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DAMAGE PROCESS AND PATTERN OF AN RC STRUCTURE AFFECTED BY COMBINED FROST AND SALT ACTIONS

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In this study, a RC bridge wall rail affected by frost and salt actions was investigated in order to propose a maintenance planning of a RC structure subject to the combined attacks. A studied structure had been in service for more than forty years in Hokkaido in the northern part of Japan. Experimental results of material properties brought relationship between deterioration degrees of concrete and reinforcement. A compressive strength / Young's modulus ratio was defined as the deterioration degree of concrete influenced by frost action and the deterioration degree of reinforcement was expressed by weight reduction rate. Further, the relationship was classified by degradation in appearance. On the assumption that the degradation in appearance depends on a balance between frost damage and salt damage, a developing process of the combined deterioration was observed. As a result, the deterioration degrees of concrete and reinforcement could be associated with the damage patterns. Especially, in case of the RC bridge wall rail with a loose concrete cover, the deterioration degree of concrete had a characteristic trend. Next, passage of time was considered and a time axis was added to the relationship between the deterioration degrees of concrete and reinforcement. Consequently, this relationship was proposed as assembly of damage developing process of a RC structure affected by combined frost and salt actions.

Keywords: Degradation in appearance, Deterioration degree, Compressive strength, Young's modulus, Loose concrete cover, Combined deterioration.

1 INTRODUCTION

A number of RC structures are in an environment where they are affected by multiple deterioration factors. Actually, Hokkaido has lots of RC structures damaged by frost and salt actions. Although the JSCE standard specifications for concrete structures 2013 (maintenance) indicates that a RC structure shall be maintained considering an influence of combined deterioration, they are not suitable for a structure deteriorated by multiple factors. Therefore, a maintenance method for the RC structure affected by combined deterioration influences should be built as soon as possible.

This study focused on a developing process of combined deterioration due to frost and salt actions and presented a relationship between material deterioration and degradation in appearance. A studied structure was an actual RC bridge wall rail in Hokkaido and various mechanical properties of concrete and reinforcement were examined. A tendency of combined deterioration was found from the experimental results of the materials. Also a deterioration degree including degradation in appearance was investigated and condition of the deteriorated concrete which does not meet the functional safety was found.

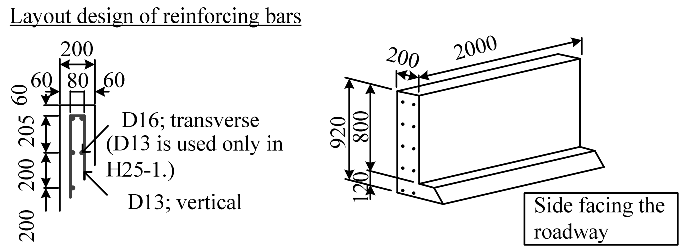

Figure 1. Configuration of a RC bridge wall rail.

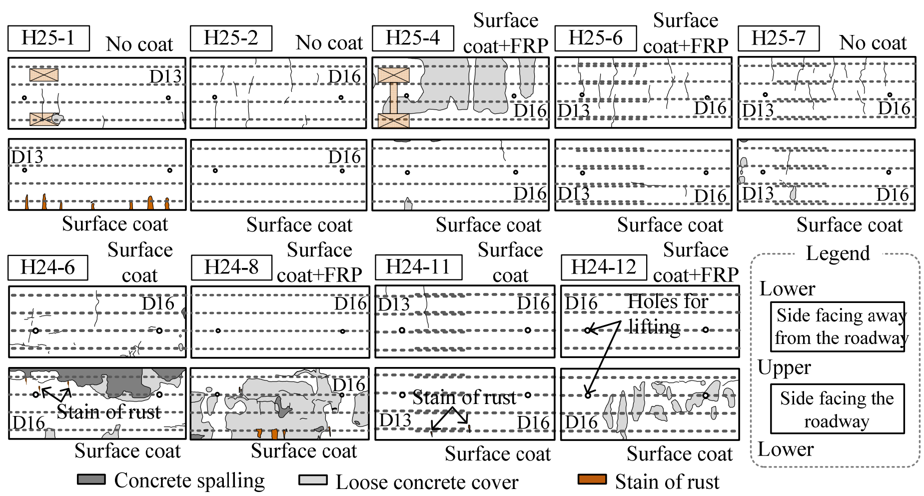

Figure 2. Results of visual observation and hammer tapping.

2 SURVEY OF ACTUAL RC BRIDGE WALL RAILS

2.1 Overview

Studied RC bridge wall rails had been in service in Hokkaido for around forty years, which they were exposed to an environment of combined frost and salt. They had been installed in a railway viaduct with the span of 412m. Also they have the vertical sides facing the roadway and facing away from the roadway.

The configuration of the RC bridge wall rail and its reinforcement arrangement are shown in Figure 1. Nine parts of RC bridge wall rails with different damage patterns were chosen in order to obtain developing process and tendency of the combined deterioration. They had latticed reinforcements at intervals of around 200mm. Vertical and transverse bars were D13 and D16, respectively. Also the vertical bars were spliced on the side facing away from the roadway. The design strength of concrete was

24N/mm^2. The surfaces of some wall rails had been repaired by resin coating and/or FRP mesh sheets as noted in Figure 1.

More than sixteen concrete cores of 50mm in diameter were extracted from each wall rail in order to inspect the mechanical properties. Concerning the transverse bars, a state of corrosion was observed after removal of concrete.

2.2 Degradation in Appearance

Figure 2 shows the results obtained by visual observation and hammer tapping. The figure also provides information about the repaired state of the surfaces, the splices and the diameters of transverse bars.

The followings were the major degradation in appearance for each wall rail: a concrete spalling in H24-6, a loose concrete cover in H24-8, H24-12 and H25-4, stain of rust in H25-1. The other four parts of the wall rails were slightly damaged.

2.3 Material Deterioration

Compressive strength, f'_c and Young's modulus, E_c of concrete were measured by compression test. Regarding reinforcement, a weight reduction rate, W_L of a transverse bar was examined. Here, W_L represents the percentage of the weight reduced due to corrosion compared to the material weight in a sound condition and is calculated by the following equation.

$$W_L = \frac{W_{cor} - W_0}{W_0} \times 100\,(\%) \tag{1}$$

W_{cor} is weight of reinforcement after removal of corrosion products and W_0 is weight of reinforcement without corrosion.

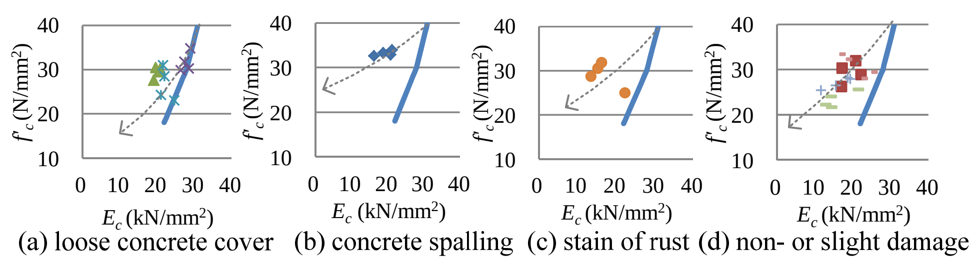

Figure 3. Relationship between compressive strength and Youn's modulus.

Figure 3 shows the relationship between compressive strength, f'_c and Young's modulus, E_c of concrete. According to the major degradation in appearance for each wall rail, Figure 3 is classified into four. All figures include the relationship by the JSCE standard specifications for concrete structures.

3 TENDENCY OF COMBINED DETERIORATION

3.1 Deterioration of Concrete

Experimental results were investigated referring to the JSCE standard specifications because of no initial information. Most of all results of the compressive strength were larger than the design strength. However, the results of the Young's modulus were likely to be less than expected comparing with the JSCE relationship between f'_c and E_c.

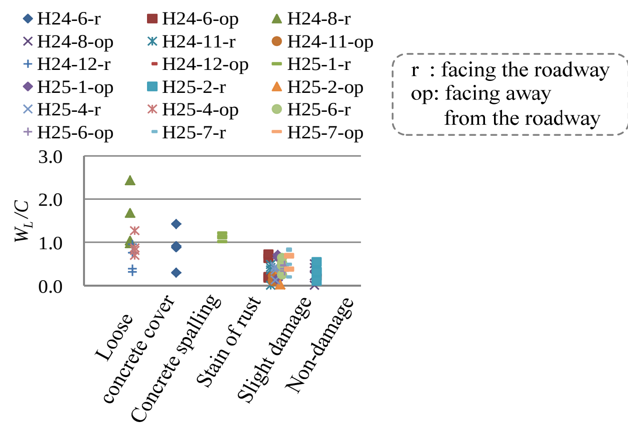

Figure 4. Relationship between W_L/C and a damage pattern.

Regarding the major degradation in appearance, the concrete properties of H24-8, H24-12 and H25-4 with a loose concrete cover had a specific tendency and they were close to the JSCE relationship. In view of the previous results, it is likely that non- or slight damage of Figure 4(d) will develop into more serious condition of Figure 4(a) to (c) and that a damage pattern will be associated with relationship between f'_c and E_c. On the basis of this consideration, a hypothesis was framed as following; Freezing and thawing action has an influence on compressive strength, f'_c and Young's modulus, E_c of concrete and the change of f'_c/E_c ratio is brought by the continuous action. Thus, a gradient of an arrow, f'_c/E_c in Figure 4 is defined as a deterioration degree of concrete affected by frost action. Further, in case of combined deterioration of frost and salt actions, a ratio of frost damage to salt damage decides the observable appearance.

3.2 Deterioration of Reinforcement

Although a deterioration degree of reinforcement should be defined as a weight reduction rate, the reinforcements were not in the right place designed because of the cast-in-place RC bridge wall rails. Therefore, a deterioration degree of transverse bar was represented by a weight reduction rate, W_L to a concrete cover, C, which means distance from the center of the reinforcement to the surface of concrete. And the damage patterns were considered as the degradation in appearance of each side, facing the roadway or facing away from the roadway.

Relationship between W_L/C and the major degradation in appearance as shown in Figure 4 was obtained. Although some wall rails have uneven values of W_L/C, it is likely that the value of W_L/C will be related to the observable appearance. Therefore, W_L/C is chosen to be a deterioration degree of a reinforcement damaged by salt action.

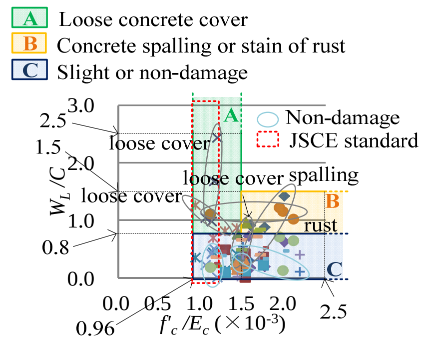

Figure 5. Relationship between deterioration degrees of concrete and reinforcement involving a damage pattern.

3.3 Combined Deterioration of Frost and Salt Actions

Figure 5 shows a relationship of deterioration degrees between concrete and reinforcement. The Y axis is a deterioration degree of reinforcement itself and more serious corrosion makes the value of W_L/C larger. Naturally, the larger value of W_L/C leads to the more serious degradation on a surface. The X axis represents a deterioration degree of concrete with the value of f'_c/E_c on the basis of the previous hypothesis. According to the JSCE standard specifications, f'_c/E_c of 0.96 to 1.19 is derived from the experimental results of f'_c of 24 to 35N/mm^2. However, this range does not include most of the experimental results of f'_c/E_c.

4 Developing Process of Deterioration Due to Combined Frost and Salt

Developing process of combined deterioration was proposed as shown in Figure 6. This figure was obtained by the following procedures.

(1) The time axis of Z was added to the relationship of Figure 5. The origin was set to the values such as X(f'_c/E_c)=0.96, Y(W_L/C)=0 and Z=0. The value of f'_c/E_c=0.96 was decided on condition that E_c was calculated by the JSCE standard specifications at f'_c =24 N/mm^2 of the design strength. The other values were determined by W_L =0% and Z=0 year.

(2) The positions of all results in Figure 5 were identified by X, Y coordinates at Z=40 years. If initial defects were neglected, these results could be connected with the origin.

(3) The only range of the pattern C with slight or non-damage was reflected in the plane at Z=0.

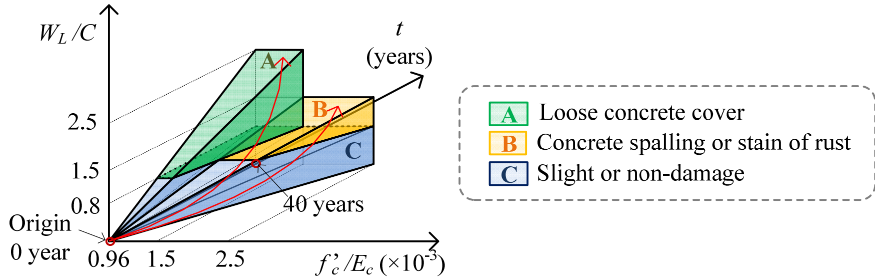

Figure 6. Developing process of combined deterioration.

Figure 6 is considered to be a set of damage process affected by combined frost and salt actions. Two red arrows in the figure offer explanations for developing damage process. The combined deterioration starts from the origin which is involved in the region of damage pattern C and the direction of the arrow means the deterioration development. Thus, this figure can be effectively used to predict a damage pattern in the future or judge the present material properties by observable appearance.

5 CONCLUSIONS

(1) A relationship of deterioration degrees between concrete and reinforcement considering degradation in appearance was proposed. The proposed relationship may be used to predict the occurrence of a loose concrete cover.

(2) Further, the previous relationship was connected with a passage of time. The proposed figure is considered to be a set of damage process affected by combined frost and salt actions.

(3) The proposed relationship between the deterioration degrees of materials and a passage of time will be used to predict a damage pattern in the future and a material property at present.

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