V -116 CONDITION RATING METHODOLOGY FOR THE DETERIORATION ASSESSMENT OF RC BRIDGE

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1. INTRODUCTION

Deterioration of concrete in RC bridge may be caused by a variety of physical and chemical processes, such as over traffic volume than that designed, attack by acids, carbonation, or chloride penetration. This deterioration is not only harmful to concrete itself, but also leads to a more serious problem, that is corrosion of steel reinforcement which will result in a reduction in the cross sectional area of steel bars and ultimate disruption of concrete due to spalling of concrete cover. From the deterioration condition of concrete material, one can monitor the structural-condition of RC bridge at a quite reliable extent. The purpose of this study is to develop a rating methodology that can be used to assess the deterioration condition of existing RC bridge in terms of the following five items: crack, mixture proportion (water-cement ratio and absorption), compressive strength, depth of carbonation, and chloride ion content. The interaction of the five items is also taken into account in the rating methodology. This methodology is applied to the assessment of 6 RC bridges tested by authors.

2. DESCRIPTION OF THE RATING METHODOLOGY

The deterioration rating of a RC bridge can be expressed as the linear weighted combination of the condition rating of each specific item in the following equation

$$DR = DR_1 \cdot F_1 + DR_2 \cdot F_2 + \cdots + DR_n \cdot F_n \quad (1)$$

where DR is deterioration rating of the superstructure, DR_i is deterioration rating of the ith item, and F_i is the corresponding weighting function to express the relative importance of the item. Five items including crack, mixture proportion (water-cement ratio and absorption), compressive strength, depth of carbonation, and chloride ion content were consisted in evaluation of the deterioration rating of a RC bridge. The rating criteria for each item are given in Table 1. These criteria were proposed based on the related specifications and experimental results.

Table 1 Criteria for deterioration condition rating

Rating (DR_i)	Crack condition*1			Mixture proportion		Compressive strength (MPa) (mean-1.5 σ)	Depth of carbonation (mm)	Free chloride ion content (%)
	Space (m)	Width (mm)	Density (m/m²)	W/C Ratio	Absorption (%)			
1	>1.0	<0.05	<2	<0.4	<3.5	> 30	<10% cover depth	<0.01
2	0.5~1.0	0.05~0.1	2~4	0.4~0.5	3.5~4.5	20~30	10~25%	0.01~0.015
3	0.5	0.1~0.2	4	0.5~0.6	4.5~5.5	15~20	25~50%	0.015~0.02
4	0.2~0.5	0.2, spall existing	4-8	0.6~0.7	5.5~7.0	10~15	50~100%	0.02~0.03
5	<0.2	>0.2, continuous spall existing	>8	>0.7	>7.0	< 10	> cover depth	>0.03

Note: *1 by Construction Office of Kinki Region, Ministry of Construction. Crack density is the total length of cracks appeared in unit area (m/m²).

How to determine the importance of a specific item depends on associating specifications, deterioration rating of the item itself, the age of the bridge and the interaction strength of the item. In this study the importance of an item was simplified as a constant that could be obtained from the follow equation

$$F_i = \frac{DR_i + IS_i}{\sum (DR_i + IS_i)} \quad (2)$$

where IS_i is the interaction strength of the ith item. For the five items used in this study the effect of one item on the other items has been studied extensively, so the interaction strength can be

Table 2 Matrix for the interaction strength

	I1	I2	I3	I4	I5	IS_i
I1	0	0	0.5	1.5	2.0	4.0
I2	1.0	0	2.0	2.0	0.5	5.5
I3	1.0	0	0	1.0	0.5	2.5
I4	0	0	0	0	0.5	0.5
I5	0	0	0	0.5	0	0.5

Note: I1 through I5 present crack, mixture proportion, compressive strength, depth of carbonation and chloride ion content, respectively.

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determined from previous studies. Table 2 shows an example about the matrix for interaction strength. The interaction strength level 0 presents no significant interaction and level 2 presents critical interaction.

3. RATING METHODOLOGY APPLIED TO RC BRIDGES

Experiments on material deterioration of 6 RC bridges aged from 32 to 63 years were conducted. For each bridge some or all of the following items were included in measurement: crack distribution in slab, deduction of mixture proportion, absorption, compressive strength, depth of carbonation, and chloride ion content in concrete. Crack distribution in concrete slab was obtained by field observation and the other items were tested on the concrete core specimens bored from these structures. The results are listed in Table 3.

Table 3 Experimental results about material deterioration in 6 RC bridges

Testing item		Bridge A	Bridge B	Bridge C	Bridge D	Bridge E	Bridge F
Age at testing (year)		63	51	39	36	38	32
Crack density (m/m^2)		5.8	0.5	6.1	2.9	0.12	8.9
Coefficient of crack *Kcd*($m/m^2 \cdot$ year)		0.092	0.01	0.16	0.08	0.003	0.28
Mixture proportion Deduced	Water/cement ratio	0.75	0.67	0.49	0.66	0.50	0.54
	Absorption (%)	6.37	4.94	4.65	5.67	4.31	3.95
Compressive strength (MPa)	Mean	9.4	23.9	22.4	23.2	39.4	26.8
	Standard deviation σ	2.0	5.7	5.3	4.6	8.1	4.1
Depth of carbonation (mm)		84.2	26.8	19.3	33.2	7.80	30
Coefficient of carbonation *Kc* ($mm/year^{0.5}$)		10.58	3.78	3.10	7.08	1.28	5.39
Free chloride ion content (%)		-	0.18	-	0.12	0.08	0.022
Coefficient of chloride ion K_{Cl} ($\%/year^{0.5}$)		-	0.025	-	0.02	0.013	0.004

Table 4 lists the deterioration ratings of the 6 bridges by applying the methodology proposed in this study to the evaluation. DR1 through DR5 responded to the order of the items in Table1. The deterioration condition of a RC Bridge can be divided into 5 ratings from rating 1 that presents a new bridge or almost no deterioration to rating 5 that presents a very serious deterioration and the bridge should be replaced. From the rating results in Table 4 it can be said that the deterioration in Bridge A was the most serious among the 6 bridges.

Table 4 Deterioration ratings of the 6 RC bridges

	DR_1	F_1	DR_2	F_2	DR_3	F_3	DR_4	F_4	DR_5	F_5	DR
Bridge A	4	0.242	5	0.318	5	0.227	5	0.167	1	0.045	4.576
Bridge B	1	0.167	4	0.317	4	0.217	3	0.117	5	0.183	3.567
Bridge C	4	0.286	3	0.304	4	0.232	3	0.125	1	0.054	3.411
Bridge D	2	0.188	4	0.297	4	0.203	4	0.141	5	0.172	3.797
Bridge E	1	0.185	3	0.315	3	0.204	2	0.093	5	0.204	2.944
Bridge F	5	0.281	3	0.266	3	0.172	4	0.141	4	0.141	3.844

The development of crack condition with time is quite complicated. In this study it is assumed that crack density and time have a linear relation: *crack density*=$Kcd \cdot t$, where *Kcd* is defined as coefficient of crack. It has been pointed out that the depth of carbonation and the chloride ion content are roughly proportional to the square root of exposed time, there are $Xc=Kc \cdot t^{0.5}$ and $C_{Cl}=K_{Cl} \cdot t^{0.5}$, where *Kc* is known as coefficient of carbonation and K_{Cl} is defined as coefficient of chloride ion. *Kcd*, *Kc* and K_{Cl} can be obtained from present information, so one can estimate the crack density, depth of carbonation and chloride ion content in the future time. From these results the rating methodology proposed can be used to predict the condition rating of deterioration at any given future age. Table 5 shows the deterioration ratings of the 6 bridges after 20 years from the present testing time.

Table 5 Deterioration ratings of the 6 bridges after 20 years after present testing time

Bridges	A	B	C	D	E	F
Present time	4.576	3.567	3.411	3.797	2.944	3.844
After 20 years	4.924	3.917	4.148	4.250	3.348	4.341

4. CONCLUSION

The methodology proposed in this study involves the interaction of five deteriorating items and provides a rational approach to the assessment of deterioration of RC bridges. This methodology can be used to predict the deterioration ratings based on present deterioration data.

[REFERENCE]

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