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# Investigation and Repair Work for Superstructures of Jetty Deteriorated by Chloride Induced Corrosion and ASR in the Osaka Port Container Terminal

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## ABSTRACT

Located at the hub of the Osaka metropolitan area in Japan, the Port of Osaka has been playing an important role of a logistics base. On the other hand, many berths in this port are over 40 years after construction, and the concrete superstructure of jetty has been in use under severe marine environments for a long period. In these superstructures, the serious damage caused by Alkali-Silica Reaction (ASR) as well as chloride induced deterioration has been confirmed. In such situation, for the efficient operation of the whole facilities in this port, it is important and indispensable that the effective repair and maintenance premising the preventive maintenance is conducted strategically. For the sake of this purpose, based on the investigation results and newly proposed selection strategy of countermeasure, design and execution of repair work were performed for the superstructure suffering from chloride induced deterioration and/or ASR.

**Keywords.** Chloride Ion, Residual Expansion Capacity, Cathodic Protection, Selection Strategy of Repair Method, Preventive Maintenance

## INTRODUCTION

Located at the hub of the Osaka metropolitan area with a population of 21 million, the Port of Osaka has been playing an important role of a comprehensive logistics base combining sea, land and air transportation as a Japan's economic and industrial center along with Tokyo area. The Port of Osaka is linked to the world mainly via liner service and called by more than 5,900 ocean-going vessels per year, of which more than 3,800 are container carriers. The Port enjoys increasing volume of container cargo, particularly with Asia. In order to become competitive with the emerging Asian ports, the National Government designated the Port of Osaka as "Super Gateway Port" in 2005 and then Hanshin Port, combining Osaka and Kobe, as an international strategic container port in 2010. In such situation, the importance of the Osaka Port Container Terminal shown in Figure 1 is increasing more than former.

On the other hand, many berths in this port are over 40 years after construction, and the concrete superstructure of jetty has been in use under severe marine environment for a long period. In these superstructures of jetty, serious damage caused by Alkali-Silica Reaction (ASR) as well as chloride induced deterioration has been confirmed. So it has become to be apprehensive about the prospective functional decline of the structures. In such situation, for the efficient operation of the whole facilities in the Port of Osaka, it is very important and indispensable that the effective repair and maintenance premising the preventive maintenance is conducted for the deteriorated structures strategically.

The authors have investigated the observable deterioration, chloride ion content of concrete and so on in superstructures of jetty composing the Osaka Port Container Terminal. The probability of future deterioration of ASR was also examined by the residual expansion test for concrete cores in accelerated curing conditions. Based on these investigation results, repair work using the cathodic protection method was planned as a main countermeasure. While drawing up this plan, the selection strategy of repair method for the concrete members suffering from the chloride induced corrosion and/or ASR was studied.

In this paper, the outline of the investigation for the deterioration members of the concrete superstructure of jetty in C1 to C4 berths of Osaka Port Container Terminal is described. And also, the design and execution of repair work in C3 berth already executed in 2009 is explained.

**Figure 1. View of the entire Osaka Port Container Terminal**

## OUTLINE OF THE SUPERSTRUCTURE OF JETTY

C1 to C4 berths of Osaka Port Container Terminal was equipped in the second half of the 1960s to the 1970s as 5 berths, old C1 berth to old C5 berth. After that, in the 1990s, improvement work for responding to enlargement of the crane for cargo work and entering vessels was performed, and old 5 berths were reorganized to 4 berths (350m in length per one berth). Typical cross-section of this berth is shown in Figure 2.

The concrete superstructure of jetty is composed of beams, slabs and pile heads. In this jetty, the curtain wall hanging down to the height of middle water level is set up at the front row characteristically. Here, each interval from high water level (H.W.L.) to the bottom level of beams and slabs is 1.05-1.35m and 1.97m.

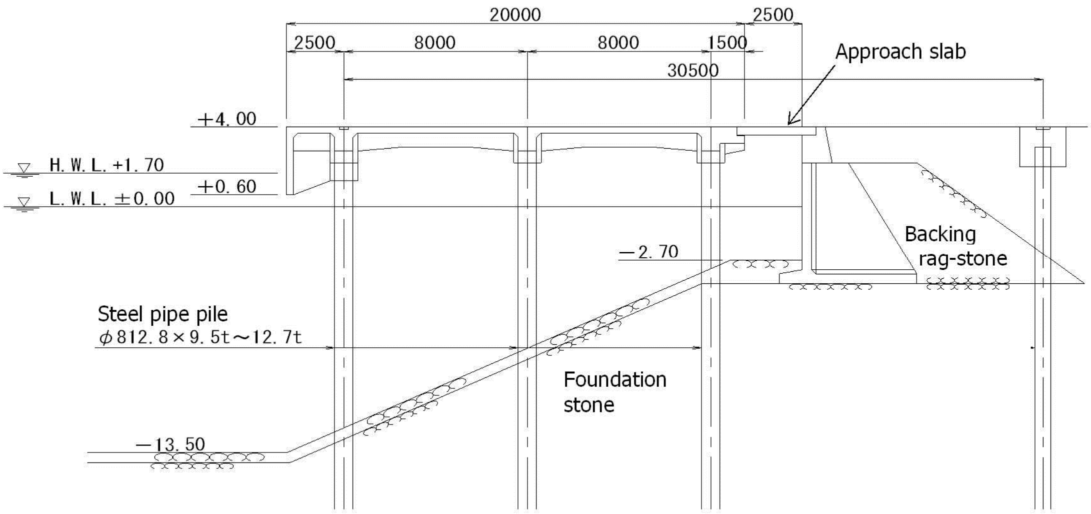



**Figure 2. Typical cross-section of the jetty**

## INVESTIGATION RESULTS

**Visual observation.** The jetty has been exposed in severe marine environment, so the superstructure has been suffering from chloride induced deterioration. As a result, in 1988 and 1990 when about 18 years passed after construction, partial repair (patch repair) for chloride induced deterioration was carried out for the first time. And afterwards, in 2001 when about 30 years passed after construction, visual observation for the bottom surface of the superstructures was executed to clarify the outline of the deterioration of these concrete superstructures.

As the result of this visual observation, a lot of degradations of concrete caused by the chloride induced deterioration (corrosion induced crack, peeling, flaking etc.) were confirmed. In addition, a lot of degradations of concrete caused by the ASR (map cracks, white deposits etc.) were confirmed in these superstructures.

**Detailed investigation.** Based on the results of visual observation, detailed investigation was executed to clarify the state of deterioration caused by chloride induced deterioration and ASR in 2003 and 2007. In these investigations, visual observation of concrete surface, measurement of total chloride ion content in the concrete (according to JIS A 1154), visual observation of corroded reinforcing bar and residual expansion test called Danish Method (Chatterji, 1978) were carried out. Incidentally, there have been very few studies concerning the combined effects of ASR and seawater attack in marine structures (Habuchi et al, 2004).

An example of degradation caused by chloride induced corrosion and ASR confirmed by visual observation is shown in Figure 3.

Concerning the chloride induced deterioration; Figure 4 illustrates the examples of distribution of total chloride ion content in concrete. In these superstructures, cover of reinforcing bar was about 60 – 70mm in beams and 40 – 60mm in slabs. It can be understood that the chloride ion content in concrete of beams was larger than that of slabs, and the chloride ion content in concrete at the depth of reinforcing bar in beams were about 2 –

5kg/m$^3$ and in slabs were about 0.5 – 3kg/m$^3$. Also, corrosion of reinforcing bar was comparatively prominent in beams, and that in slabs was observed as partial degradation. However, although about 40 years have passed after construction of these structures, penetrated chloride ion content in concrete seems to be comparatively little. It is assumed that the chloride penetration into concrete was influenced by the curtain wall (Amino et al, 2008). Furthermore, all results show that the chloride ion content in surface layer of concrete were very little. This seems to be influenced by the carbonation of surface layer of concrete, because the measured carbonation depths of concrete were about 15 – 25mm.

(a) Chloride induced corrosion of reinforcing bar of a slab

(b) Cracks of a beam caused by ASR

**Figure 3. An example of degradation caused by chloride induced corrosion and ASR**

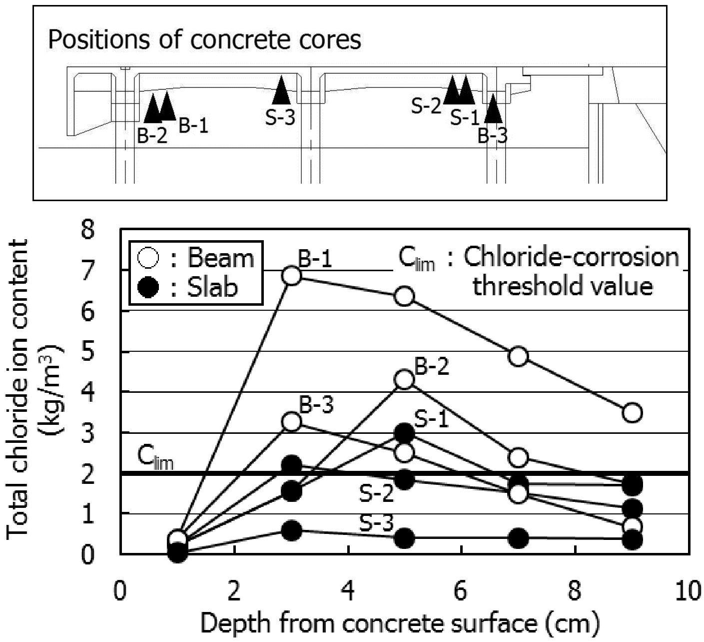



**Figure 4. Examples of distribution of total chloride ion content in concrete**

Concerning the degradation caused by ASR, the progress of ASR was confirmed by the reaction limb of coarse aggregates and the test results of chemical analysis for the deposits. Examples of the results of residual expansion test for concrete cores are shown in Figure 5. In Danish Method, ASR expansion of concrete core is accelerated by soaking in the saturated solution of sodium chloride in 50 degrees Celsius. Almost all measured data of expansion rate after 91 days acceleration were below 0.1%. Although one data showed the expansion rate of 0.2%, it can be diagnosed that the ASR expansion almost converged. Still more, as shown in Figure 6 (a), because the damage of asphalt pavement was confirmed in several points along the run way of trailer, the asphalt pavement of these damaged areas were removed. The many cracks of concrete slabs were observed under the damage of asphalt pavement as shown in Figure 6 (b). These cracks of concrete slabs seemed to have occurred by the repeated load of heavy vehicles to the ASR cracks.

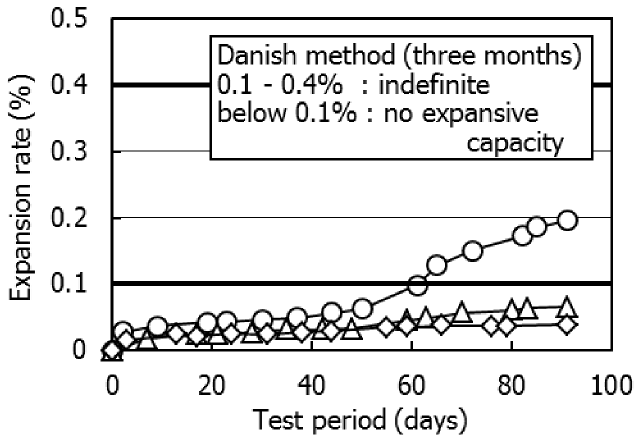



**Figure 5. Examples of the result of residual expansion test for concrete cores**

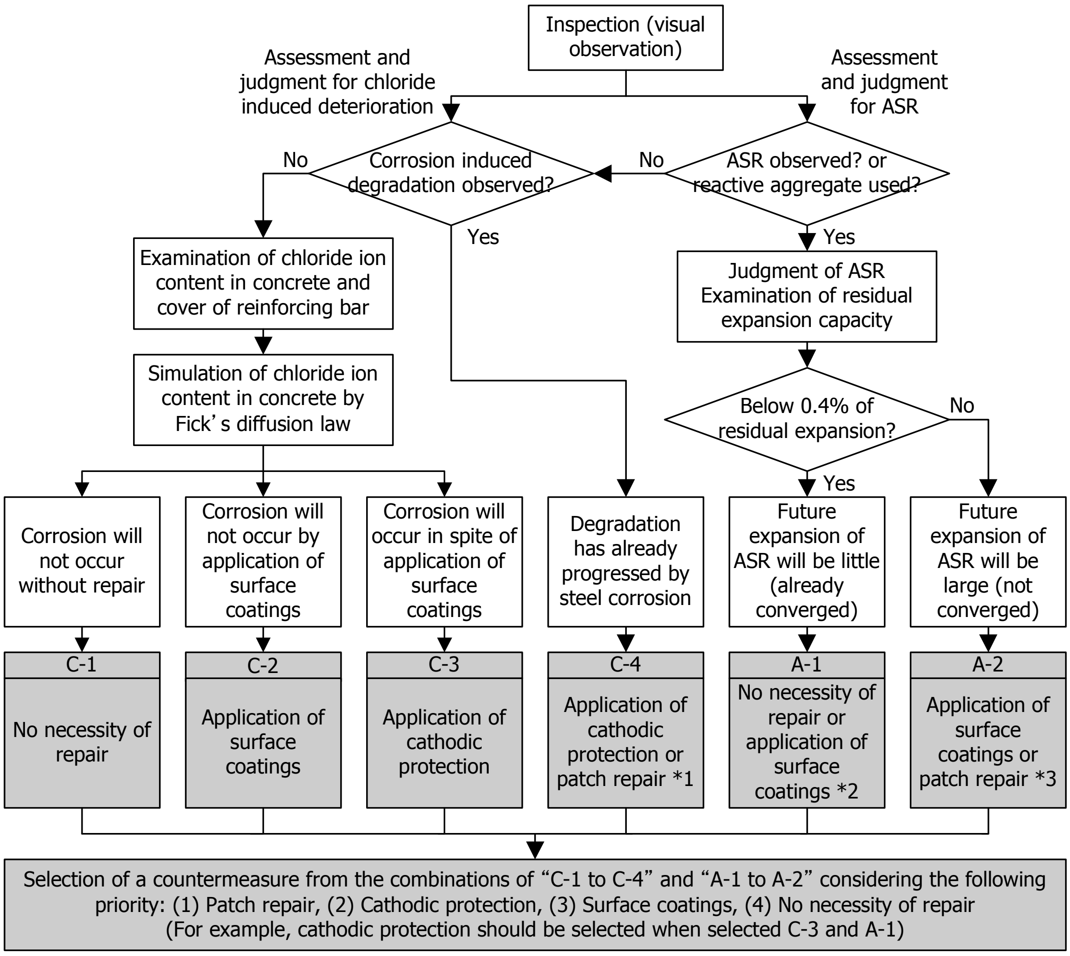
(a) Damage (cracks) of asphalt pavement

(b) Cracks of concrete slab under the damaged asphalt pavement

**Figure 6. Damage of asphalt pavement and cracks of concrete slab**

## REPAIR DESIGN AND EXECUTION

**Repair Design.** As the basic policy of repair, deteriorated members have to be repaired, and also preventive countermeasure should be carried out for members where damage has not appeared yet. It is because these superstructures are exposed in severe marine environment. According to this basic policy, repair design was studied referring to "Maintenance Manual for Harbour Facilities" (CDIT, 2007). Some selection procedures of repair method for concrete members suffering from chloride induced deterioration were already proposed (Okudaira et al, 2002). However, these superstructures are deteriorated due to both influence of chloride induced deterioration and/or ASR, so newly proposed selection strategy of countermeasure represented in Figure 7 was adopted. At first, based on the result of prediction of chloride ion penetration and measurement of residual expansion added to the result of visual observation, countermeasure for chloride induced deterioration and that for




*1 Select the application of cathodic protection normally except for the case of suffering from remarkable peeling, spalling and/or corrosion-induced cracks of cover concrete

*2 Select the application of surface coatings normally at the concrete members supplied large amount of chloride from the environment (large surface chloride ion content)

*3 Select the application of patch repair normally in the case of suffering from terrible ASR degradation (map cracks etc.)

**Figure 7. Selection strategy of countermeasure for the superstructure suffering from chloride induced deterioration and/or ASR**

ASR are selected. After that, repair method that achieves the most expected effect among the pairs of countermeasure is selected. Here, prediction of chloride ion penetration is calculated under the following conditions; 1) surface chloride ion content of concrete and diffusion coefficient of chloride ion is the constant value, 2) concrete is completely insulated from the external chloride ion after treated surface coatings. And also, the criterion for the residual expansion of ASR is set referring to the criterion of the Danish Method (expansion capacity is estimated as large: over 0.4% of expansion rate after 91 days acceleration) and "Guideline for Application of Electrochemical Corrosion Control Method with the care to ASR" (JSMS, 2007). For the structures exposed in severe corrosion environment, for prevention against steel corrosion progress and for retention of mechanical performance even if suffering from ASR, application of cathodic protection is recommended for the concrete member showing its residual expansion rate of less than 0.4% in this guideline.

Applied countermeasures for the superstructures are shown in Table 1. In this table, applied countermeasure for the pavement (top surface of slab) is included.

**Table 1. Applied countermeasures for the superstructures**

| Object | Countermeasure for degraded member | Intent of countermeasure (mainly for corrosion prevention of reinforcing bar) |
|---|---|---|
| (a) Beams | Patch repair for degraded area | Preventive maintenance by applying cathodic protection for all surfaces of beams (Considering structural importance and difficulty of future removal / replacement) |
| (b) Slabs | ditto | follow-up maintenance (routine inspection) (Considering the little volume of penetrated chloride ion content, taking the possibility of future application of cathodic protection into account) |
| (c ) Pile heads | ditto | follow-up maintenance (routine inspection) (Considering structural inportance) |
| Common to (a) - (c) | --- | Crack injection (Using cementitious injection material considering application of cathodic protection) |
| (d) Pavement | Removal and restoration of damaged slab concrete and asphalt pavement, restoration using liquid-applied membrane waterproofing simultaneously (Considering restraint of ASR progress and ooze of free lime from slab) | |

As for beams and slabs on lower side of superstructures, calculation of chloride ion penetration into concrete in the future using measured data of chloride ion content in concrete as shown in Figure 8 was performed, and necessity of repair itself and application of surface coatings were assessed according to the result of former calculation. As a result, it was assumed that the application of surface coatings for beams would not be effective, so cathodic protection method premising the preventive maintenance was selected for all beams taking the importance of beams into consideration. Here, the concrete was suffering from ASR, but supposed residual expansion capacity was below 0.4%. So, referring to the abovementioned Guideline, cathodic protection method was selected giving priority to the prevention of steel corrosion. On the other hand, as regards the slabs, it was assumed that there was nothing to worry about the corrosion of reinforcing bar because of the little volume of penetrated chloride ion content. According to this, it was determined that the slabs would be unnecessary to be repaired for the moment, and follow-up maintenance (routine inspection) was selected. Here, for already degraded area, it was necessary to apply patch repair in the members of beams, slabs and pile heads. Moreover, as regards the pavement (top surface of slab), after the removal and restoration of damaged slab concrete, both damaged asphalt restoration and liquid-applied membrane waterproofing were selected to prevent the relapse of asphalt damage by restraining the water penetration into the minute ASR cracks.

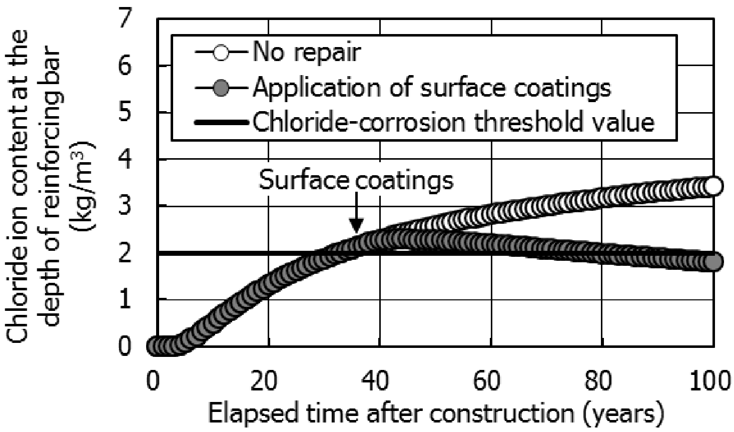



**Figure 8. Result of calculation of chloride ion penetration (example of beam)**

**Repair Method.** Execution of repair work was conducted according to the flow represented in Figure 9. At first, the approach slabs (precast slab connecting revetment to jetty) were removed in order to secure the delivery entrances for scaffold materials and repair materials. And, patch repair was executed by plastering for one repair area of less than $0.25m^2$ and by wet mixed splaying for one repair area of over $0.25m^2$. As the cathodic protection system for beams, rod-typed anode system (ribbon mesh anode system) which has many execution results was adopted to make visual observation easy after setting anodes. Figure 10 shows the states of spot welding in setting anodes and completion of cathodic protection. In the execution of patch repair, cover concrete was removed up to the back of reinforcing bars, and cement mortar was used for the area in where cathodic protection method was applied, as well as polymer cement mortar was for other methods. After the execution of cathodic protection, measured potential differences of depolarization at the all monitoring points were confirmed as the values of over 100mV by using reference electrode.

When repairing the pavements (top surface of slab), rapid restoration work was required by the restriction of cargo handling work. Therefore, damaged slab concrete was removed up to the back of reinforcing bars and was restored with high early set concrete containing steel fiber (slump : 5cm, water cement ratio : 0.40, content of steel fiber : $100kg/m^3$). Finally, asphalt pavement was restored by using liquid-applied membrane waterproofing with methyl-methacrylate resin simultaneously.

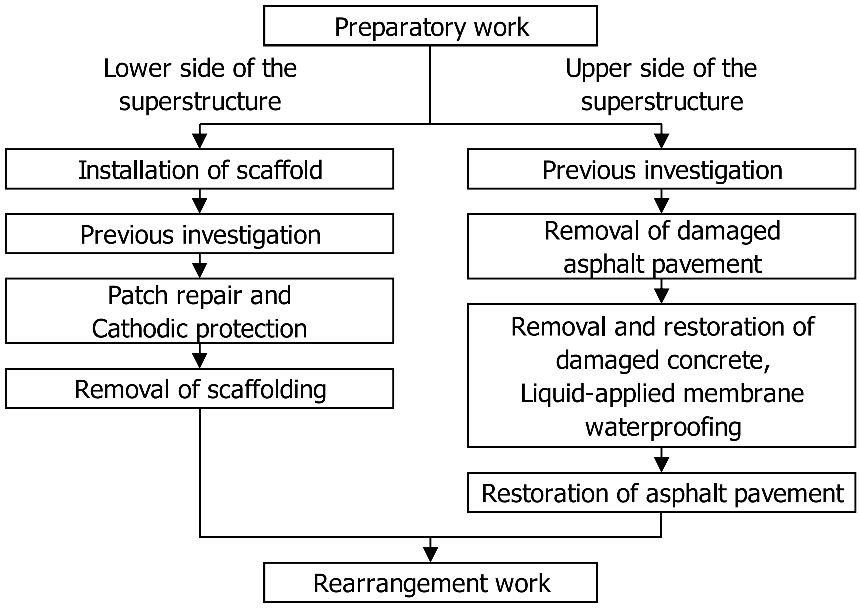



**Figure 9. Execution flow of repair work for the superstructure**

(a) State of spot welding in setting anodes

(b) State of completion of cathodic protection

**Figure 10. State of setting anodes and completion of cathodic protection**

## CONCLUSIONS

The conclusions obtained in this study are as follows:

(1) Concerning the superstructures of jetty deteriorated by chloride induced corrosion and ASR, the outline of deterioration affairs, the intent of repair design and the summary of repair work regarding cathodic protection mainly were described. Especially, newly proposed selection strategy of countermeasure for the superstructure suffering from chloride induced deterioration and/or ASR was introduced.

(2) The volume of chloride penetration into concrete in these superstructures of jetty was relatively little, because of the effect of the curtain wall hanging down at the front row of the jetty.

(3) It was confirmed that the obvious damages occurred in the pavements and top surfaces of concrete slabs as well as in the bottom surfaces of members, when the defects affected by ASR developed in the concrete of superstructures.

Adding some postscripts, it is considered that the "record" is important to appropriately carry out the long-term maintenance on the concrete superstructures of jetty in large scale container berth. So, it is significant to do the compilation of the results of investigations and intent of adopting the repair methods, as well as measures and used materials of repair work, and to do the information sharing between all the parties concerned about the maintenance. Finally, because the repair work generally has to be conducted at the jetty in service, it is important to retain the appropriate communication and coordination within user and administrator of the facility and constructor of repair work from the standpoint of safety of the site work.

## REFERENCES


Amino, T., Moriwake, A., Habuchi, T. and Otsuki, N. (2008). "The influence of differences in structural and wave conditions on spatial saline environment for chloride induced deterioration in the superstructures of Jetties" Proceedings of the international workshop on life cycle management of coastal concrete structures, Hangzhou, China

Chatterji, S. (1978). "An Accelerated Method for the Detection of Alkali-Aggregate Reactivities of Aggregate" Cement and Concrete Research, Vol.8, No.5

Coastal Development Institute of Technology (CDIT). (2007). *Maintenance Manual for Harbour Facilities,* Library of Coastal Technology No.26 (in Japanese)

Habuchi, T., Miyasaka, N., Tsuji, H. and Torii, K. (2004) "Evaluation of Combined Deterioration of Concrete Structures in Marine Environment due to Alkali-silica Reaction and Seawater Attack" Proceedings of the Fourth International Conference on Concrete Under Severe Conditions, vol.2

Okudaira, Y., Kawada, H., Hagino. A., Matsumuro, Y. and Habuchi, T. (2002) "Repair Work for Concrete Superstructure of Pier Carried out on the Large-scale Container Terminal Redevelopment Project" Proceedings of the first fib Congress 2002, Vol.4

The Society of Materials Science, Japan (JSMS) et al. (2007). "Guideline for Application of Electrochemical Corrosion Control Method with the care to ASR" Textbook for the seminar on application of Electrochemical Corrosion Control Method with the care to ASR (in Japanese)