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A STUDY OF MAINTENANCE METHODS OF DETERIORATED CONCRETE STRUCTURES WITH A RISK MATRIX

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In this study, a risk matrix for maintaining the deteriorated RC structures was proposed, in which the difference between the results based on investigation and the actual performance was regarded as risk. The risk matrix was defined as the relation between the degree of material deterioration and the level of influence on the structural performance. This matrix was characterized by involving the range of risk reduction that serves as an index for determining the need for repair. In addition, survey results from an actual RC structure that had undergone the combined damage of frost and salt for more than forty years in Hokkaido were applied to the proposed risk matrix.

Keywords: Risk reduction, RC Structures, Deterioration, Performance, Spalling.

1 INTRODUCTION

Since the 2001 publication of “Standard Specifications for Concrete Structures (Maintenance)” by the Japan Society of Civil Engineers (JSCE), a more efficient and effective method for maintaining structures is needed. Many structures built during Japan’s high economic growth period are facing obsolescence. It is very important to extend the lifespan of structures towards realizing a sustainable society and preserving the global environment.

This study aims to propose a maintenance method that facilitates the comprehensive evaluation of inspection data and the determination of remedial measures. More specifically, the relation between the degree of material deterioration and the level of influence on the performance of a structure and/or its members was defined as a simple diagram. In order to frame this definition, the required performance matrix based on the Vision 2000 concept by the Structural Engineers Association of California (SEAOC), and the risk assessment method by the Society of Practical Study on R-Map in the Union of Japanese Scientists and Engineers (JUSE), were referenced. Further, the usefulness of the proposed maintenance method was examined with reference to survey results from actual RC structures deteriorated by the combined effect of frost and salt.

2 SURVEY OF ACTUAL RC STRUCTURES

2.1 Survey Overview

We studied a deteriorated RC bridge wall rail in Hokkaido, in service for more than forty years, exposed to an environment of combined frost and chloride attacks. As shown in Figure 1, a 2 meter-long section was removed from the RC bridge wall rail by vertical cutting. Beam specimens (1) to (4) cut from the section were inspected, and transverse reinforcing bars were regarded as a longitudinal ones to resist an external force. First, a loading test was conducted to confirm the load bearing capacity and the occurrence of deformation and cracking. Next, a compression test was executed on a concrete core (φ50x100mm) obtained from the beam specimen, to measure compressive strength and modulus of elasticity. Then a tension test was carried out on the transverse reinforcing bar, to obtain tensile strength, yield strength, and elongation. Finally, the weight of the transverse reinforcing bar was measured after rust removal. More detailed information on the survey is reported in the References (Mizuta et al. 2013).

2.2 Survey Results

2.2.1 *Degradation in appearance*

Figure 2 illustrates the results of two sections of the RC bridge wall rail. No. 6 and No. 12 were obtained by visual observation and hammer tapping. On the side facing the roadway, No. 6 had considerable spalling of concrete and extensive unstableness of the cover concrete. Possible corrosion was found in No. 12. Multiple cracks were observed in No. 6 on the side facing away from the roadway, whereas No. 12 had no deformation.

2.2.2 *Deterioration of the concrete and the reinforcing bars*

Table 1 shows the results of a compression test of concrete. They are the mean values obtained from four or more concrete cores. The modulus of elasticity was chosen to be an index reflecting deterioration of concrete in the following examination. Table 1 also lists the results of a tensile test of transverse reinforcing bars. The type of reinforcing bar is SD30, present notation of SD295A specified by the JIS. The weight loss ratio was used as an index indicating deterioration of reinforcing bar hereafter.

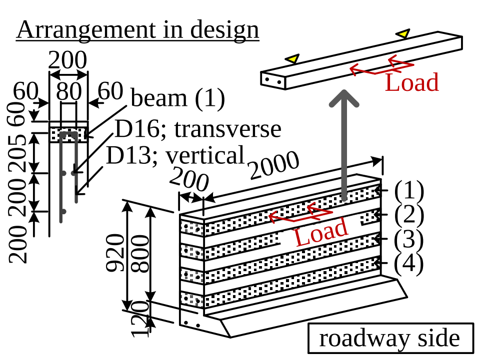

Figure 1. Actual RC bridge wall rail.

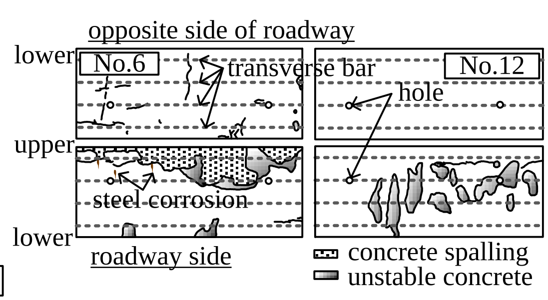

Figure 2. Degradation in appearance.

2.2.3 *Results of the loading test*

Table 1 shows the results exclusive of beam specimen (2). The load bearing capacity and the deflection were classified by comparing them with theoretical values, and the bond was estimated by crack patterns.

Table 1. Experimental results.

Wall No.	Beam No.	Side	Concrete	Re-bar	Level of influence on performance			
			E_c	W_L	Damage	Load bearing capacity	Ductility	Bond
6	(1)	a	16.3	10.2	Spalling	○	○	▲
		b		4.6	Cracking			
	(3)	a	18.8	5.7	Spalling	○	▲	▲
		b		1.7	Cracking			
	(4)	a	21.3	4.9	Spalling	○	▲	▲
		b		1.5	Cracking			
12	(1)	a	19.7	4.5	Possible corrosion	◎(P_e>1.3P_t)	○	◎
		b		2.0	None			
	(3)	a	19.2	3.9	Possible corrosion	◎	△	◎
		b		1.6	None			
	(4)	a	20.8	1.6	Possible corrosion	◎	△	◎
		b		2.0	None			

Notes:

E_c: modulus of elasticity (kN/mm^2), W_L: weight loss ratio (%),
a: side facing the roadway, b: side facing away from the roadway
◎(excellent)→○(good) →△(fair) →▲(poor)
P_e: experimental load bearing capacity, P_t: theoretical load bearing capacity
Load was subjected on the side facing away from the roadway except for No.6 (4) specimen.

3 A MAINTENANCE METHOD FOR DETERIORATED RC STRUCTURES

3.1 Deterioration and Risk

ISO/IEC Guide 51 was published in 1999 as an international safety standard. This guide proposes standards related to various safety aspects for protecting people, property or the environment, or a combination of these. Also, in the guide, safety is defined as freedom from unacceptable risk, and risk is defined as combination of the probability of occurrence of harm and the severity of that harm.

In evaluating the present state and predicting the deterioration of a RC structure, there are some uncertainties. The uncertainties lead to variations in evaluation results. It was assumed that there were differences between the evaluation results and the present state, and such differences were regarded as risk in this study.

3.2 A Risk Matrix for Deteriorated RC Structures

A risk matrix can be ideally divided into four regions for each risk measure, as shown in Figure 3(a). According to the R-Map technique, the risk matrix is divided into three, and the risk reduction and the risk transfer regions in Figure 3(a) correspond to Region B in Figure 3(b). Region B is called ALARP, abbreviation for “as low as reasonably practicable.” In both matrices, risk reduction measures can be taken by eliminating hazards or reducing risks.

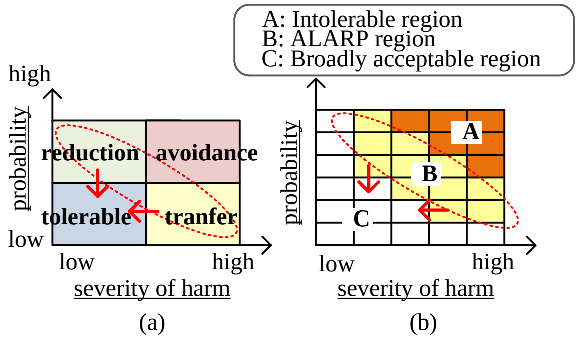

Figure 3. Risk matrix.

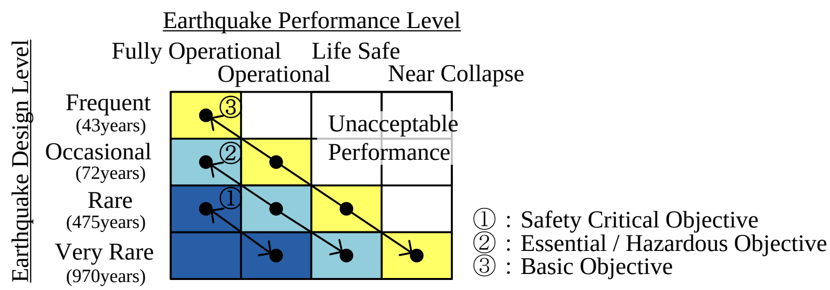

Figure 4. Performance matrix.

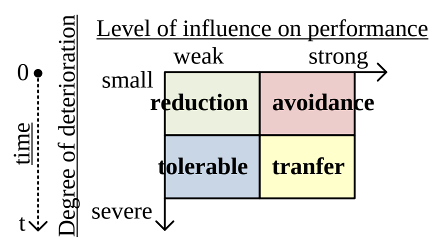

Figure 5. Proposed risk matrix.

The severity of harm can be easily replaced by the level of influence on performance. On the other hand, it is difficult to define the probability of risk for a deteriorated RC structure. Then the seismic performance matrix in the Vision 2000 shown in Figure 4 was applied. The vertical axis represents not only the probability of an earthquake but also its amplitude. In the case of a deteriorated RC structure, the degree of deterioration is expressed by the vertical axis. The performance of a RC structure increasingly deteriorates downward in the matrix. The vertical axis is also considered a time axis because deterioration develops with time. Thus, the risk matrix for a deteriorated RC structure is defined as in Figure 5.

3.3 Risk Reduction Measures

Each of the risk positions in Figure 5 are discussed with reference to the three-step method shown in ISO/IEC Guide 51. Below is an overview of risk-reduction measures.

- Step 1: Inherently safe design
- Step 2: Risk reduction measures
- Step 3: Information for use

By taking these steps from 1 to 3, the risk will be reduced. Therefore, it is considered that Step 2 corresponds to the risk position of "reduction" or "transfer". In case of the maintenance of a deteriorated RC structure, the risk position of "reduction" corresponds to the repair of the structure, while the position of "transfer" deserves the strengthening of the structure. Therefore, determining the boundary of "reduction" is taken as synonymous with evaluating and judging the necessity for remedial measures.

3.4 Application of Actual RC Structure to Risk Matrix

The survey results shown in Section 2 are applied to the proposed risk matrix. A matrix was developed according to each degree of material deterioration and to each level of influence on the structural performance. The following were selected as factors that affect the performance of an RC beam specimen: deformation observed on the opposite side of the loading, the presence of concrete spalling, load bearing capacity, ductility, and bond. The degree of material deterioration is shown in Table 1, and the level of influence on performance in Table 2. In addition, the degree of material deterioration is classified into the three levels shown in Figure 6, with reference to the distribution range of the survey results. Figure 7 is obtained by plotting the survey results. The positions of "reduction" in the figure are determined on the basis of the following concepts:

(1) The red vertical line between "reduction" and "avoidance" was determined by judging whether each factor was equal or superior to the theoretical one. Additionally, as for the degradation in appearance, the occurrence of cracking was defined to be involved in "reduction".

(2) The range to the right side of the red vertical line corresponds to "avoidance" and "transfer". It is unlikely that there is a need for "avoidance" measures for the RC structure over forty years after construction. Therefore, the red horizontal line was determined on the assumption that the plot at the minimum degree of deterioration indicated the lower limit of "transfer".

As shown in Figure 7, regarding the relation between the degree of material deterioration and the level of influence of the structural performance, it was visually defined that the RC structures in the same deterioration condition of material had different performances. Further, applying this relation to a risk matrix made it possible to provide an index for determining the need for repair.

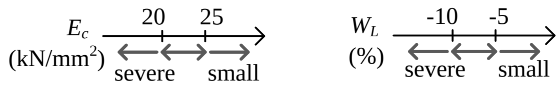

Figure 6. Deterioration degree.

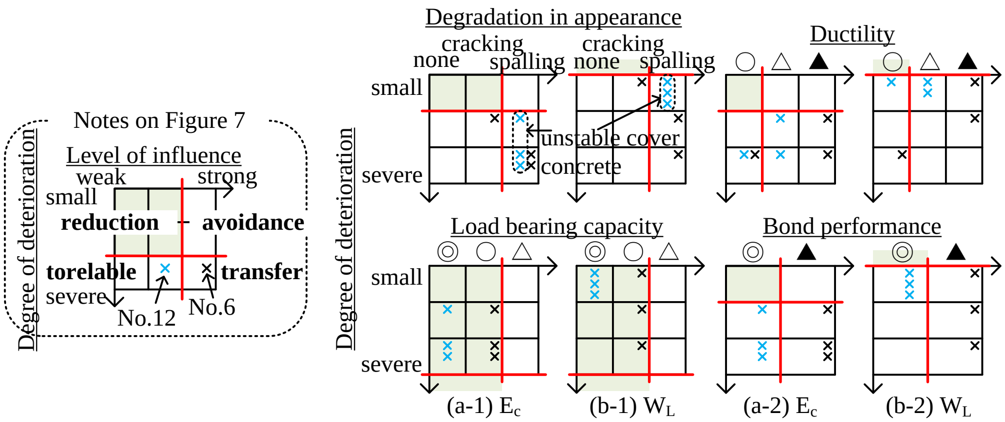

Figure 7. Risk matrix for a deteriorated RC structure.

4 CONCLUSIONS

In this study, a risk matrix for deteriorated RC structure was proposed. It was assumed that there were differences between the theoretical values and the actual capacity of an RC structure subjected to deterioration, and that such differences were regarded as risk. Moreover, the index for determining the need for repair was shown in the matrix. The survey results of an actual RC structure affected by frost and salt damage were applied to the proposed risk matrix. Further surveys are being carried out to enhance the quality and quantity of results of deteriorated RC structures. A maintenance method with a risk matrix should be established as well.

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