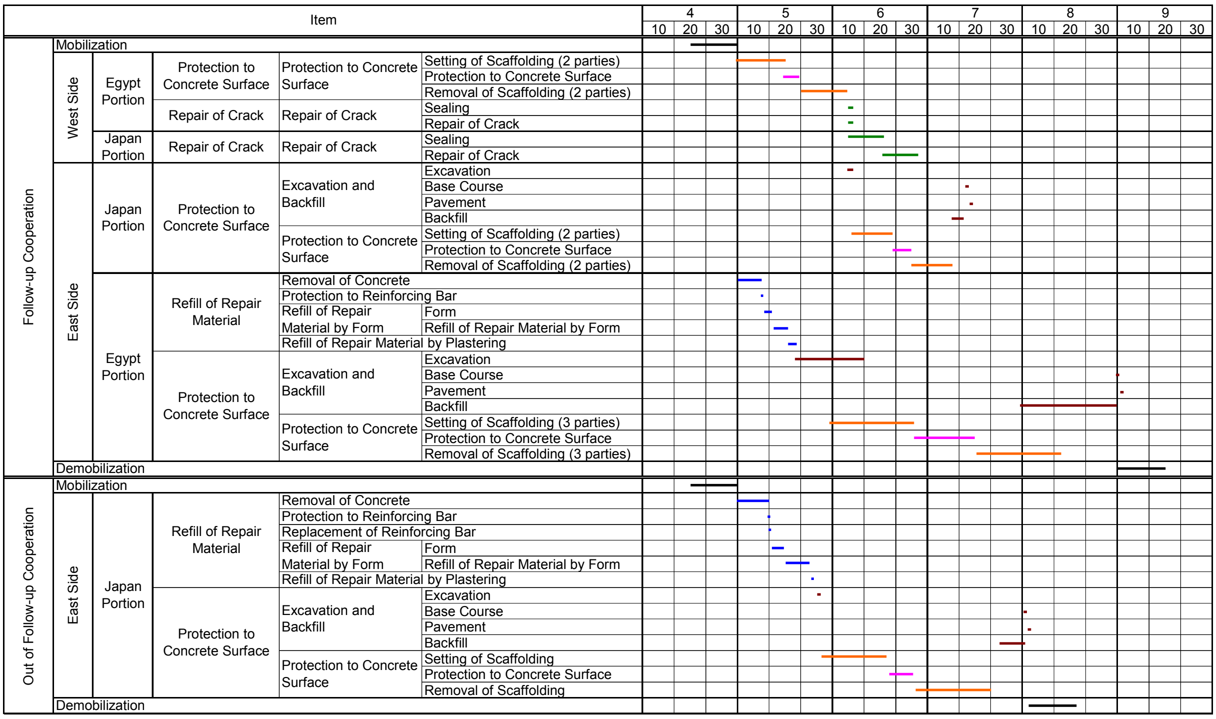


Figure 4.3.1 Construction Schedule

CHAPTER 5 COST ESTIMATES

5.1 Implementing Organization for Repair

The responsibility for the damage and implementing organization for further repair work for each section were discussed in the site survey report meeting held on August 17, 2011.

In the meeting, it was concluded that the contractor who implemented original construction has no responsibility to repair the damages, for the following reasons. However, the contractor proposed to implement the repair work by his own expense in the sections which were originally implemented by the contractor.

- According to the record, chloride content tests for cement and aggregate were carried out periodically, and the value satisfied the criteria.
- Concrete cover is insufficient at some piers, but 10 years have passed since the construction was completed and there is no critical impact on structural soundness.
- Defects liability period (1 year for grant aid project) was expired.

As shown in Table 5.1.1, Implementing organization for local section, Japanese section in west side and local section, a part of Japanese section in east side is JICA, that for a part of Japanese section in east side is the contractor who implemented original construction.

The section implemented by the contractor is out of scope of the follow-up cooperation.

Table 5.1.1 Implementing Organization for Repair

Follow-up Cooperation	Follow-up Cooperation				Out of F/U Cooperation
Section	West Side		East Side		East Side
	Egypt Section	Japan Section	Japan Section	Egypt Section	Japan Section
Implementing Organization	JICA				Contractor
Refill of Repair Material	0 column	0 column	0 column	36 columns	10 columns
Protection to Concrete Surface	12 columns	0 column	11 columns	38 columns	10 columns
Repair of Crack	1 pile caps	9 pile caps	0 pile cap	0 pile cap	0 pile cap

5.2 Quantity

Quantity for each section is shown in Table 5.2.1.

Table 5.2.1 Quantity

No.	Item		Unit	Follow-up Cooperation Quantity West Side Egypt Section	Follow-up Cooperation Quantity West Side Japan Section	Follow-up Cooperation Quantity East Side Japan Section	Follow-up Cooperation Quantity East Side Egypt Section	Follow-up Cooperation Quantity Total	Out of F/U Cooperation Quantity East Side Japan Section	Out of F/U Cooperation Quantity Total
1	Refill of Repair Material	Removal of Concrete	m2				9.175	9.175	11.650	11.650
2		Protection to Reinforcing Bar	m				63.870	63.870	78.200	78.200
3		Replacement of Reinforcing Bar	m					0.000	9.000	9.000
4		Refill of Repair Material by Form	m3				0.629	0.629	1.304	1.304
5		Refill of Repair Material by Plastering	m3				0.290	0.290	0.024	0.024
6	Protection to Concrete Surface	Protection to Concrete Surface	m2	768.000		752.000	2432.000	3952.000	664.000	664.000
7		Excavation and Backfill	m3			334.200	4816.100	5150.300	190.300	190.300
8	Repair of Crack		m	3.600	643.600			647.200		0.000

5.3 Cost Estimates

5.3.1 Cost Estimates for Follow-up Cooperation

Construction cost for the repair work in the follow-up cooperation is 59,210 thousand Japanese Yen (4,314 thousand EGP) as shown in Table 5.3.1.

Table 5.3.1 Construction cost for the Follow-up Cooperation

Item	Class	Unit	Quantity	Unit Price JPY	Unit Price EGP	Unit Price USD	Amount JPY	Amount EGP	Amount USD	JPY Equivalent
Repair Work										
Removal of Concrete		m2	9.175		225			2,064		28,332
Protection to Reinforcing Bar		m	63.870		85			5,429		74,507
Replacement of Reinforcing Bar		m	-	-	-	-	-	-	-	-
Refill of Repair Material by Form		m3	0.629		16,000			10,064		138,119
Refill of Repair Material by Plastering		m3	0.290		13,500			3,915		53,730
Protection to Concrete Surface		m2	#######		630			2,489,760		34,169,546
Excavation and Backfill		m3	#######		330			1,699,599		23,325,351
Repair of Crack		m	647.200		160			103,552		1,421,151
Total								4,314,383		59,210,735

5.3.2 Cost Estimates for out of Follow-up Cooperation

Construction cost for the repair work out of the follow-up cooperation is 7,031 thousand Japanese Yen (512 thousand EGP) as shown in Table 5.3.2.

Table 5.3.2 Construction cost for out of the Follow-up Cooperation

Item	Class	Unit	Quantity	Unit Price			Amount			JPY Equivalent
				JPY	EGP	USD	JPY	EGP	USD	
Repair Work										
Removal of Concrete		m2	11.650		225			2,621		35,974
Protection to Reinforcing Bar		m	78.200		85			6,647		91,224
Replacement of Reinforcing Bar		m	9.000		90			810		11,116
Refill of Repair Material by Form		m3	1.304		16,000			20,864		286,338
Refill of Repair Material by Plastering		m3	0.024		13,500			324		4,447
Protection to Concrete Surface		m2	664.000		630			418,320		5,741,037
Excavation and Backfill		m3	190.300		330			62,799		861,855
Repair of Crack		m	-		160			-		-
Total								512,385		7,031,992

CHAPTER 6 IMPLEMENTATION PLAN

6.1 General

The repair work will be executed as the follow-up cooperation project by Egyptian contractor funded by JICA Egypt Office.

Japanese consultant for tender assistance and construction supervision will be procured after the follow-up cooperation study. Tender process will be executed from middle of January to middle of April, 2012 in Egypt. Construction work will be executed from middle of April to middle of September.

6.2 Implementation Schedule

Implementation schedule for the project is shown in Table 6.2.1.

Table 6.2.1 Implementation Schedule

Item	Period	2011					2012											
		8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Follow-up Cooperation Study	Detailed Design	—	—	—	—													
	Preparation of Tender Document			—	—													
Procurement of Consultant	TA / CS					—	—											
Tender Assistance / Construction Supervision	Tender Assistance						—	—	—	—								
	Construction Supervision									—	—	—	—	—	—			
Tender Process	Approval of Tender Document						—											
	Tender Notice						★											
	Provision of Tender Document							—										
	Opening of Tender								★									
	Evaluation of Tender									—								
	Signing of Contract									★								
Construction	Mobilization									—								
	Refill of Repair Material										—							
	Protection to Concrete Surface										—	—	—	—				
	Repair of Crack											—						
	Demobilization														—			

CHAPTER 7 OPERATION AND MAINTENANCE PLAN

7.1 Existing Maintenance

Maintenance of Suez Canal Bridge has been carried out based on the "Operation and Maintenance Manual" prepared by Kajima - NKK Nippon Steel Consortium in July 2001.

Existing inspection item is shown in Table 7.1.1 and 7.1.2.

Table 7.1.1 Inspection Item for Main Bridge (Steel)

Object	To be inspected	Method of Inspection	Maintenance period
Steel box girder	abnormal deformation deterioration of painting	side walk from the ground inspection walkway	Routine (daily) General (every year)
	crack on welding joint abnormal sound looseness of bolts	inspection walkway inspection vehicle maintenance platform	General (every year)
Survey of Girder profile	girder elevation temperature of girder inclination of pylon	road surface inspection walkway from ground	Principal (every five years)
Bearing	looseness of setting bolt/nut surface crack of rubber / grouting damage of bearing plate deterioration of painting crack on welding joint abnormal sound of bearing plate	through manhole of pylon side walk lower cross beam through inspection walkway manhole of girder platform on pier	General (every year)
Cable	abnormal sag damage of sheathing	side walk	Routine (daily)
	measured by vibration method abnormal slip of zinc-copper alloy	side walk inspection vehicle gondola lifted by crane	Principal (when cable has abnormal sag)
Cable damper	looseness of setting bolt abnormal crack on rubber material coming out of anchor bolt	inspection vehicle gondola lifted by crane	Principal (when cable has abnormal vibration)
Pavement	deterioration	by the car	Routine (daily)
Drainage system	abnormal drainage	side walk	Routine (daily)
	leakage of water at joint part looseness of setting bolt/nut corrosion of pipe	through inspection walkway manhole of girder	General (every year)
Guard fence/ Net fence	damage of deformation	side walk	Routine (daily)
	looseness of setting bolt/nut	side walk	General (every year)
Expansion joint	abnormal sound excess gap of finger joint	side walk	Routine (daily)
	looseness of setting bolt/nut corrosion of finger/basement	through manhole of end diaphram	General (every year)
	distance of expansion joint between fixed finger and moved finger temperature of girder	manhole of end diaphram	Principal (every five years)

Object	To be inspected	Method of Inspection	Maintenance period
Inspection vehicle	looseness of setting bolt/nut breaking system moving system	on the inspection vehicle	General (every year)
Anemometer	irregularity	side walk	Routine (daily)
	looseness of setting bolt/nut	side walk	General (every year)
Navigation light	irregularity burn-out	side walk	Routine (daily)
	looseness of setting bolt/nut	side walk	General (every year)

Table 7.1.2 Inspection Item for Approach Bridge (Concrete)

Object	To be inspected	Method of Inspection	Maintenance period
Bearings	cleanliness protective coating wearing surface PTFE disc seals fixings for corrosion	Not mentioned	Principal (every five years)
Expansion joints	cleanliness side seam sealing condition concrete condition	Not mentioned	General (every six months)
	after any road repaving after any sandstorm	Not mentioned	Special
Gully grates	abnormal drainage	Not mentioned	Routine (every week)
	condition of the grilles condition of the drain body	Not mentioned	General (every six months)
Pylon lightning protection system	check the earth resistance check the copper tape conductor	Not mentioned	General (every year)
Pylon	condition of the ladders condition of the hand rails condition of the man holes	Not mentioned	General (every year)
Aviation warning lighta system	check all electrical power connections	Not mentioned	General (every six months)
Seismic sensor system	check all electrical power connections check the recording meter	Not mentioned	General (every six months)
Electrical power system	measure the insulation between the cable ends and earthing	Not mentioned	General (every six months)
	check the riser attachment to the supporting wires checking all connections	Not mentioned	(every three months)
	testing the boards earth leakage breaker	Not mentioned	General (every year)
	checking for signs of rodents	Not mentioned	(every month)
Asphalt paving	inspecting any changes	Not mentioned	Routine (every week)
	check the cracks…etc	Not mentioned	General (every six months)
Road markings & Curb painting	checking for signs of wear	Not mentioned	General (every year)

7.2 Maintenance Plan on Pier and Pile Cap

7.2.1 Inspection Method

(1) Inspection Item

It was evaluated that deterioration on piers was caused by chloride attack and crack on pile caps was caused by heat of cement hydration.

Inspection item to be executed for piers and pile cap was determined by reference to Japanese standard since it is not stated in "Operation and Maintenance Manual".

Inspection item for piers and pile cap is shown in Table 7.2.1.

Table 7.2.1 Inspection Item for Piers and Pile Caps

Object	To be inspected	Method of Inspection	Maintenance period
Concrete (Damage, Deterioration)	Efflorescence	Visual inspection	Daily/Periodical (every year) ※1
	Delamination	Test hammering	Periodical (every five year) ※1
	Carbonation	Chipping	Periodical (every five year) ※1
	Chloride content	Drilling, Coring	Periodical (every five year) ※2
	Generation of cracks	Crack scale	Periodical (every five year) ※2
Reinforcement (Corrosion)	Rate of corrosion	Chipping, Half-cell potential	Special/Emergency ※3

※1 Maintenance period was determined by Japanese standard.
※2 Maintenance period was determined considering follow-up observation, since chloride attack and carbonation were found in the site investigations.
※3 Corrosion of reinforcement is checked when delamination and crack on concrete are observed.

(2) Inspection Method

1) Free Lime and Water Leakage

a) General Condition

- Water or lime is leaking from crack of concrete.

b) Relation with Other Damage

- Water remaining concrete surface due to the defect of drainage system is not categorized as free lime and water leakage.
- Damage of concrete such as crack, delamination or spalliing should be recorded in each category.

c) Evaluation and Record

Evaluation

Degree of damage is evaluated with following Table.

Table 7.2.2 Evaluation for Free Lime and Water Leakage

Degree	General Condition
a	No damage
b	-
c	Water is leaking from crack, but there is little rust fluid or free lime.
d	Free lime is leaking from crack, but there is little rust fluid.
e	Much water or free lime is leaking from crack, or clay or rust fluid is included in the water.

Other Records

- Place, area and condition of water leakage and free lime are recorded by sketch and photo.
- Conditions such as only water leakage, with free lime, or with rusty fluid are recorded.
- Crack conditions at these places are recorded by sketch.

2) Delamination

a) General Condition

- Concrete surface is delaminated (but not remomoved).
- Where delamination can not be identified by visual inspection, it can be indentified by hammer test.

b) Relation with Other Damage

- Where concrete is spalled (removed), it is recorded as spalling and reinforcing bar exposure.

c) Evaluation and Record

Evaluation

Degree of damage is evaluated with following Table.

Table 7.2.3 Evaluation for Delamination

Degree	General Condition
a	No damage
b	-
c	-
d	-
e	Delaminating

Other Records

- Place, area and condition of delamination are recorded by sketch and photo.

3) Crack

a) General Condition

- Surface of concrete is cracked

b) Relation with Other Damage

- Where Delamination or reinforcing bar exposure occurs in addition to crack, they should be evaluated as well.

c) Evaluation and Record

Evaluation

Degree of damage is evaluated with following Table.

Table 7.2.4 Evaluation for Crack

Degree	The Largest Crack Width	The Smallest Crack Interval
a	No damage	No damage
b	Small	Small
c	Small	Large
	Medium	Small
d	Medium	Large
	Large	Small
e	Larrge	Large

Degree in the Table 7.2.4 is determined with Table 7.2.5 and 7.2.6.

Table 7.2.5 The Largest Crack Width

Degree	General Condition
Large	$W \geq 0.3$
Medium	$0.3 > W \geq 0.2$
Small	$0.2 > W$

Table 7.2.6 The Smallest Crack Interval

Degree	General Condition
Large	$I < 0.5$
Small	$I \geq 0.5$

Other Records

- Place, area and condition of crack are recorded by sketch and photo.

4) Carbonation, Chloride Content and Condition of reinforcing bar corrosion

Survey of carbonation, chloride content, condition of reinforcing bar corrosion, etc. is carried out by subcontract.

(A) Chipping

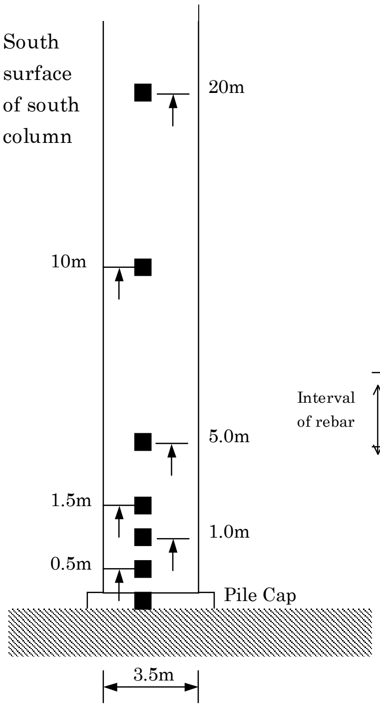
Condition of reinforcing bar corrosion and carbonation depth shall be surveyed. After checking them, the chipped areas shall be repaired with suitable material.

a) Scanning of embedded reinforcing bar positions with RC radar

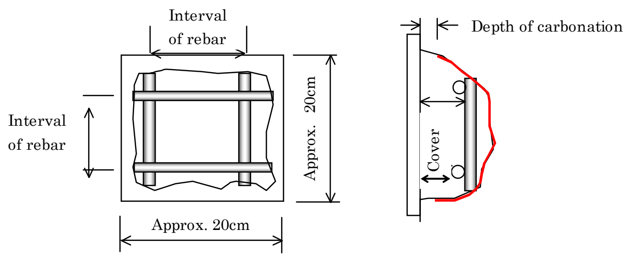
With using aforesaid RC radar, the chipped areas shall be predetermined in the preparatory work. The center of the chipping area shall be marked with a line 20 cm square.

b. Chipping

The above square area shall be chipped, and condition of reinforcing bar corrosion and carbonation depth shall be surveyed. Size of chipping area shall be 20 cm x 20 cm.



Chipping Position



Chipping Work

(B) Coring

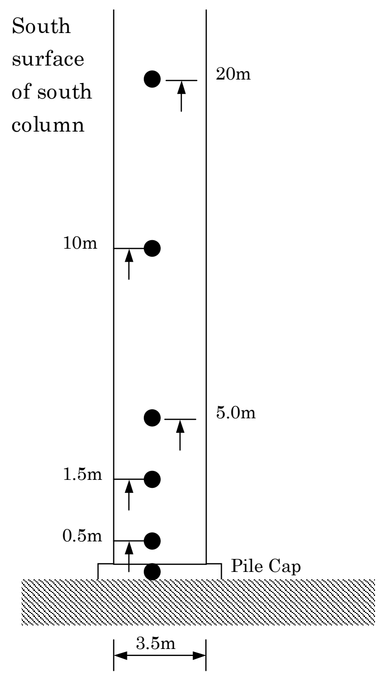
Concrete Core is obtained to utilize as specimen for each test.

a) Coring position

Coring works shall be carried out on the various positions including Egypt section, Japan section in west side and Egypt section, Japan section in east side.

b) Dimensions of core specimens and others

- Diameter of core specimens shall be 45mm for testing chloride ions.



Coring Position

- Length of the core shall be 20cm.
- In order to prevent damage to the pier, the number of core specimens shall be the minimum necessary
- Coring holes shall be repaired with suitable material after testing

c) Notes regarding the coring

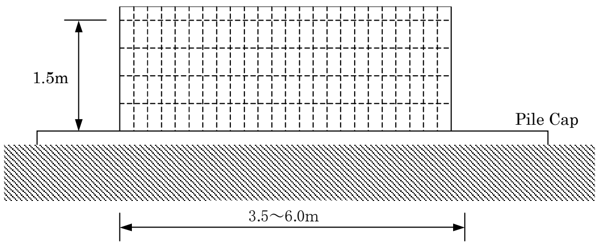
- The Coring machine shall be installed accurately by using the aforesaid RC radar.
- In case of encountering embedded rebar during coring, the rebar shall not be cut and the coring position must be changed

(C) Reinforcing Bar Corrosion Survey

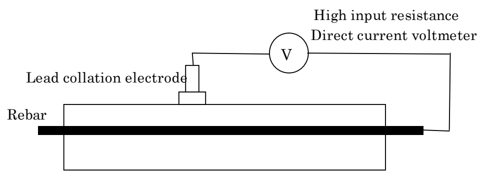
Natural potential shall be measured by the lead collation electrode, and the embedded rebar corrosion in the concrete shall be diagnosed.

The surface from column to pile cap at intervals of 30cm within the range of 1.5m height shall be measured, and measurement results shall be described in a drawing.

Embedded rebar in the concrete shall be exposed by a coring machine with a diameter of 70mm, and then natural potential shall be measured using the exposed rebar as the earth wire.



Location of Measurement of Half-cell Potential



System of Measurement of Half-cell Potential

(D) Analyses of Concrete Core Samples

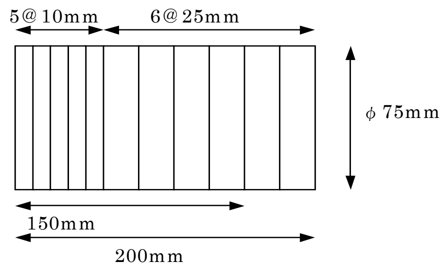
The following tests are executed using the concrete core samples taken from the piers.

- Compressive strength test
- Static elastic modulus test
- Carbonation test
- Chloride content test

<Testing procedure>

1. Cut a core with the length twice the diameter.
2. Measure the diameter, length and weight.
3. Cap and finish the end surfaces smoothly in parallel.
4. Stick longitudinal strain gauges on opposite sides of the core.
5. Execute compressive strength test using a test machine and record outputs from the strain gauges using a static strain measuring machine.

6. After the compressive strength test is complete remove the capping and the strain gauges and divide the sample into two halves of longitudinal pieces. Spray with a solution of phenolphthalein immediately, record the length of the area dyed in red violet at 5 locations and take their photographs.



Slicing of the Concrete Core Sample

7. Put the two halved samples together to restore the original shape by taping and cut it, as shown in Figure, into slices which will be analyzed for chloride content tests.
8. Crush and mill the slices to be tested for chloride content.
9. Chloride content tests shall be executed and the analysis of the chloride ions shall be done by potential difference titration.

7.2.2 Repair Work

When delamination is observed at the inspection, the repair work shall be carried out based on the following work procedure.

(1) Refill of Repair Material

1) General

Refill of repair material will be executed as a repair work for delamination or spalling on piers under the corrosion environment.

2) Removal of Concrete

Objectives

Concrete will be removed in order to protect or replace reinforcing bar at delamination or spalling points.

Procedure

a) Identification of the Location to be Repaired

- Identify the location of delamination or spalling by hammer sounding under the direction of the Engineer.

b) Preparation of Surface Repair Boundaries

- Prepare surface repair boundaries by cutting with disc cutter to prevent feather edged conditions before chipping.
- Depth of cutting shall be around 30mm not to cut reinforcing bar.

c) Chipping

- Remove deteriorated concrete in the boundaries by hand breaker.

- Depth of chipping will be around 100mm in order to expose reinforcing bar.
- Chipping shall be carried out without damage of reinforcing bar.

3) Protection to Reinforcing Bar

Objectives

Reinforcing bar will be coated with corrosion Inhibitor in order to prevent deterioration of concrete structure.

Procedure

a) Removal of Corrosion

- Remove corrosion on the reinforcing bar surface by abrasive blast cleaning or wire brushing.

b) High Pressure Water Cleaning

- Clean reinforcing bar surface by high pressure water.

c) Coating with Corrosion Inhibitor

- Coat reinforcing bar with corrosion inhibitor.

4) Replacement of Reinforcing Bar

Objectives

Reinforcing bar will be replaced where it is pretty rusty.

Procedure

a) Removal of Reinforcing Bar

- Cut and remove the lost section of reinforcing bar.
- Reinforcing bar shall be cut by gas cutting, etc.

b) Replacement of Reinforcing Bar

- Splice new reinforcing bar to the existing reinforcing bar.
- New and existing reinforcing bar shall be spliced with required lap.

5) Refill of Repair Material by Form

Objectives

Repair material will be refilled by form after protection or replacement of reinforcing bar.

Procedure

a) Surface Preparation

- Smooth the concrete surface by hand breaker.
- Clean the concrete surface by high pressure water.

b) Installation of Form

- Install the form.
- Install 2 tubes which are utilized for refilling the repair material and confirming the completion of refill.

c) Refill of Repair Material

- Refill the repair material by a tube.
- Confirm whether the refill is completed by another tube.
- Remove the form.

6) Refill of Repair Material by Plastering (Hand Applied)

Objectives

Repair material will be refilled by plastering after protection or replacement of reinforcing bar.

Procedure

a) Surface Preparation

- Smooth the concrete surface by hand breaker.
- Clean the concrete surface by high pressure water.

b) Refill of Repair Material

- Refill the repair material by plastering (hand applied).

(2) Repair of Crack

Objectives

Filling material will be refilled on cracks to prevent ingress of water into the concrete structure.

Procedure

a) Identification of crack to be repaired

- Identify the crack to be repaired by crack scale under the direction of the Engineer.

b) U-shape Cut of the Crack

- Make U-shape cut along the crack by disc cutter.

c) Surface Preparation

- Smooth the U-shape cut surface by wire brushing.

d) Refill of filling Material

- Refill the filing material to U-shape cut.

CHAPTER 8 CONCLUSION AND RECOMMENDATION

8.1 Conclusion

Conclusion in the follow-up cooperation study is as follows.

(1) Study, Analysis

- Insufficient concrete covers were approximately 50% of total.
- No tendency of corrosion of reinforcing bar was found at all chipping points including with minimum cover depth and minimum natural potential.
- Carbonation depths will not reach to the design cover depth of 70 mm in 100 years.
- Chloride contents in deeper than 60 mm were less than critical value of 1.2 kg/m^3.
- High chloride content of 1.5 kg/m^3 in PE21 will not influence on corrosion of reinforcing bar because it is still stable inside coarse aggregates.
- It is considered that delaminations have occurred by chloride attack with water and oxygen supply from ground surface.
- It is considered that cracks have occurred by thermal restraint with heat of cement hydration.

(2) Repair Work

- In case concrete surface is not damaged and concrete cover is sufficient, it is evaluated that No repair work is required (Grade I).
- In case concrete surface is not damaged but concrete cover is insufficient, it is evaluated that no repair work is required (Grade I) or preventive work is required (Grade II).
- In case concrete surface is damaged, it is evaluated that repair and preventive work are required (Grade III).
- Repair work is required for cracks with wider than 0.35 mm.
- Number of columns required for repair work or preventive work is 46 columns or 71 columns, respectively, and number of pile caps required for repair work is 10 pile caps.
- In above columns and pile caps, repair work or preventive work will be implemented at 36 columns or 61 columns, respectively, and repair work will be implemented at 10 pile caps as the follow-up cooperation project.
- The contractor who implemented original construction has no responsibility to repair the damages. However, the contractor proposed to implement the repair or preventive work by his own expense in the sections which were originally implemented by the contractor.

- Repair work or preventive work will be implemented at 10 columns or 10 columns, respectively by the contractor as out of the follow-up cooperation project.

8.2 Recommendation

(1) Maintenance Work

The Suez Canal Bridge, being a symbol of the friendship between Egypt and Japan, was constructed by cooperative works of both the countries with Japan's Grant Aid.

The proper maintenance work is very important to secure the safety and preserve its function for a long period.

It is important for GARBLT, implementation agency, to conduct the maintenance work proposed in the study properly and steadily.

(2) Technical Transfer

The repair work of the Suez Canal Bridge will be carried out in the follow-up cooperation. For the purpose of technical transfer, it is important for engineers in GARBLT to execute the construction supervision together with consultant.