User-friendly Indices for Bridge Management

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Abstract

The Road Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) is promoting scientific bridge management to effectively preserve the enormous number of bridges in Japan. In the process of strategic bridge management, it is important to explain the needs for preventive investment or management level of highway bridges using proper indices. The National Institute for Land and Infrastructure Management (NILIM) is carrying out a study on intelligible indices for users and administrators. In this paper, a fundamental concept of bridge management indices and examples of trial calculation are reported.

１． Introduction

The number of highway bridges over 15m in Japan is more than 140,000 as illustrated in figure 1. An enormous number of bridges were constructed during the period of rapid economic growth that started in the middle of the 1950's. Therefore it is expected that rehabilitation or renewal costs of highway bridges will rapidly increase in the future.

On the other hand, serious damage which influences the loading capacity of bridges such as fatigue cracks of concrete slab, fatigue cracks on steel members, salt damage or alkali-silica-reaction (ASR) of concrete members is reported recently in Japan.

In these circumstances, a strategic and efficient bridge management system is required to reduce life-cycle-cost (LCC) of highway bridges and keep the highway network in good condition for the future. In the process of decision making of strategic bridge management, user accountability using proper and intelligible management indices are very important. NILIM is carrying out a study on intelligible indices for user and administrator.

In this paper, a fundamental concept of bridge management and examples of trial calculation are reported.

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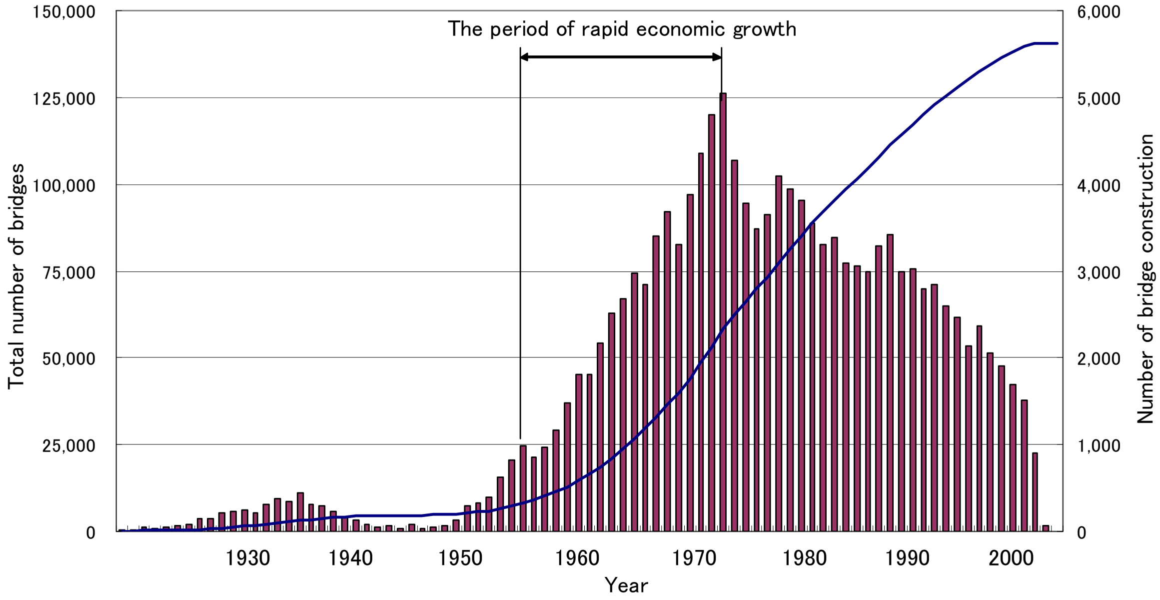


Figure 1 Total number of bridges and annual bridge construction in Japan

2 . The need for intelligible indices

In order to promote preventive bridge management, it is important to have an adequate level of investment at the best timing. However, in the case of highway bridges, it is difficult to recognize the actual condition of bridges for both bridge user and bridge administrator since usual damage of highway bridges is not visible for its users.

It is said that the importance of planned bridge management was realized after serious accidents such as the Silver Bridge in the case of the United States. Our worry is that it is difficult to emphasize the importance of preventive bridge management until serious accidents happen in Japan.

Therefore, in order to conduct preventive investment for Japan's aging bridges, user accountability using intelligible management indices is very important in the process of decision making. NILIM is now trying to develop management indices that express the condition of bridges.

3. Fundamental concepts of bridge management indices

3.1 Required performance of highway bridges

When we are trying to evaluate the condition of highway bridges, it is necessary to classify and select the required performance of highway bridges depending on the purpose of investigation. Table 1 shows examples of performance of the highway bridges that are now being discussed in the revision works of specification for highway bridges aiming at the format of performance based design.

Table 2 shows a relationship between purposes of application of management indices and the performance of the bridge. As shown in Table 2, the combination of required bridge performances should change depending on the purposes. For example, if you are trying to pick up hazardous bridges that are in a serious condition, the load carrying capacity is the most important performance. On the other hand, if you are trying to explain maintenance works located in an urban area, influence on residents or users is very important in the evaluation of the bridge condition.

Table 1 Example of highway bridge performance

Safety	Load carrying capacity Earthquake resistance ability Stability
Serviceability	Comfortableness for driving
Influence on others (residents or users)	Damage on others Noise or vibration Landscape

Table 2 Relationship between the purpose and performance

	Safety	Serviceability	Influence
Picking up hazardous bridges	○		
Planning of bridge maintenance	○	○	○
Explanation of serviceability in case of disaster	○	○	
Explanation of user's satisfaction	○	○	
Explanation of resident's satisfaction			○

○: important

3.2 Relationship between score, condition and measure

In order to conduct bridge management effectively the result of evaluations should be related to the practical actions of maintenance works. Therefore, quantitative and absolute evaluation is required using a score or point system. Table 3 shows an example of relationship between score from 0 to 100, bridge condition and maintenance work. In our inspection system, we rank bridge condition and measure in 5 categories for each members or parts as shown on the right in table 3.

Table 4 shows an example of the relationship between conditions and retrofitting methods in the case of concrete slab. By showing the relationship between condition and measures, the highway administrator can easily know which practical maintenance actions should be taken.

Table 3 Relationship between score, condition and measure

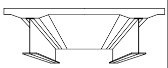
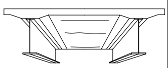
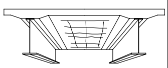
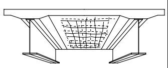
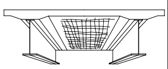
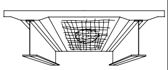
Examples if evaluation as a bridge

Score	Condition	Measure
100	Excellent	Usual maintenance
	Good	
	Satisfactory	Repair
	Poor	Reinforcement
0	Critical	Replacement

Ranking in inspection

Condition	Measure
Ⅴ	A
Ⅳ	B
Ⅲ	C
Ⅱ	E2
Ⅰ	E1

Table 4 Retrofitting methods for concrete slab

Figure	Stage of damage	Measures
	no damage	no need
	drying shrinkage crack	reinforcement against bending CFRP attachment
	grid style crack	reinforcement against bending steel plate attachment
	progressing of grid style crack	reinforcement against bending and shearing steel plate attachment, thickness increasing
	surface scratching in crack	reinforcement against bending and shearing thickness increasing, replacement
	dropping off of concrete	replacement

3.3 Structure of evaluating items

Table 5 shows the structure of evaluating items. We divide evaluating procedures in 4 steps. In the first step shown on the far right of this table, evaluation for each members or parts is conducted in a regular bridge inspection. Inspection data is classified in 5 ranks, Ⅴ, Ⅳ, Ⅲ, Ⅱ and Ⅰ. In the second step, evaluation per members is conducted in consideration of the types, area or size of damage using bridge inspection data. In the third step, types of structure are taken into consideration in case of girder saved system or composite girder. In the last step, the total score as a bridge is calculated in consideration of the importance of each member.

Table 5 Structure of evaluating items

Total ↔ Local

Kinds of member		Types of structure	Kinds of area of damage	Rank of inspection
Super structure	Main girder	Saved girder Composite girder	Corrosion Crack···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Cross beam		Corrosion, Crack, ···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Bracing		Corrosion, Crack, ···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Deck	Composite deck	Crack, Exfoliation, ···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Sub total score			
Sub structure	Abutment Pier		Crack, Exfoliation, ···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Sub total score			
Bearing	Bearing		Corrosion, Crack, ···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Anchor bolt		Corrosion, Crack, ···	Ⅴ/Ⅳ/Ⅲ/Ⅱ/Ⅰ
	Sub total score			
Total				

3.4 Weighting methods

In the process of evaluation, we have to integrate data from local information for the total score as a bridge. There are mainly 2 types of integrating methods to calculate total or subtotal scores using importance factors. The first method is used in order to extract the critical defect as shown equation (1). We call it the critical rule. The second method is used in order to express the total amount of defects as shown equation (2). We call it the average rule.

Critical rule: extract critical defect

$$\text{Index}_{cr} = \min(a_1, a_2, a_3, \cdots\cdots\cdots, a_n) \quad (1)$$

Average rule: express total amount of defects

$$\text{Index}_{ave} = a_1w_1 + a_2w_2 + a_3w_3 + \cdots\cdots\cdots + a_nw_n \quad (2)$$

Table 6 shows an example of the relationship between integrating methods and the purpose of index's application. The critical rule is suitable for picking up hazardous bridges or explaining the serviceability in case of disaster, because the worst scored performance is important in these kinds of application. On the other hand, the average rule should be used for the planning of total bridge management, explanation of user's or resident's satisfaction. This is because the total amount of defects or trouble effect on these kinds of problem.

Table 6　Purpose of application and weighing methods

Purpose of application	Member Level	Bridge Level
Picking up hazardous bridges	Critical rule	Critical rule
Planning of bridge maintenance	Average rule	Average rule
Explanation of Serviceability	Critical rule	Critical rule
Explanation of use's satisfaction	Average rule	Average rule
Explanation of resident's satisfaction	Average rule	Average rule

3.7 Weighting factors

Table 7 shows a fundamental concept of weighting among different kinds of damage. For example, when we are picking up hazardous bridges, damage that affects safety such as corrosion or cracks is important. And, when you are checking serviceability in case of disaster, displacement or deformation is also important. And, when you are explaining user or resident's satisfaction noise or vibration is also needed.

Table 8 shows a fundamental concept of weighting factors among different kinds of members. For example, if you are trying to evaluate safety, main girders or decks are important against traffic weight, piers or abutments are important against seismic force. And, if you are trying to evaluate serviceability, condition of expansion joint, pavement or slab is important.

Table 7 Concept of damage's weighting factors

	Hazardous	disaster	User	resident	maintain
	Safety	Serviceability		Influence	Total
Corrosion (End of girder)	◎	—	○	△	○
Corrosion (other)	◎	—	○	△	○
Crack (End of girder)	◎	◎	○	△	○
Crack (other)	◎	◎	○	△	○
Looseness of bolt	○	△	△	○	○
Falling off of bolt	○	△	△	◎	○
Deterioration of paint	○	△	△	○	○
Noise	△	△	△	◎	○
Vibration	△	○	◎	◎	○
Displacement	△	◎	◎	△	○
Deformation	△	◎	◎	△	○

◎: very important, ○: important, △: standard

Table 8 Concept of member's weighting factors

		Safety		Serviceability
		traffic	seismic	
Superstructure	Main girder	◎	◎	△
	Cross beam	○	○	△
	Bracing	△	○	△
	Floor system	○	△	△
	Deck	◎	○	○
Substructure	Abutment	◎	◎	○
	Pier	◎	◎	○
Ends of girder	Bearing	○	◎	○
	Expansion Joint	△	△	◎
	Unseating prevention system	△	○	△
Others	Pavement	△	△	◎

◎: very important, ○: important, △: standard

4. Trial calculations using inspection date of plate girder bridges

In order to investigate fundamental characteristics of proposed indices, trial calculations were carried out using inspection date of I-section plate girders. Trial calculations include a lot of patterns of damage, kinds of bridges or aspects of evaluation. In this paper, 3 examples of I-section plate girder bridges as shown in Table 9 were reported. In these calculations, the critical rule was employed as an integrating method in order to evaluate in terms of load carrying capacity.

Table 9 Conditions of bridges

Name of bridges	Oumi	Daiichi-Tonogawachi	Shin-Oku
Completion year	1965	1964	1965
Length (m)	26	33	45.5
Types of structure	Simple, I-section, Steel girder	Simple, I-section, Steel girder	Simple, I-section, Steel girder
Traffic (tracks/day)	4620	1561	3747
Environment	Salty		
State of damage (parts	Corrosion (main girders)	Cracks (RC slab) Local damage	Local damage

The Oumi Bridge which is located near the Sea of Japan coast has seriously damaged steel members as shown in picture 1. This bridge is considered as a hazardous bridge, special investigations and emergency measures have been conducted. The Daiichi-Tonogawachi Bridge has grid style cracks on RC slabs and some local damage as shown in picture 2. For this bridge, rehabilitation is considered as required for cracked slabs. The Shin-Oku Bridge which have some local damage but they are not serious one as shown in picture 3. For this bridge, no rehabilitation is considered as required for the time being.

Table 10 shows the result of evaluation in terms of load carrying capacity. The result reveals a possibility of application for selecting bridges that need emergency measures or rehabilitation by classifying bridge conditions in several groups with scores. However, in order to evaluate precisely depending on various purposes of application, it is necessary to improve the logic or items of calculation.

(a)end of girder (b)girder and bracing

Picture 1 state of the Oumi Bridge

(a)cracks on RC slab (b)corrosion in bearing

Picture 2 state of the Daiichi-Tonogawachi Bridge

(a)cracks on RC slab (b)end of girder

Pictuire 3 state of the Shin-Oku Bridge

Table 10 Result of calculation

Name of bridges	Superstructure				Substructure	Bearing	Total score
	girder	Cross beam	Bracing	slab	Pier, Abutment		
Oumi	12	88	94	75	78	86	12
Daiichi-Tonogawachi	76	96	98	37	100	93	37
Shin-Oku	100	100	100	77	98	93	77

5. Conclusion

In order to create user-friendly indices for bridge management, NILIM will try to enhance accuracy and variety of quantitative evaluation and make it possible to keep the balance between automatic calculation and knowledge of experienced engineer or needs that are difficult to explain with quantitative indices such as social value. The management system in Japan has not been sophisticated yet. NILIM will try to improve and establish bridge management system from the knowledge of the actual use and newly developed technologies.

Reference

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