RILEM Week 2023
Vancouver, BC, Canada
September 4-8, 2023

PROPOSAL FOR A NEW MAINTENANCE AND DETERIORATION PREDICTION SYSTEM USING CENTER OF CORE

Takeshi Iyoda[12]

[1] Professor, Shibaura Institute of Technology, iyoda@shibaura-it.ac.jp

ABSTRACT

Reinforced concrete structures are used worldwide, but there are many deteriorated structures needing repair or renewal due to steel corrosion and concrete deterioration. To efficiently maintain and manage these structures, it is essential to establish more accurate deterioration prediction systems. In the current maintenance management, the surface of the structure is visually inspected for cracks, rust soup, delamination and peeling. If an abnormality is detected, the structure should be investigated using non-destructive test or a core should be taken to investigate the compressive strength and carbonation depth. The criterion is whether the deterioration factor has reached the rebar. In these cases, it is possible to deal with steel corrosion caused by deterioration factors penetrating from the surface layer. However, it is not possible to take into account internal defects and internal cracks caused by the materials used and construction, or concrete deterioration such as ASR and frost damage. The proposed system simultaneously assesses the condition of the internal concrete from cores taken for preventive maintenance and other purposes, using the centre of the core to (1) compare the surface and deep layers, (2) detect internal deterioration, and (3) predict deterioration based on the results of the comparison.

Keywords: Deterioration prediction, Reinforced concrete structures, Mass permeability, Centre of core samples

T. Iyoda, PhD

3-7-5, Toyosu, Koto-ku, Tokyo, Japan 135-8548

Email: iyoda@shibaura-it.ac.jp **Tel:** +81-3-5859-8356 **web:** http://www.db.shibaura-it.ac.jp/~iyoda/

1. INTRODUCTION

Reinforced concrete (RC) structures are widely used throughout the world. However, many of RC structures have deteriorated due to long-term use. In Japan, these structures constructed during the period of high economic growth in the 1960s are deteriorating, and maintenance, repair, and reinforcement are becoming indispensable. Deterioration of reinforced concrete structures can be broadly classified into steel corrosion and concrete deterioration. Steel corrosion is known to progress due to the penetration of deterioration factors from the outside, such as carbonation and salt damage, which cause the deterioration factors to reach the location of the steel bars. On the other hand, concrete deterioration, such as frost damage and ASR, causes cracks not only in the surface concrete but also in the interior concrete, resulting in a loss of structural capacity. In order to confirm the progress of such deterioration, in addition to visual inspection from the surface layer, compressive strength and carbonation depth have been measured by core sampling. However, internal deterioration is difficult to determine in general, and is especially difficult to detect by non-destructive inspection. In addition, defects in the materials used or in the construction process, and initial defects such as internal cracks in the early ages are difficult to detect by inspection, and if these defects are present in the coverings, it can be imagined that the resistance of mass penetration will decrease.

In past maintenance management, future maintenance plans have been calculated by visual inspection at the surface layer and by measuring the penetration of deterioration factors from the surface layer. However, when considering internal deterioration and internal defects as described above, we considered that it would be difficult to calculate a maintenance management plan based only on information from the surface layer. Therefore, in this study, a new system was devised to examine the diagnosis and prediction of deterioration by using the depth of cores taken from actual structures to estimate the internal defects, soundness, and penetration rate of deterioration factors.

2. COMPREHENSIVE DETERIORATION DIAGNOSIS SYSTEM USING STRUCTURAL CORES

Cores from structures were used to construct a new comprehensive deterioration diagnosis system. Considering that cores cloud be utilized to depths more than the affected surface layer, it was decided to combine (1) vacuum water absorption tests, (2) carbonation progression from the surface layer, and (3) accelerated carbonation tests at the internal core.

Figure1. shows the procedure of the proposed diagnostic system using core samples. First, a core is taken from the structure to determine whether it is a cover or structural part. Then, (a) phenolphthalein solution is sprayed on the side of the core to determine the depth of carbonation to some extent. Then, (b) a vacuum water absorption test using the entire core is performed. (c) The specimen is cut in two, about 10-20 mm deeper than the carbonated zone from the surface layer. In the surface layer, (d) phenolphthalein solution is sprayed on the cracked surface to measure the depth of carbonation under realistic conditions. On the other hand, using internal cores in the un-carbonated zone, (e) accelerated carbonation tests will be conducted to calculate the carbonation rate coefficients at four ages. Details of each test are given below.

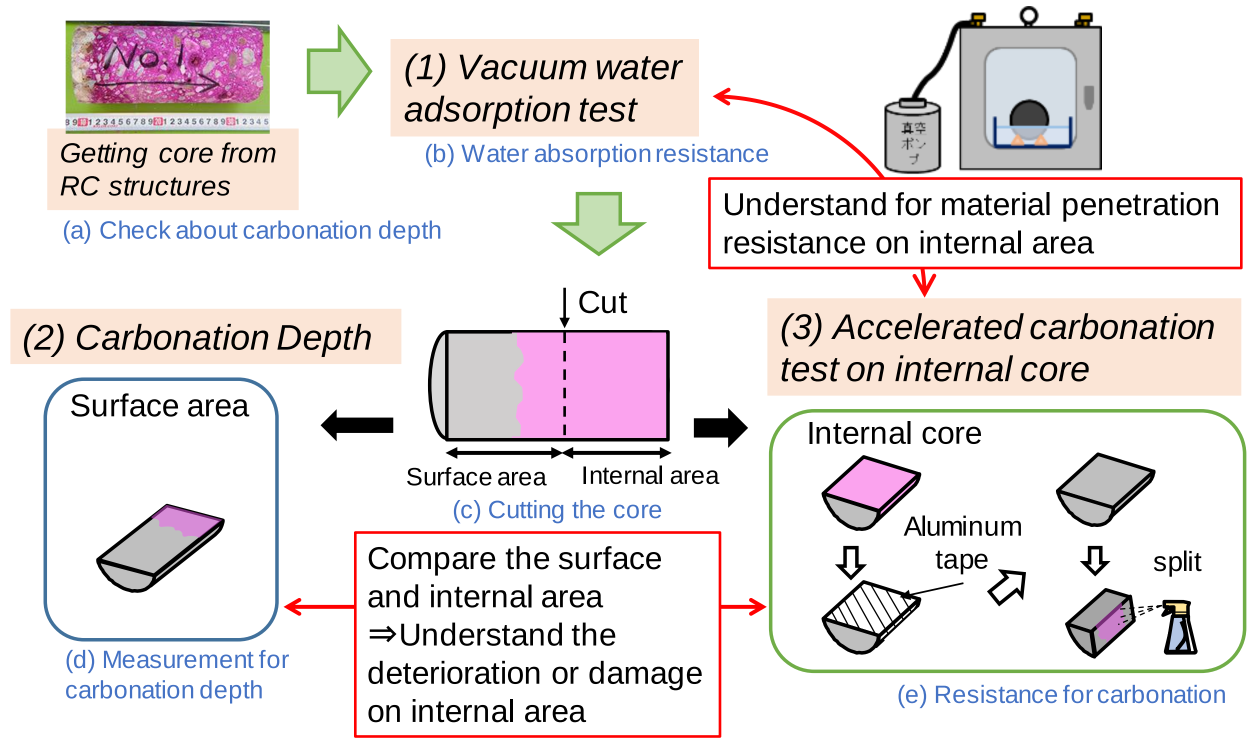

Figure 1. System for a new maintenance method using core samples

2.1. Vacuum Water Absorption Test

The vacuum water absorption test is a test method proposed by the author's research group to simply evaluate the resistance of concrete to continuous mass movement in the depth direction. The specimens (in this case, core specimens) are dried at 40 degrees Celsius for 5 days to ensure a constant water content in samples, and then sealed with 5 cm wide aluminium tape on both ends and part of the sides of the specimen cylinder. A container was filled with water so that the cylindrical specimen was immersed 26 mm, placed in a desiccator, and vacuumed (-0.1 MPa) for 1 hour with a vacuum pump (see Figure1.). The specimen was then split, and the height of water suctioned up was measured in the longitudinal direction of the penetration surface. The higher the suctioned-up height, the easier it was for water to move, and its continuity in the depth direction was used to evaluate the resistance to mass movement in the depth direction.

2.2. Accelerated Carbonation Tests Using Internal Core

An accelerated carbonation test is performed using split core-depth specimens. Two specimens are sealed with aluminium tape to release one side. The specimens are then placed at 20 degrees Celsius, 60% relative humidity, and 5% CO_2 concentration, and split at 7, 14, 28, and 56 days of age, and the carbonation depth is measured using phenolphthalein solution. Then, carbonation rate coefficients are calculated to determine the penetration of carbon dioxide gas from the outside.

2.3. Methods of Evaluating the Test Results

Through the above tests, the following shall be determined.

The determination of the resistance to mass movement in the cover and structure sections can be done using two methods. One is using (b) Vacuum water absorption test result, to determine the effects of curing during construction, partial defects, coarsening of voids, etc. Second is combining (b) Vacuum water absorption test and (e) Accelerated neutralization test results. This is possible to quantitatively evaluate the ease of penetration of liquids and gases in the interior concrete.

On the other hand, for identification of the differences between surface and interior concrete, using (d) Actual environmental neutralization depth and (e) Accelerated neutralization test results. This is possible to determine the difference in mass transport between the surface and interior concrete layers and its effect on the progress of neutralization in the actual environment.

3. APPLICATION EXAMPLES AND EFFECTIVENESS

3.1. Investigation of structures subject to frost damage

3.1.1. Introduction of the structure

The structure is a 68-year-old sluice gate in a cold region in northern Japan. The following three types of members were subjected to the survey. (1) the side walls of the box, (2) the gate columns with snow cover, and (3) the gate columns without snow cover, as shown in Figure 2. In addition, the visual inspection showed no significant external damages.

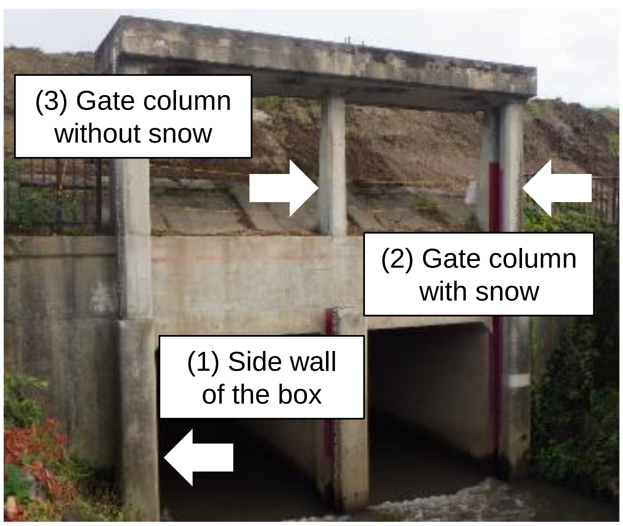

Figure 2. Case1 Investigation of Concrete structure

3.1.2. Details of the investigation using cores

(1) Vacuum water absorption test

Figure 3 show the results of the vacuum water absorption test conducted on the core specimens extracted from each structure part. Comparing the water absorption height, the water absorption height is smallest at (1) the side walls of the box. On the other hand, it is the largest at (3) the gate columns without snow. The comparison between the surface and interior layers shows that the water absorption height is larger in the surface layer, but the water absorption height is also larger in the internal layer in (3) the gate columns without snow.

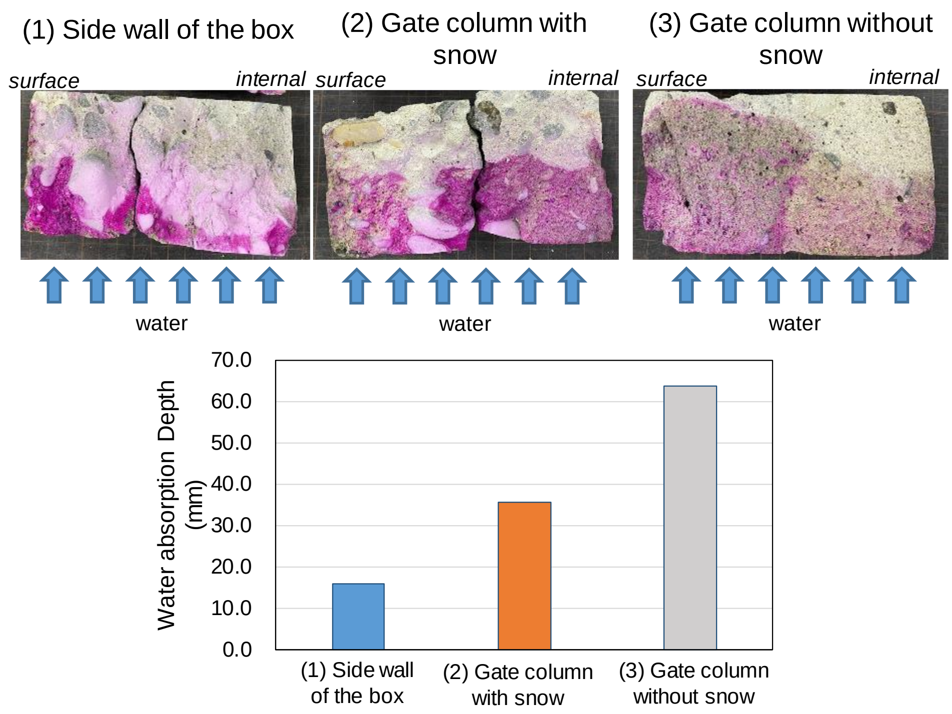

Figure 3. Results of the vacuum water absorption test

(2) Carbonation depth in actual environment

Figure 4 shows a comparison of the depths of natural carbonation in the cores of the structure that has been in service for 68 years. (1) The side wall of the box has a remarkably small depth of carbonation. This can be attributed to the fact that the sidewalls of the box had a constant flow of water, which provided sufficient moisture, and that the accumulation of mad on the surface layer suppressed the progression of carbonation. On the other hand, significant carbonation depths were detected in (3) the gate columns without snow accumulation. This value was significantly larger than the 62-year carbonation depth of concrete made with blast furnace cement Class B, for example, as determined by the Japanese Standard Specification for Concrete (JSCE). This may be due to the lack of moisture supply during the winter season, but it is still a remarkably large value compared to the standard, and we believe that some kind of deterioration or defect must have existed internally.

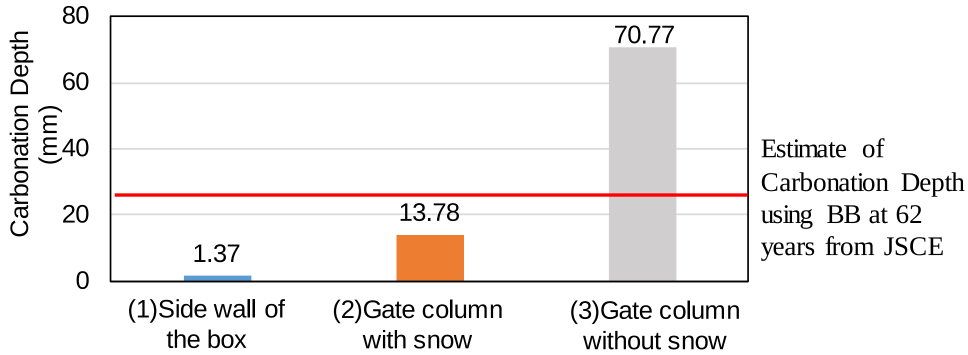

Figure 4. Result of natural carbonation depth in real structures

(3) Accelerated carbonation test using internal core

Figure 5 shows the result of accelerated carbonation test and the coefficient of carbonation rate calculated from the results of accelerated carbonation tests using internal cores for each part of the structure. The progression of carbonation was suppressed in (1) the side walls of the box, while a significant carbonation rate was observed in (3) the columns without snow accumulation. The results of the vacuum water absorption test in the Figure 3, showed a similar trend, with a significant permeation rate independent of whether the permeant was a gas or a liquid. Considering the background of the construction of this structure, it is difficult to imagine that the type of cement or water-cement ratio differs only in one location, and therefore, it can be imagined that the effect of construction or internal deterioration has occurred.

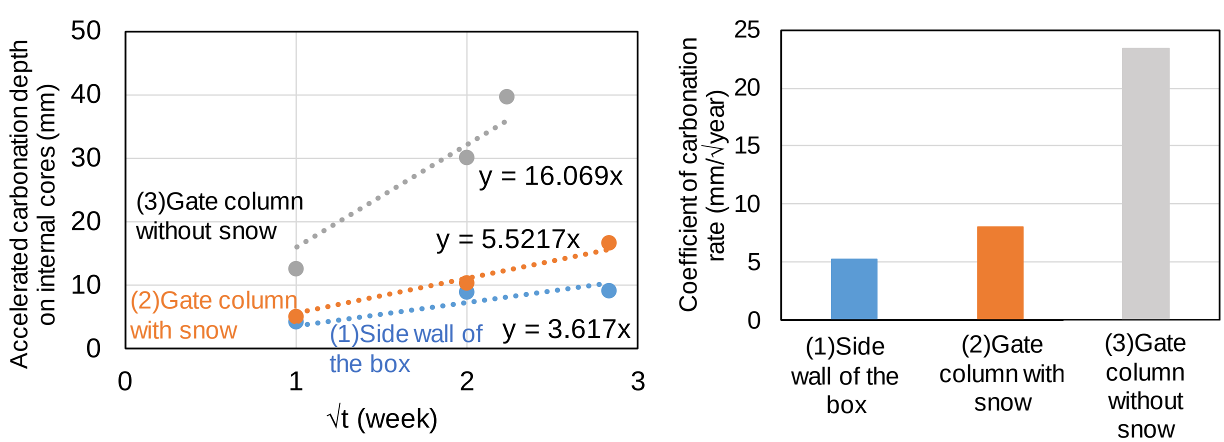

Figure 5. Result of accelerated carbonation test and calculated coefficient of carbonation rate

3.1.3. Comprehensive Deterioration Assessments

Based on the above results, the results for the internal core of the present structure suggest that the progression of carbonation was suppressed to some extent at the box and at the locations of the gate columns with snow cover, due to various external environmental influences. Specifically, it is considered that carbonation tended to be suppressed in the side walls of the box due to dust adhesion to the surface and moisture supply conditions, as well as in the columns with snow cover, due to the influence of moisture supply. On the other hand, the significant progress of carbonation was observed on the surface and inside of the columns without snow cover, which suggests that there was not much difference in the concrete quality. Then, it is likely that micro-cracking in the interior, caused by the freeze-thawing action in this cold region, accelerated the overall deterioration progression of the concrete. Thus, we believe that internal cores can be used to develop a deterioration prediction that represents the internal deterioration of the concrete.

3.2. Breakwater structures with excessive salt supply

3.2.1. Introduction of the structure

The structure are breakwaters facing the Pacific Ocean in Japan that has been in service for about 54 years. The cores were taken at the same height of 1 km pitch of the continuous breakwaters. And the visual inspections cloud not find any cracks and rusty patches due to salt damage.

3.2.2. Details of investigation using cores

(1) Comparison of Accelerated carbonation Tests in Actual Environment and Internal Core

Figure 6. shows a comparison of the coefficient of carbonation rate between natural carbonation depth and the accelerated carbonation test from the internal cores on each number. The levees were investigated over 10 km. The results show that some of the structures have similar coefficients of carbonation rate for the progression of carbonation in the actual environment and accelerated in the internal core, while others show significantly greater coefficient for accelerated conditions. Since the structures are located along the coastline and water is constantly supplied by seawater, it is conceivable that the water content in the actual environment would inhibit the progress of carbonation. However, the difference of carbonation rate coefficient from No.67 to No.75 was significantly large, the accelerated carbonation rate of the inner core is very large.

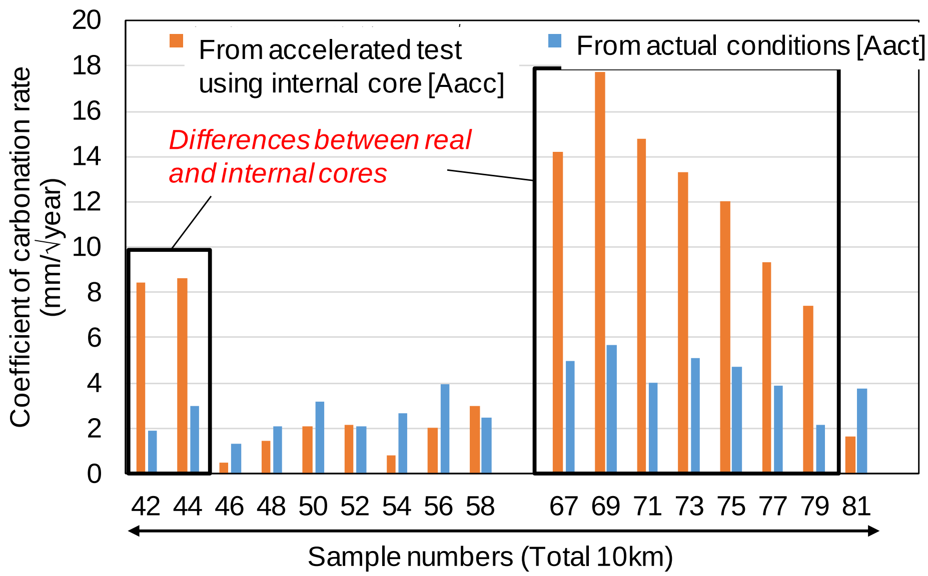

Figure 6. Result of comparing the coefficient of carbonation (Case2)

Figure7. shows a comparison between the estimated and actual carbonation depths after 54 years by converting the carbonation rate coefficients obtained from the accelerated carbonation test results. As mentioned above, the estimated carbonation depths from the surface cores are very large for the samples No.67-81. The reason for the suppression of the carbonation progression in the actual environment may be the presence of moisture in the concrete due to water exposure.

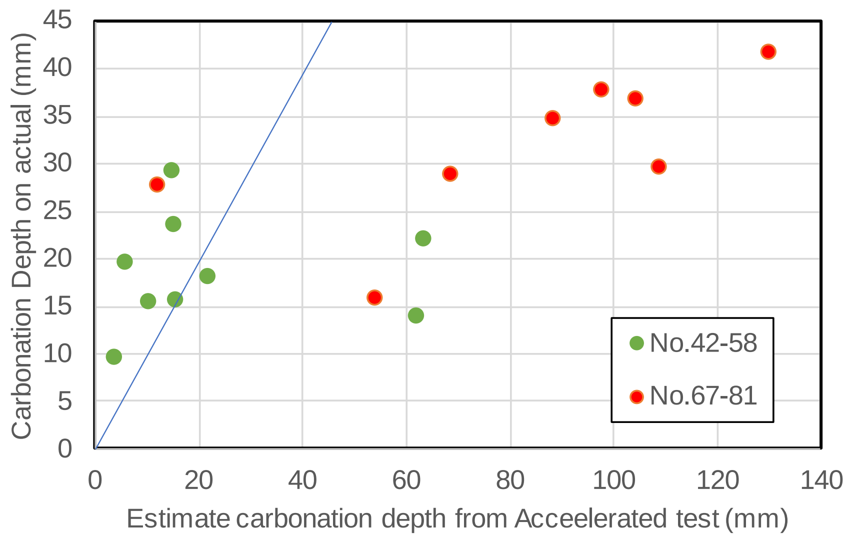

Figure 7. Relationship between estimated carbonation depth and real carbonation depth

(2) Relationship between Compressive Strength and Coefficient Carbonation Rate

Figure8. shows the relationship between the compressive strength of the cores and the actual carbonation depth in 54 years. Note that No.42-58 and No.67-81 are shown in different colors. It can be seen that the higher the compressive strength of the cores, the smaller the depth of carbonation. In addition, the strength levels are generally different by the color classification. This may be due to differences in the construction period or concrete material, depending on the construction area where the work was performed.

(3) Comparison of Chloride ion and Coefficient of Carbonation rate at Internal Area

Figure9. shows the relationship between the estimated amount of chloride ion at 55mm and 85mm from the surface based on the separately investigated core chloride ion profile and the actual coefficient of carbonation rate [Aact] and the internal accelerated carbonation rate coefficient [Aacc]. Neither [Aact] nor [Aacc] showed much correlation with chloride ion contents at the 55 mm position, but at the 85 mm position, the carbonation rate from the surface layer using [Aact] showed no relationship with amount of chloride ion, but using [Aacc] showed a correlation with the amount of chloride ion.

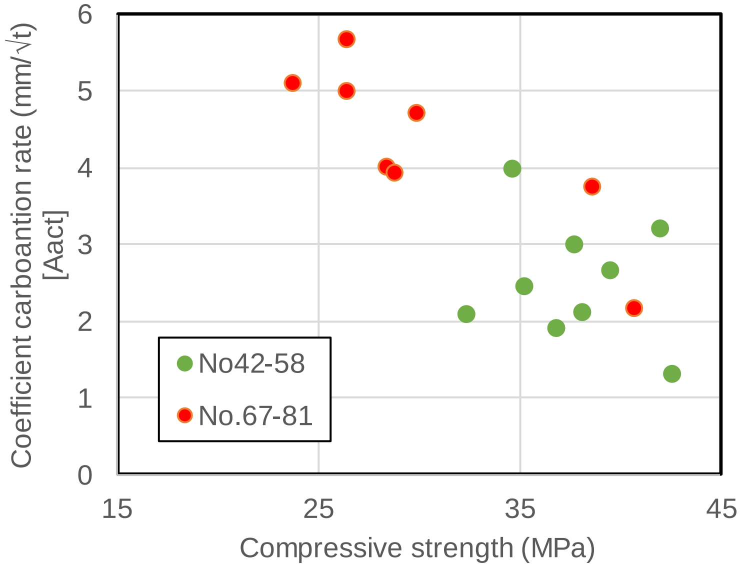

Figure 8. Relationship between compressive strength and carbonation rate

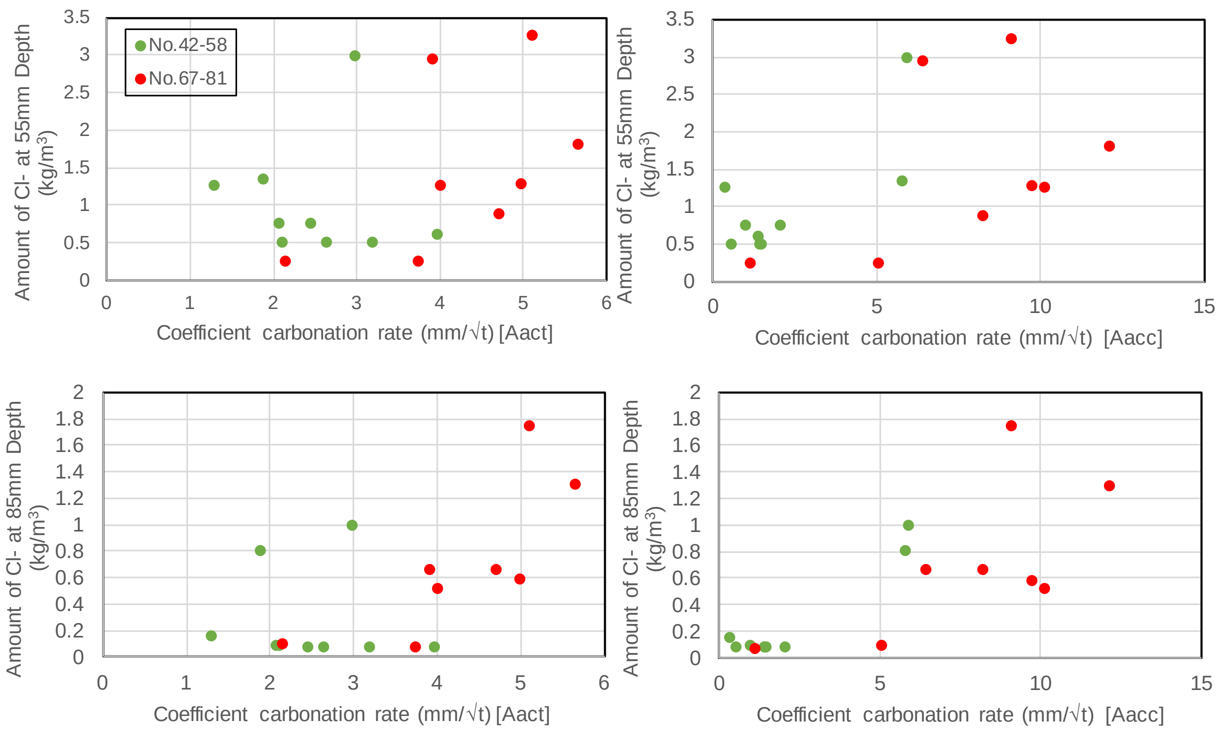

Figure 9. Relationship between carbonation rate and amount of chloride ion

3.2.3. Comprehensive Deterioration Assessments

Comprehensive deterioration diagnosis of the structure is performed considering the above results. In particular, the cores where the accelerated carbonation rate coefficient increased, differences in the ready-mixed concrete used (differences in materials and W/C) and initial defects during construction can be assumed based on the different construction zone on this structure. The chloride ion penetration results also showed high concentrations of chloride ions, suggesting that there was a high supply of chloride ions, but also that the mix proportion of concrete used and initial defects during construction may have existed.

4. TOWARD ADVANCED DETERIORATION PREDICTION

The use of internal concrete cores will allow evaluation of the potential of the structure itself for focusing the material penetration on concrete. Specifically, it is expected to reveal deterioration of the internal concrete and initial defects due to materials and construction. Furthermore, the conventional deterioration prediction curve calculated from the depth of deterioration from the surface layer does not allow us to see the situation inside the structure, there is an undeniable possibility of excessive deterioration prediction, misjudging the progress of deterioration. We believe that the application of such method to many structures will enable more advanced deterioration prediction in the future, and we will introduce it in many surveys as soon as possible to accumulate data.

ACKNOWLEDGMENTS

In conducting this research, Mrs. Shirakawa from Seibu Construction Co. and Mr. Amano provided the structural cores. We also thank Mr. Miyawaki, a master's student at the Shibaura Institute of Technology, for his cooperation in conducting this research.

REFERENCES

[1] Takeshi Iyoda, A. Sugiyama & M. Miyawaki (2022). A Study on Estimation Method of Curing Influence Area for Prediction of Remaining Life on Real Concrete Structures, *The 17th East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-17)*

[2] Takeshi Iyoda, Shinichiro Matsuzaki (2010). New method for evaluation of concrete durability in different curing condition, *The 4th ACF International conference*

[3] Erika Honna, Takeshi Iyoda (2015). Effect on mechanism of carbonation in different concentration of carbon dioxide and using ground granulated blast-furnace slag, *International Conference on the Regeneration and Conservation of Concrete Structures （RCCS）*

[4] Takeshi Iyoda, Satoshi Maehara (2017). SURVEY ON ENVIRONMENTAL IMPACT OF CARBONATION PROGRESS AND REBAR CORROSION IN ACTUAL CONCRETE STRUCTURE, *The Fifteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-15)*, p1325-1332