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Sixty-Year Old Concrete in a Marine Environment

Shinobu OZAKI and Noriyuki SUGATA

Abstract

The deterioration of concrete structures due to age, particularly in marine environments, has recently become a subject of great concern. In this study, the properties of 60-year old concrete in a marine environment are examined, taking the opportunity of the demolition of the northern breakwater of Muroran Port in 1984 to obtain samples. As a result of the study it was found that the concrete, which was made from blast furnace slag and volcanic ash and appeared to contain sea sand, had scarcely deteriorated at all, even though it had been exposed to sea water environment for 60 years.

1. Introduction

Because of the increasing number of aging concrete structures, the deterioration of concrete due to age is becoming increasingly important. Many studies have been conducted into this problem, among them being case studies performed on aging, obsolete concrete structures. These studies provide important data on the long term durability of concrete.

In this study, the opportunity of the 1984 demolition of the northern breakwater of Muroran Port, constructed about 60 years ago, was taken to perform tests for mix proportion estimation, salt content and neutralization, on aging marine concrete. The concrete strength was also measured, and the corrosion status of the reinforcing bars examined.

2. Northern Breakwater of Muroran Port

According to the first-term colonization plan for the exploitation of Hokkaido (1), work on the northern breakwater of Muroran Port commenced in 1918. The hydrographic conditions at Muroran Port are relatively mild; the average wave height is approximately 30 cm, and the probability of the wave height exceeding 1.6 m, approximately 1%.

The breakwater is composed mainly of reinforced concrete caissons, with a reinforcement ratio of about 0.33%. As shown in Figure 1, the caisson height was 7.9 m, and the top was installed at a level of 0.3 m above the datum plane. The concrete caissons were filled with concrete and a 1.3 to 2.7 m thick upper layer was cast on top of caissons. Cocncrete protection blocks, each with a

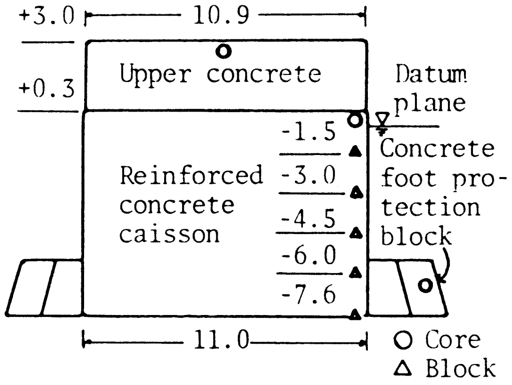

Fig. 1. Breakwater and sampling of concrete

Table 1 Mix proportions

Location		Cement	Volcanic ash	Sand	Gravel & crushed s.
Caisson cast in	summer	0.8	0.2	2.5	5.0
	winter	1.0	0.1	2.2	5.0
Fill concrete		1.0	1.0	10.0	20.0
		1.0	-	8.0	16.0
Concrete block		1.0	1.0	5.0	10.0

Table 2 Concrete properties

Location	Compressive strength (kg/cm^2)	Unit weight (kg/m^3)	Elastic modulus ($10^5 kg/cm^2$)
R.C. caisson	347	2372	2.69
Concrete block	181	2236	1.58
Upper concrete	254	2269	2.27

weight of 27 tons, were installed on the same level as the foot of each caisson.

3. Concrete Samples

Six cores and 5 crushed block samples were taken from the reinforced concrete caissons, 7 cores and 1 crushed block from the upper concrete, 15 cores from the foot protection blocks, and one crushed block from the fill concrete. The crushed block samples from the caissons were taken at −1.5m −3.0m, −4.5m, −6.0m, and −7.5m from the datum plane as shown in Figure 1.

4. Mix Proportions and Concrete Constituents

According to the construction records (1), the mix proportions of the concrete were as shown in Table 1. The cement used was blast furnace slag cement manufactured by the Wanishi Iron Mill of the Japan Steel Works Ltd., and was known to have a specific gravity of 2.85 (bulk density: 1023 kg/m^3). The cement appeared to have been made from granulated blast furnace slag, of which the main components seemed to have been approximately 50% lime and 29% silica, each with a 1% insoluble residue and ignition loss, mixed with 15 to 30% Portland cement, and proper calcium hydroxide.

Volcanic ash from the Toya area seemed to have been used in the mixing of the concrete, which was performed under the directions of Dr. Hiroi, who introduced the use of volcanic ash at Otaru Port in 1902. Sea sand from Kogane beach in Date appeared to have been used as the fine aggregate, while gravel and crushed stone from Masuichi beach were used as the coarse aggregates.

5. Compressive Strength and Mix Proportion Estimation

Compressive strength tests were performed on 3 cores from the caissons, 5 from the upper concrete, and 8 from the foot protection blocks. Table 2 shows the average compressive strength, unit weight and elastic modulus for each group of samples. The compressive strengths of the samples from the caisson and the upper concrete were relatively high. However, according to the results of the mix proportion estimation tests, by means of chemical analysis based on the reports of the Committee on Concrete of the Cement Association of Japan, the concrete mixture was considerably lean. Table 3 shows the estimated mix proportions. The water/cement ratios were dubiously high in comparison to the values recorded at Otaru Port (2).

Considering that the recorded tensile strengths of mortar briquette specimens made during the construction of the caissons was approximately 8 kg/cm^2 at the age of 1 to 2 weeks, the concrete seems to have retained its strength even after 60 years of exposure to a marine environment.

Table 3 Estimated mix proportions

Location	Estimated unit content (kg/m^3)			Water cement ratio (%)
	Water	Cement	Aggregate & volcanic ash	
R.C. Caisson	136	186	2032	73
Concrete block	146	155	2035	94
Upper concrete	164	177	1960	92

Table 4 Porosity of mortar in concrete, measured by mercury porosimeter (cc/g)

Location		Range of pore size(μm)		Total porocity
		0.003-10	10-100	
-1.5m under datum plane	Surface portion	0.065	0.005	0.071
	8cm from surface	0.064	0.010	0.075
-6.0m under datum plane	Surface portion	0.064	0.006	0.069
	8cm from surface	0.052	0.006	0.059
Ordinary concrete		0.049	0.010	0.059

6. Porosity

Table 4 shows the results of porosity measurements performed on the concrete mortar using a mercury porosimeter. The sea water depth appears to make little difference, however, the porosity of the internal concrete in the lower part of the caisson was quite low, being approximately the same as that of ordinary concrete. Figure 2 shows the pore size distribution in the concrete mortar. The pore sizes were generally smaller than those of ordinary concrete, although the total porosity was the same. This is thought to be due to the use of volcanic ash, which improves the water tightness by a pozzolan reaction.

In addition, the water absorption coefficients, measured in accordance with the test for the absorbed moisture contents of aggregates, were quite high as shown in Table 5. From this table it can also be seen that the coefficient for the surface portion of the foot protection blocks is unexpectedly low.

7. Corrosion of Reinforcing Bars

Samples of reinforcing bars were taken at sea level and at −6.0m from the datum plane, and their corrosion statuses tested in compliance with the JCI standard. After the corroded portions and corrosive developments on the reinforcing bars had been noted and their weights recorded, the bars were immersed in a 10% ammonium citrate solution to remove the corrosion products. Table 6 shows the results. It can be seen from these values that the corrosion of the bars was minimal.

8. Chloride Content

Tests for determining the chloride content of the concrete were performed in accordance with the test method for the chloride content of sea sand, issued by the

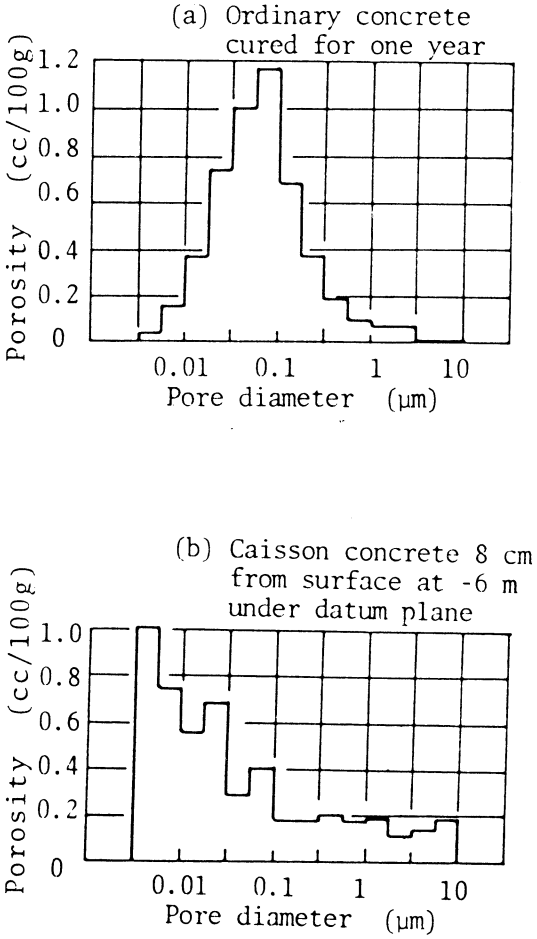

Fig. 2. Pore size distribution of mortar in caisson concrete compared with ordinary concrete

Table 5 Water absorption coefficients

Location	Surface (%)	Interior (%)
R.C. caisson	7.3	8.7
Concrete block	6.9	7.9
Upper concrete	7.9	7.1

Table 6 Corrosion of ϕ 19 mm reinforcing bars in caisson concrete

Location	Concrete cover (mm)	Weight loss (%)	Corroded thickness (mm)	Corroded area (%)
Near sea water level	175	0.66	0.33	11.7
-6 m under datum plane	75	1.11	0.05	18.0

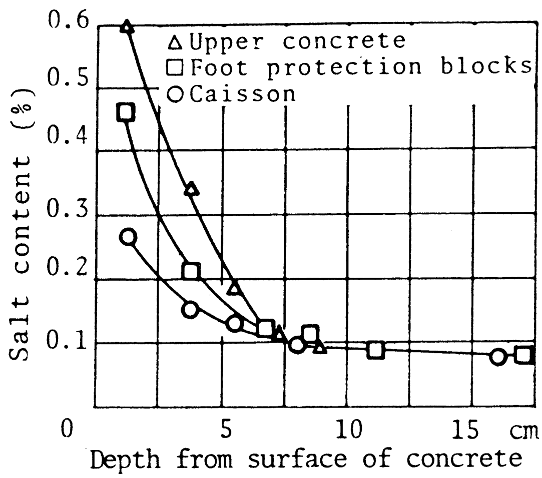

Fig. 3. Salt content in the concrete cores of breakwater

Japan Society of Civil Engineers and the Japan Road Association. The chloride content in the concrete was expressed as a salt content by converting it to NaCl.

Figure 3 shows the salt content of each sample. The salt content near the surface of the upper concrete was highest, at approximately 0.6%, which corresponds to the fact that salt intrusion is generally highest in the splash zone.

The salt content near the surfaces of the foot protection blocks was also high, being similar to that of the upper concrete. However, this is to be expected because of the leanness of the concrete mix. At a depth of approximately 8 cm from the surface, however, the salt content fell to 0.1%, suggesting that the volcanic ash used in the mixing, which was responsible for the low water absorption coefficient, had resulted in a great improvement in watertightness.

The concrete of the caisson itself yielded the lowest salt content. As the cover for the reinforcing bars was very thick, at 175 mm, corrosion of the bars was minimal, the salt content at this depth being 0.1% and the chloride content 1.4 kg/m^3 of concrete.

The salt contents at various depths below sea level were then examined using the crushed block samples from the caisson. Figure 4 shows the results. Although the surface salt content was approximately the same for all depths, the internal salt content appeared to be affected by the sea water pressure, yielding a value of about 0.2%, as opposed to the value of 0.1% shown in Figure 3.

Although it is known that sea sand was used in the mixing of this concrete, its contribution to the salt content is assumed as being 0.09 %, hence the effect due to the infiltration of sea water appears to be approximately 0.1 %.

Additionally, samples of reinforcing bars with 75 mm cover were taken at −6.0m from the datum plane, however, these showed little sign of corrosion despite the 0.2% salt content.

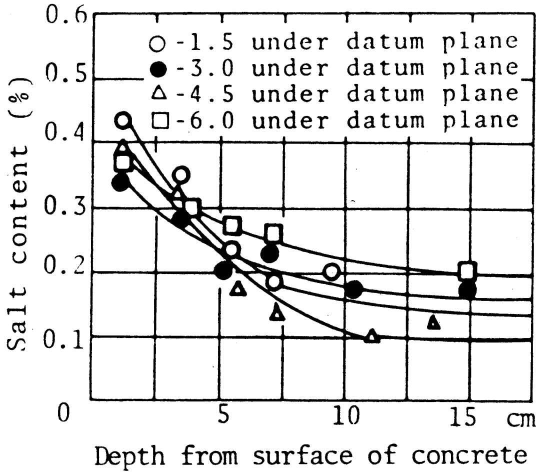

Fig. 4. Salt content in the crushed blocks of concrete from the caisson

9. Degree of Neutralization

Tables 7 and 8 shows the average depths of neutralization measured by a phenolphtalein solution. The average depth of neutralization in the foot protection blocks exceeded 30 mm, while there was no evidence of neutralization in the caisson and upper concrete at all.

Therefore, the pH values in the concrete were measured. As shown in Figure 5, the pH value re-

Table 7 Neutralization depths

Location	Neutralization depth (mm)
R.C. caisson	0.0
Concrete block	30.8
Upper concrete	0.0

Table 8 Neutralization depths in caisson

Concrete of caisson		Neutralization depth (mm) Max.	Min.	Mean.
Depth under datum plane	-1.5m	7	3	4
	-3.0m	0	0	0
	-4.5m	4	2	2
	-6.0m	3	3	3

mained low for a considerable depth into the foot protection block concrete, and the neutralization inside the concrete was considerable. In the caisson and upper concrete, on the other hand, there were no signs of neutralization. This lack of neutralization leads to the conclusion that the depth of the sea water has little influence on neutralization, however, was observed that neutralization had actually progressed a little more near sea level than in other places. This observation was supported by the results of pH measurements as shown in Figure 6.

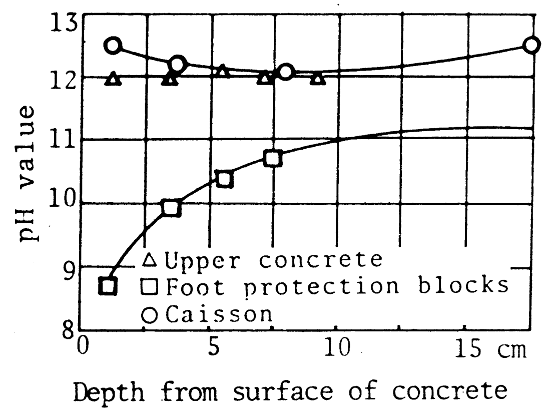

Fig. 5. The pH value in the concrete cores of breakwater

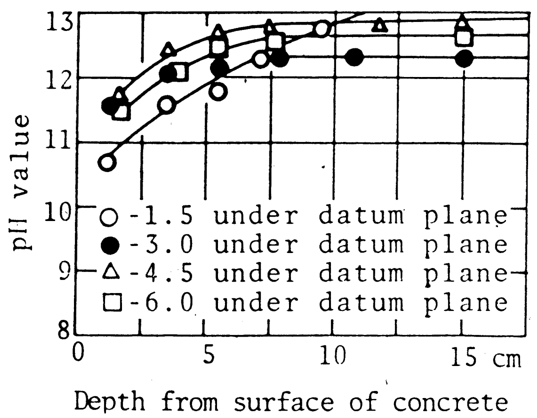

Fig. 6. The pH value in the crushed blocks of concrete from the caisson

10. Conclusions

As a result of the study performed on samples of 60-year old concrete from the northern breakwater of Muroran Port, the following conclusions were reached.

(1) The concrete of the breakwater appears to have retained its strength, considering the tensile strength of the mortar briquettes made during construction.

(2) The water/cement ratios obtained by mix estimation were dubiously high when compared to the value used at Oraru Port (2).

(3) Neutralization of the concrete had scarcely occurred except in the lean-mixed foot protection blocks. The results of porosity measurements indicate that the volcanic ash used during the mixed improved the watertightness of the concrete by pozzolanic reaction, and seems to be useful in controlling the deterioration of concrete.

(4) The salt content near the surface of the concrete was very high. However, it reduced to a constant value of about 0.1% at a depth of approximately 8 cm. Even at the base of the caisson, which was subject to the pressure of sea water, the salt content decreased to a constant level of approximately 0.2%.

(5) Although sea sand was used in the mixing of the concrete, there was no evidence of severe corrosion of the reinforcing bars. In concrete with adequate cover and no cracks, large scal corrosion does not seem to occur.

In summation, it can be stated that even after 60 years of exposure to a marine environment the northern breakwater of Muroran Port had maintained its structural soundness.

11. Acknowledgments

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