THE DISTRIBUTION OF CHLORIDE IONS IN THE CONCRETE BRIDGES LOCATED NEAR THE COASTLINE IN JAPAN

DIFFUSION DES IONS CHLORE DANS LES PONTS EN BETON SITUES A PROXIMITE DE LA CÔTE DU JAPON

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ABSTRACT - In this paper, chloride ion contents in two concrete bridges are reviewed to discuss the inspection method for concrete bridges in coastal area. In the case of Atsumigawa-bashi Bridge, 80 core samples were taken and chloride ion distribution in each core was measured to discuss the ingress of chloride ions in different sections. In the case of Koyataro-bashi Bridge, chloride ion distributions at different time were compared to discuss the long term behaviour of ingress of chloride ions. As a result, it is confirmed that small difference in the inspected location can widely affect the appraisal of structures. Data also show the residual time before re-bars start to corrode will be controlled by the diffusion coefficient of chloride ions more than the chloride ion content on the concrete surface.

***RÉSUMÉ* -** Dans cet article on passe en revue les concentrations en chlorures mesurées sur deux ponts en béton, afin de mettre au point la méthode d' inspection des ponts en béton dans la zone côtière. Dans le cas du pont Atsumigawa-bashi, 80 carottes ont été prélevées et la concentration en chlorures a été mesurée pour chaque carotte pour analyser les variations de pénétration des chlorures dans les différentes zones de l' ouvrage. Dans le cas du pont Koyataro-bashi, la concentration en chlorures a été suivie à différentes échéances pour analyser la pénétration à long terme des chlorures. Sur la base de ces résultats on confirme qu' une petite variation concernant la zone inspectée peut avoir une grande influence sur l' évaluation structurale. Les données montrent aussi que la durée qui reste avant que les armatures ne commencent à se corroder est davantage contrôlée par le coefficient de diffusion des ions chlore que par la teneur en chlorures à la surface du béton.

1. Introduction

In Japan, many highway bridges are located near the coastline and corrosion induced by chloride ions is one of the biggest problems in the maintenance of existing concrete bridges. To reduce maintenance costs, it is important to do regular inspections and carry out countermeasures before bridges are heavily deteriorated due corrosion. Recently, in addition to the visual observation, measurement of chloride ion content in hardened concrete has been introduced for highway road bridges in Japan where bridges are located near coastline. However, in the actual bridges, chloride ion content can vary widely and it makes difficult to utilize the measured chloride ion contents for effective maintenance.

In this paper, chloride ion contents in existing two concrete bridges are reviewed to discuss the inspection method for concrete bridge under severe environment.

2. Case study in Atsumigawa-bashi Bridge

2.1. Outline of the bridge

In this study, concrete girders for pedestrian use in Atsumigawa-bashi Bridge are investigated. These girders, prestressed concrete by the post tensioning system, had been located on the coastline of the Sea of Japan for 16 years. Though these girders had been in sound condition, they were removed when the most part of bridge, adjacent girders for carriageway, was needed to be replaced.

The plan of Atsumigawa-bashi Bridge is shown in Figure 1. Compressive strength of concrete is 73N/mm^2 in average and carbonation depth of concrete is considerably small in all cores, 1mm in average.

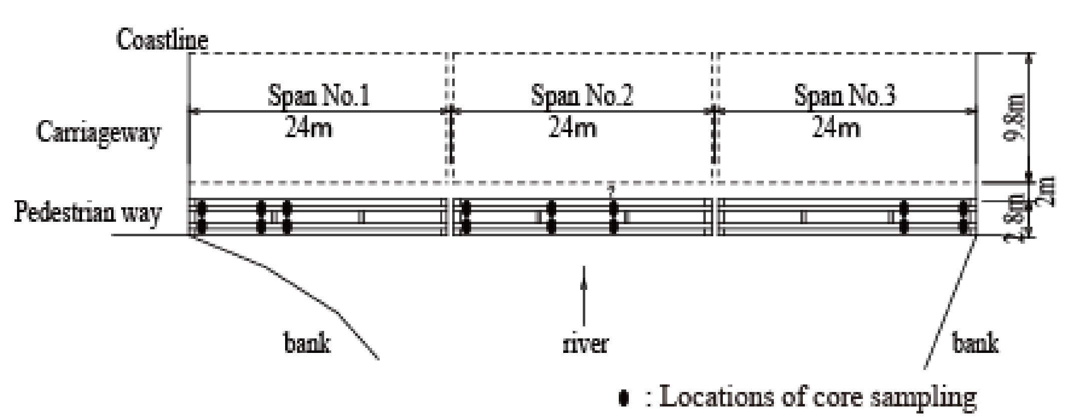

Figure 1. Plan of Atsumigawa-bashi Bridge

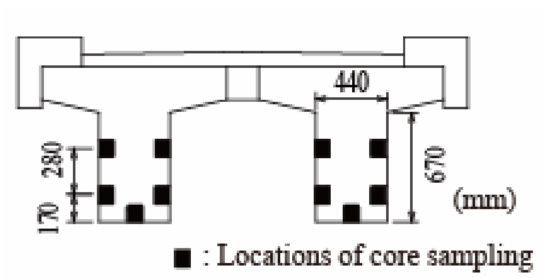

Figure 2. Section of Atsumigawa-bashi Bridge

2.2. Investigation method

Eighty cores were taken form the bridge (Figure 1 and Figure 2), to examine the difference of the ingress of chloride ions in different sections of the bridge. Cores are 100mm in diameter. Total chloride ion contents were measured at 5 different distances from the surface, 0-10mm, 10-20mm, 20-30mm, 30-40mm and 70-80mm. Measurement were done by JIS A 1154.

From five data in a core, chloride ion content at concrete surface, diffusion coefficient of chloride ions in concrete and remaining time before re-bars start to corrode are estimated by Fick's second law of pure diffusion (Equation 1).

$$C(x,t) = C_i + C_o\left(1 - erf\left(\frac{0.1 \cdot x}{2\sqrt{D \cdot t}}\right)\right) \tag{1}$$

where,

C(x,t) : chloride ion content at certain depth (x) and time (t)
C_i: chloride ion content introduced as materials of concrete
C_o: chloride ion content at concrete surface
x: distance from concrete surface
D: diffusion coefficient of chloride ions in concrete
t: time after construction

2.3. Results and discussion

2.3.1. Chloride ion content at concrete surface

Chloride ion contents at concrete surface are shown in Figure 3. They scatter widely and the maximum value in this bridge is approximately five times bigger than the minimum (Table I).

Comparing the data of three spans in the bridge, the average chloride ion content at concrete surface is smaller in the span No.2 than in span No.1 and No.3.

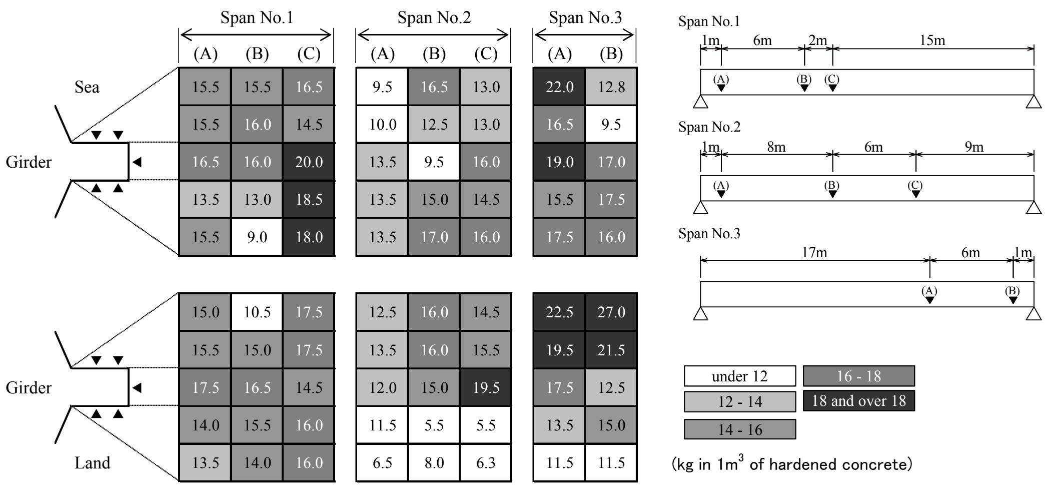

Figure 3. Chloride ion content at concrete surface

Table I. Average and standard deviation of chloride ion contents at concrete surface

measured area	average (kg/m^3)	maximum (kg/m^3)	minimum (kg/m^3)	standard deviation (kg/m^3)
Span No.1	15.4	20.0	9.0	2.2
Span No.2	12.7	19.5	5.5	3.6
Span No.3	16.8	27.0	9.5	4.4
total	14.7	27.0	5.5	3.7

Comparing the data in each section, in the span No.2 and No.3, chloride ion content at concrete surface is smaller in the webs facing to the outside of the bridge than the other surfaces. On the other hand, in the span No.1, chloride ion content at concrete surface is almost same in each surface. The reason of this difference between the span No.1 and the other spans is not clear, but the presence of bank protection is pointed out as one of the possible reasons. Because of the adjacent bank protection, it is estimated that wind from the sea can not flaw smoothly below the span No.1.

2.3.2. Diffusion coefficient of chloride ions in concrete

Diffusion coefficients of chloride ions are shown in Figure 4. In the design stage, diffusion coefficients of chloride ions are estimated with W/C ratio of the concrete and the type of cement (Japan Society of Civil Engineers, 2002). It is, therefore, a parameter given as a material property. However, in the case of Atsumigawa-bashi Bridge, they scatter widely and the maximum value in the bridge is approximately eight times bigger than the minimum (Table II).

Comparing the data of three spans in this bridge, the average diffusion coefficient of chloride ions is bigger in the span No.2 than in span No.1 and No.3.

Comparing the data in each section, in the span No.2 and No.3, diffusion coefficients of chloride ions are smaller in the web facing to the land. There is no relationship between the diffusion coefficient of chloride ions and the chloride ion contents at concrete surface (Figure 5).

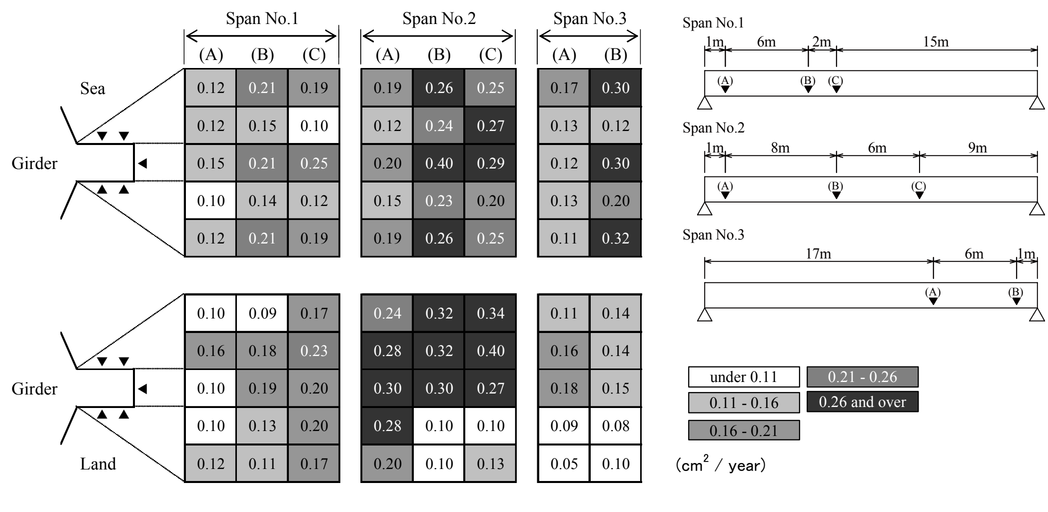

Figure 4. Diffusion coefficient of chloride ions

Table II. Average and standard deviation of diffusion coefficient of chloride ions

measured area	average (cm^2/year)	max. (cm^2/year)	min. (cm^2/year)	standard deviation (cm^2/year)
Span No.1	0.15	0.25	0.09	0.05
Span No.2	0.24	0.40	0.10	0.08
Span No.3	0.16	0.32	0.05	0.07
total	0.19	0.40	0.05	0.08

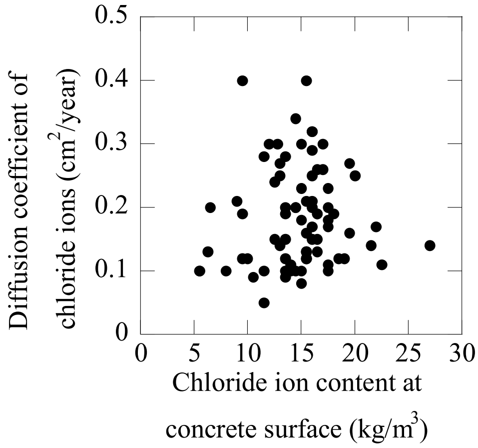

Figure 5. Relationship between the diffusion coefficient of chloride ions and the chloride ion content at concrete surface

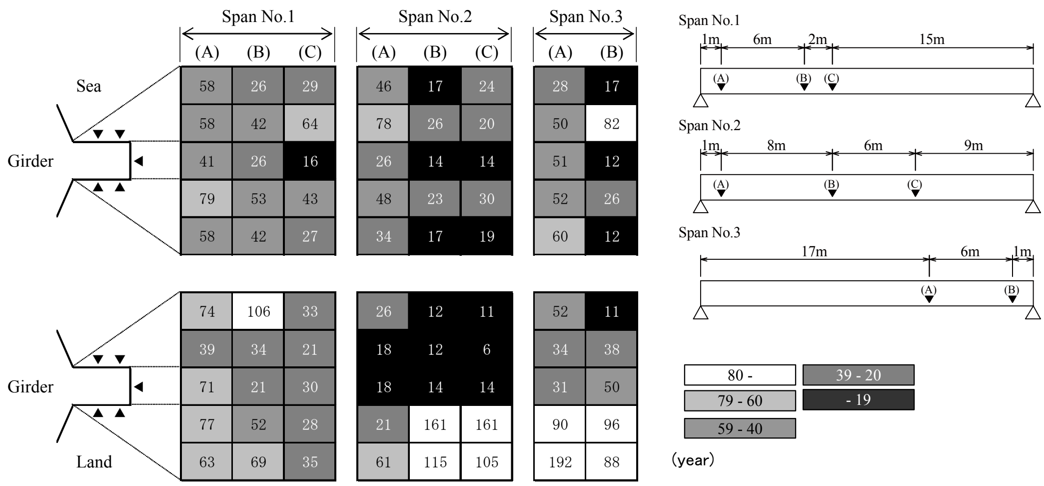

Figure 6. Residual time before re-bars start to corrode

2.3.3. Prediction of chloride ion distribution in future

In the case of Atsumigawa-bashi Bridge, the thickness of cover concrete was approximately 70mm and chloride ion had not reached the surface of re-bars in concrete. However, to assess the long-term performance of Atsumigawa-bashi Bridge, residual time before re-bars start to corrode, i.e. chloride ion content at the surface of re-bars will increase over 1.2kg/m^3, was calculated in each location. The results are shown in Figure 6.

Estimated residual time before re-bars start to corrode scatters very widely.

Especially, there are significant differences in span No.2 and No.3. It implies that the small difference in sampling can affect the appraisal of structures significantly.

Comparing Figure 6 with Figure 4 and Figure 5, residual time before re-bars start to corrosion appears to be controlled by diffusion coefficient of chloride ions more than by the chloride ion content at concrete surface. It implies the testing method targeting to the supply of chloride ions, e.g. measurement of the amount of chloride ions on the surface of structures, can not tell where the corrosion takes place first, in the case of Atsumigawa-bashi Bridge.

3. Case study in Koyataro-bashi Bridge

3.1. Outline of the bridge

In this study, one of the piers of Koyataro-bashi Bridge is investigated. The pier had been located on the coastline of the Pacific Ocean since 1975 to 2006. Though superstructure of the bridge had been severely deteriorated due to corrosion, there was no significant defect at the investigated area because of the thick cover concrete.

Average compressive strengths of three cores were 31N/mm^2 in the survey in 1996 and 25 N/mm^2 in 2006. The reason of this difference is not clear. Maximum carbonation depth in the investigated area was 22mm in 2006.

3.2. Investigation method

From the record of the bridge, chloride ion contents in three cores are obtained. These data were probably collected in 1996. In 2006, seven cores were taken form the bridge. Location of these sampling is shown in Figure 7. Total chloride ions in cores were measured in accordance with JIS A 1154 or similar methods.

From the data, chloride ion content at concrete surface and diffusion coefficient of chloride ions in concrete were calculated. In the calculation, data of carbonated area were neglected because the distributions of chloride ions are affected by carbonation.

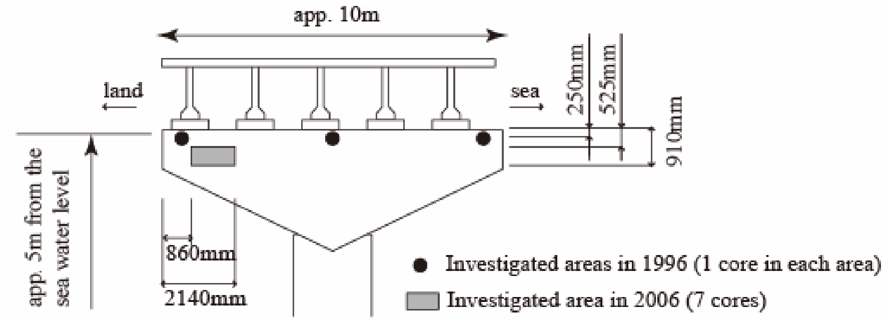

Figure 7. Locations of core sampling in Koyataro -bashi Bridge

3.3. Results and discussion

Measured chloride ion contents are shown in Figure 8. Chloride ion content in each core varies significantly also in Koyataro-bashi Bridge.

To compare the chloride ion distributions in different year, chloride ion distributions in 2006 are estimated from the data of these in 1996 (Figure 9). Experimental values in 2006 are in between the estimated values with the data in 1996.

Estimated chloride ion content at concrete surface and diffusion coefficient of chloride ions in concrete are shown in Table III. The ranges of chloride ion content at concrete surface in investigated area are similar in both surveys in 1996 and 2006. The ranges of diffusion coefficients of chloride ions in investigated area are also similar in two surveys, however, they seems to be decreasing in average.

The range and the variation of chloride ion content at concrete surface in Koyataro-bashi Bridge is similar to those of Atsumigawa-bashi Bridge, though the investigated area is much smaller than that in Koyataro-bashi Bridge. Coefficient of variation is 25 percent in all investigated area in Atsumigawa-bashi Bridge and 28 percent in Koyataro-bashi Bridge in 2006.

Diffusion coefficients of chloride ions are smaller in Koyataro-bashi Bridge than Atsumigawa-bashi Bridge. However, the variation of data is similar in two bridges. Coefficient of variation is 42 percent in all investigated area in Atsumigawa-bashi Bridge and 44 percent in Koyataro-bashi Bridge in 2006.

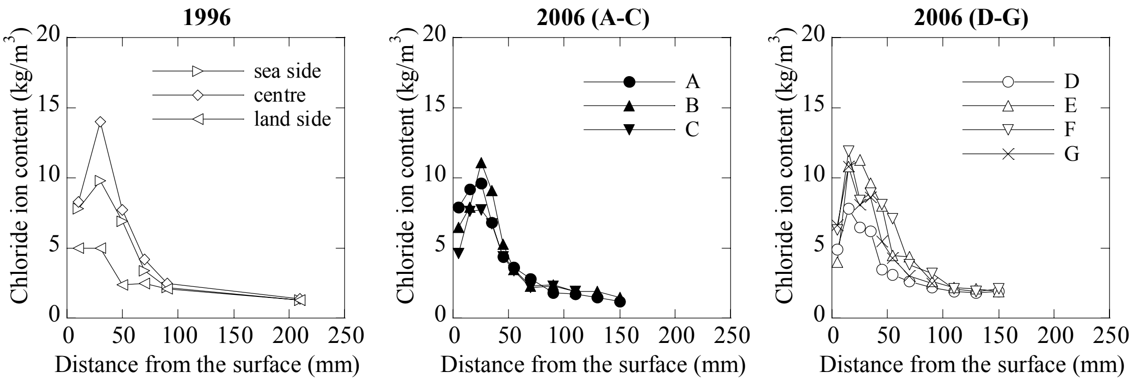

Figure 8. Distribution of chloride ions in Koyataro -bashi Bridge

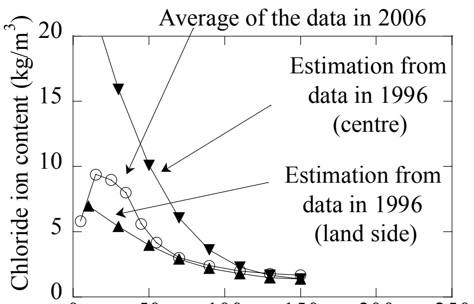

Figure 9. Comparison between the predicted chloride ion distributions and experimental one

Table III. Chloride ion content at concrete surface and diffusion coefficient of chloride ions in different time

year of severance	chloride ion content at concrete surface (kg/m^3)	diffusion coefficient of chloride ions (cm^2/year)
1996	17 in average max. 26 (centre) min. 6.7 (land side)	0.52 in average max. 0.60 (sea side) min. 0.46 (centre)
2006	15 in average max. 22 (B) min. 9.5 (D)	0.32 in average max. 0.60 (F) min. 0.18 (B)

4. Conclusions

Chloride ion distributions in two bridges were discussed in this paper. The following results were obtained.

1) Assessed long-term performance of concrete bridges can change widely by where investigation is carried out, because the ingress of chloride ions can be different significantly in a small area.

2) Values of diffusion coefficient of chloride ions, given by W/C ration and types of cement in design stage, scatters widely in actual statge. It implies that a testing method targeting to the supply of chloride ions only is not enough as an inspection method for evaluating long-term risk of chloride induced corrosion.

5. References

Japan Society of Civil Engineers (2002) Standard specifications for concrete structures-2002 Materials and Construction. *JSCE Guidelines for Concrete* ***6***, 443pages.