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Analysis of Soundness of Bridges Affected by Environmental Factors

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Abstract

In recent years extending the service life of the bridges has come to be studied. Many bridges are built in the period of high economic growth, and they reached their service life. Consideration of rebuilding and extending the service life must be carried out. But implementation of replacement or maintenance works for those bridges will be difficult in terms of both labor and cost. Moreover, possible events of bridge closure may probably bring significant negative effects on the road traffic networks. Under such circumstances, the bridges in the Ishikawa Prefecture has been placed under the harsh environment. For example, flying salt due to the weather characteristics of winter, the influence of the water from pipe buried under a road with nozzles that spray liquid to melt snow, sprinkling salt for antifreeze, the damage of alkali silica reaction that peculiar to Hokuriku region, seismic risk occurred by active fault . Therefore, each bridge is inspected once every five years and the priority of each bridge is determined and recorded depending on health of respective components and importance of the bridge. However, in and around Ishikawa Prefecture there are a number of active faults including the Morimoto-Togashi Active Fault posing a high risk of bridge damages caused by earthquakes, and the existing methods to determine bridge maintenance priorities with no consideration of the seismic risks are expected to result in significant damages in the event of a major earthquake disaster. In this study, we propose a repair priority determination method taken into account the seismic risk by using the principal component analysis. For the principal component analysis, importance and vulnerability of bridges against earthquake were used as variables. For importance of bridges, the potential impact of bridge destruction on transportation was considered from perspectives of emergency transportation, crossing, daily traffic volume and bridge length. As for vulnerability of bridges against earthquake, health scores in regular inspections that indicate possibilities of destruction in the event of an earthquake (main girder, bearing apparatus, expansion devices) and seismic risks were considered. Seismic risk-based priorities obtained in this research were compared with priorities calculated by the conventional calculation method. As a result, when the seismic risk was considered, the priority of the bridges was changed. It have become clear that the new method of calculation bridge repair priority using the principal component analysis considered importance of bridges and vulnerability of bridges against earthquake is suited to consider both the existing damage and seismic risk.

Keywords: bridge maintenance, inspection data, environmental factor, seismic risk, principal component analysis

1. Introduction

Recently the lifelong duration of bridges are discussed in Japan. There are about 70000 bridges (bridge length 2 meter or more) in Japan at present. About 18 percent of the bridges were built more than 50 years ago. It is expected that older bridges passed 50 years will account for 43 percent [1]. Many of the bridges were built in the period of high economic growth, and they will reach bridge service life all at once. In Ishikawa prefecture, about 24 percent of the bridges were built more than 50 years ago. It is expected that older bridges passed 50 years will account for about 69 percent as shown Figure 1. Rack of human resources and public works spending makes repair of bridges difficult in the future. Stopping traffic during the bridgework has a harmful effects on transportation services. Under such circumstances, National and local governments attaches importance to maintenance, and carries out regular inspections of bridges to make frameworks of asset management. It is difficult to use inspection results in determining the proper priority of bridges because inspection results has many inspection items. Present priority of bridges is determined on the basis of degradation situation and importance. But present priority of bridges are not considered seismic risk to determine the repair priority of bridges.

Bridges in the Ishikawa prefecture has been placed under the harsh environment. For example, flying salt due to the weather characteristics of winter, the influence of the water from pipe buried under a road with nozzles that spray liquid to melt snow, sprinkling salt for antifreeze, the damage of alkali silica reaction (ASR) that peculiar to Ishikawa prefecture. The Morimoto Togashi fault is active faults that develop in the southeast edge of the Kanazawa plains. It is estimated to cause the earthquake of about magnitude 7.2 in 2-8% of probability in the next 30 years [2]. As a result of this risk evaluation, a lot of bridges will be affected by earthquake.

The purpose of this study is to make the decision of repair priority including the seismic risk by using the regular inspection data.

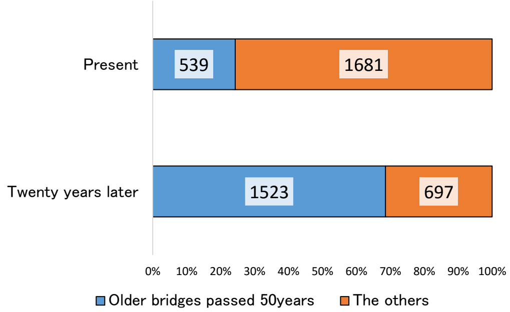

Figure 1 – The number of older bridges passed 50 years

2. Past Studies

There have been a number of researches using the regular bridge inspection data. Oshima et al. conducted a questionnaire survey among experts on items associated with seismic performance which were selected based on existing physical health evaluation data, analyzed the survey results by the quantification theory, and proposed a seismic health evaluation method in consideration of weighting factors of each item obtained [3]. Kaito et al. used the results of visual inspections on 829 bridges conducted by NY City in last nine years and proposed a deterioration prediction method based on Markoff process with focus on rate of deterioration [4]. They also defined possible top events as control limit conditions for visual inspections, configured a fault tree of sub events that cause the top events, obtained probability of sub events occurrences based on the Markoff deterioration hazard model, and thereby calculate changes in probabilities of the top events over time [5]. Chikata et al. based on bridge health data obtained from the results of the analysis of regular bridge inspection data obtained in Prefecture I from 1982 through1988 by the quantification theory type II, solved the optimization problem of maintained bridge and component combination for maximizing the overall health of a managed bridge group after maintenance, by applying the knapsack problem in the genetic algorithm approach [6].

Researches on seismic assessment indexes for road structures have also been conducted. Kuse et al. proposed three factors as seismic retrofitting priority indexes for highways: expected magnitude values determined from predicted magnitude and probabilities of multiple scenario earthquakes; importance of highway routes calculated based on detouring time; and degrees of expected transportation system trouble between interchanges calculated based on vulnerability and restoration levels of structures [7]. Hata et al. calculated a seismic assessment index of highway embankment between interchanges from 50-year probabilities of each scenario active faults and residual displacement of profiles of each scenario earthquakes [8].

However, the above-mentioned researches did not account for present damage conditions of structures and it is meaningful to propose a method of bridge maintenance priority determination in view of the seismic risks based on data that indicate the latest damage conditions, i.e. regular bridge inspection data.

3. Data Used

Regular bridge inspections are intended and performed to obtain data necessary for: comprehension and assessment of conditions of road bridge components; identification of necessary actions for each bridge, e.g. maintenance, repair, and reinforcement; and appropriate maintenance and management of bridges for securement of safe and smooth transportation and prevention of damage to areas along each road and third parties. In regular bridge inspections, damage conditions and necessary measures are identified and determined, and health of each component and the entire bridge is assessed and recorded based on these data.

The prefectural government of Ishikawa conduct a regular bridge inspection once every five years for each bridge. In the inspection, damage conditions including brine damages specific to seagirt areas like Ishikawa Prefecture (e.g. salt pollution and alkali-aggregate reaction) are investigated and recorded as the regular bridge inspection data on a scale of one to five. The six components subject to the inspections are main girder, floor slab, substructures, bearing apparatus, expansion devices and bridge deck.

3.1 Bridge Inspection Data

As shown in Table 1, the regular bridge inspection data contain general bridge specifications and inspection results. As the general specifications, construction year, number of spans, bridge length, width, maximum span length, emergency route, crossing, daily traffic volume, daily truck traffic volume, location, altitude and latitude and priority, etc. are recorded. Inspection items are main girder, floor slab, substructures, bearing apparatus, expansion devices and bridge deck, whose health is evaluated on a scale of one to five. Also, BHI (Bridge Health Index) of the entire bridge is calculated from component health data. BHI is a quantitative index calculated from component health data and weighting factors of components by the weighted average method. Bridge importance is evaluated in BPI (Bridge Public Index), which is a comprehensive index of road importance and traffic volume. BPI is calculated by the weighted average method from weighting factors set for road importance (emergency transportation roads, railroad bridges and overpass bridges) and traffic volume (traffic types). The P (Priority) value for bridge maintenance and replacement is evaluated based on resultant BHI and BPI values. In other words, the P value is determined in consideration of road importance, traffic volume and health status while their weighted values vary.

Table 1 – Example the regular bridge inspection data

Name of bridge	The year of construction	Superstructure material	Crossing	Bridge length	Daily traffic volume	Main girders	Slabs	Substructure	Bearings	BHI	BPI	P	Latitude	Longitude
A	1964	RC	Road	34.5	1200	5	3	3	5	70.5	30.0	29.7	36.110	136.688
B	2001	Steel	River	19.0	1200	5	4	5	5	94.0	30.0	15.6	36.114	136.681
C	1983	RC	River	7.2	933	5	5	4	5	89.5	30.0	18.3	36.123	136.669
D	1963	RC	River	3.2	933	5	5	4	5	90.5	30.0	17.7	36.131	136.660
E	1962	RC	River	5.7	933	5	5	4	5	90.5	30.0	17.7	36.142	136.660
F	1964	RC	River	5.6	933	5	4	4	5	86.0	30.0	20.4	36.159	136.658
G	1962	RC	The others	2.5	933	5	3	3	5	73.0	30.0	28.2	36.162	136.652
H	1962	RC	Railroad	4.5	933	5	4	3	5	76.5	30.0	26.1	36.163	136.650
I	1994	PC	The others	14.5	1200	5	5	3	5	78.0	30.0	25.2	36.163	136.650
J	1991	PC	The others	20.0	1200	4	4	4	5	75.0	30.0	27.0	36.165	136.638
K	1991	Steel	The others	30.0	1200	5	4	4	5	84.5	30.0	21.3	36.167	136.633
L	1973	RC	The others	3.8	900	5	3	3	5	73.0	45.0	34.2	36.168	136.621
M	1974	Steel	The others	148.4	702	4	4	4	5	73.0	45.0	34.2	36.170	136.621
N	1975	PC	Road	99.9	702	3	5	3	3	57.0	45.0	43.8	36.173	136.622
O	1977	PC	Road	10.5	2300	3	4	3	5	57.5	50.0	45.5	36.185	136.622
P	1975	Steel	Road	37.8	2300	4	4	3	3	64.0	50.0	41.6	36.184	136.622
Q	1973	Steel	River	27.5	900	5	2	4	5	77.0	45.0	31.8	36.178	136.624

3.2 Seismic Risks of the Bridges

In this research, the Probabilistic Seismic Hazard Map developed the Japan Seismic Hazard Information Station (J-SHIS [9]) to determine the seismic risk of each bridge. The Probabilistic Seismic Hazard Map was created by calculating probabilities of a quake at or above certain magnitude in certain locations within a certain period based on the probabilistic assessment of possible sites, occurrence probabilities and magnitude of every earthquake expected to occur in and around Japan, as well as expected seismic intensity of each earthquake and possible variations thereof. For calculation of seismic hazard of each location in the map, two of the three factors, i.e. seismic intensity, duration and probability, were fixed and the other one factor was calculated. Then values obtained thereby were plotted on the map at the resolution of 250 meshes. For the purpose of this research, the seismic intensity distribution data were used. While there are seismic intensity distribution data for varied scenarios with different durations and probabilities, data for a scenario resulting in the most severe damages were used; in the scenario, an earthquake of certain magnitude will strike Ishikawa at the probability of 2% within 50 years as illustrated in Figure 2.

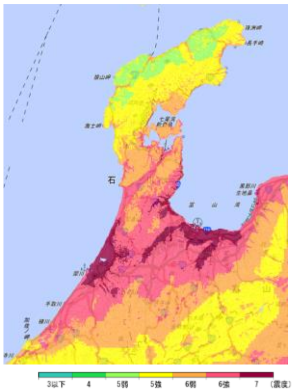

Figure 2 – Distribution of seismic intensity (occurred 2% in 50 years)

4. The Basic Analysis of Bridges in Ishikawa Prefecture

Figure 3 shows the number of bridge by the year of construction. 513 bridges has passed more than 50 years, 1443 bridges has passed more than 30 years in Ishikawa. Figure 4 shows the number of bridge by superstructure material. 624 bridges are made of prestressed concrete, 997 bridges are made of reinforced concrete, 277 bridges are made of steel. Figure 5 shows the number of bridge by length of bridge. The length of the about 65 percent of the bridges is from 2 meter to 15 meter. Figure 6 shows the number of bridge by emergency transportation route. Primary emergency transportation route and Second emergency transportation route are almost equal, with the former accounting for about 23 percent and the latter about 20 percent. Figure 7 shows the number of bridge by prediction on seismic intensity. Bridges in Ishikawa may suffer from damage caused by earthquakes

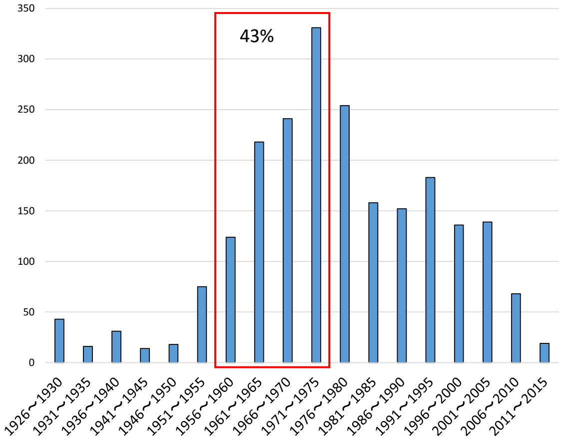

Figure 3 – The number of bridges by the year of construction

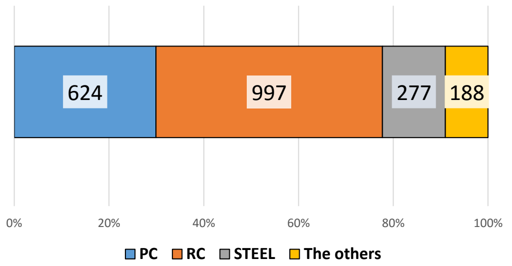

Figure 4 – The number of bridges by superstructure material

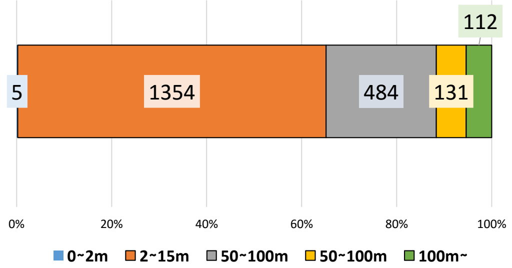

Figure 5 – The number of bridges by length of bridge

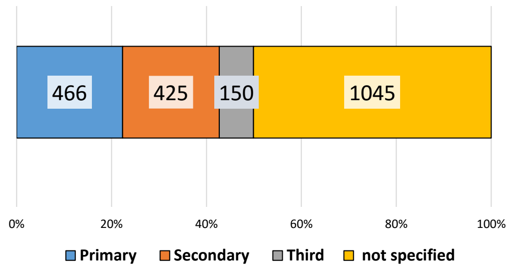

Figure 6 – The number of bridges by emergency transportation route

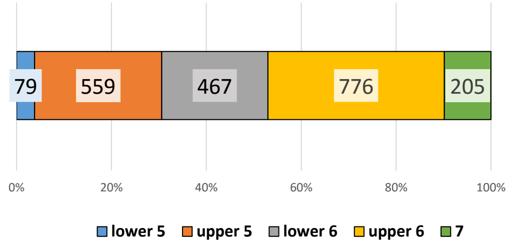

Figure 7 – The number of bridges by prediction on seismic intensity

5. Analysis Condition for Principal Component Analysis

Total score of each bridges was calculated by principal component analysis to decide repair priority taken into account the seismic risk. Importance score of bridge and destruction risk score were used as the variable. Importance score of bridge were taken into account how large impact on traffic at breakdown time, for example “Emergency route”, “Crossing”, ”Daily traffic volume”, “Length of bridge”. Destruction risk score were taken account how high probability of destruction at the time of earthquake, for example “Soundness (Main girder, Bearing apparatus, Expansion device)”, “Seismic intensity”, “Salt damage”, “ASR”.

Soundness has been evaluated in five stages in health order 5, 4, 3, 2 and 1. Figure 8, 9, 10 shows the number of bridge by soundness. Figure 8 shows that the percentage of soundness 5 about main girder was 59 percent. Figure 9 shows that the percentage of soundness 5 about bearing apparatus was 73 percent. Figure 10 shows that the percentage of soundness 5 about expansion device was 64 percent. In comparison with bearing apparatus and expansion device, soundness about main girder was worse.

Table 2, 3 shows the categorization for each variable. Principal component analysis was performed using this categorization.

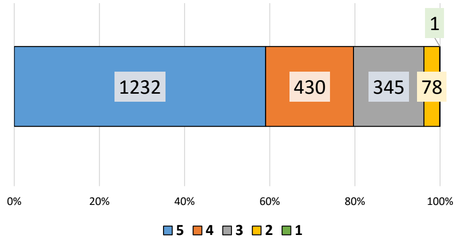

Figure 8 – The number of bridges by main girder soundness

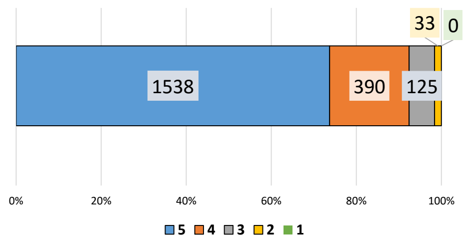

Figure 9 – The number of bridges by bearing apparatus soundness

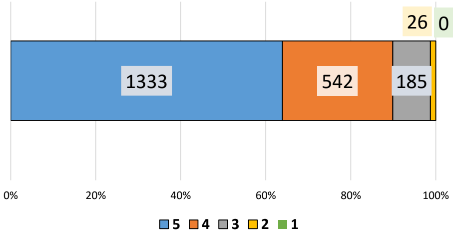

Figure 10 – The number of bridges by expansion device soundness

Table 2 – Importance of bridge

Item	Subdivision	Importance score
Emergency route	Primary	3
	Second	2
	Third	1
	Not specified	0
Crossing	Railroad,River	3
	Road	2
	The others	1
Daily traffic volume	20000 and over	5
	From10000 to 20000	4
	From 5000 to 10000	3
	From 1000 to 5000	2
	1000 and less	1
Length of bridge	100m and over	5
	From 50 to 100m	4
	From 15 to 50m	3
	From 2 to 15m	2
	2m and less	1

Table 3 – Destruction risk

Item	Subdivision	Destruction risk score
Soundness (Main girder, Bearing apparatus, Expansion device)	1	5
	2	4
	3	3
	4	2
	5	1
Seismic intensity	7	5
	Upper 6	4
	lower 6	3
	Upper 5	2
	lower 5	1
Salt damage, Alkali aggregate reaction	Yes	1
	No	0

6. Proposal of Repair Priority

Eigenvalues of the first principal component was 2.029, the contribution rate was 22.55 percent. The first principal component can be total score because all of the first principal component became positive value. Weighting of the variables by the first principal component load quantity got total score of the priority. Figure 11 shows First main component load quantity. Total score was defined as shown equation (1). We compered priority obtained based on a total score with existing priority. Existing priority was classified into five stages based on the priority index obtained by the soundness of the each elements. Priority obtained by principal component analysis was classified into five stages in the order of descending total score. Table 4 shows priority classification.

Figure 12, 13 shows the proportion of priority by prediction on seismic intensity. Figure 12 shows that percentage of bridges of priority 5 in the high prediction seismic intensity was small. Therefore, it clearly shows that how to determine existing priority didn't consider seismic risk. On the other hands, Figure 13 shows that percentage of bridges of priority 5 in the high prediction seismic intensity was high and percentage of bridges of priority 1 in the low prediction seismic intensity was low. Therefore, it is obvious from Figure 13 that priority obtained by the principal component analysis considered the seismic risk.

$$\text{Total Score} = \sum_{i=1}^{9} \alpha_i x_i \qquad (1)$$

α : The first principal component load quantity

x : The variable

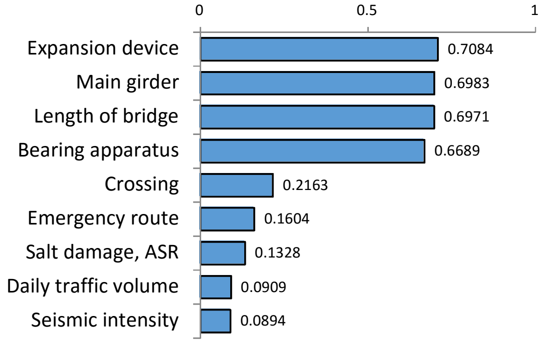

Figure 11 – First main component load quantity

Table 4 – Priority levels

Priority	Priority levels
1～417place	5
418～834place	4
835～1251place	3
1252～1668place	2
1669～2086place	1

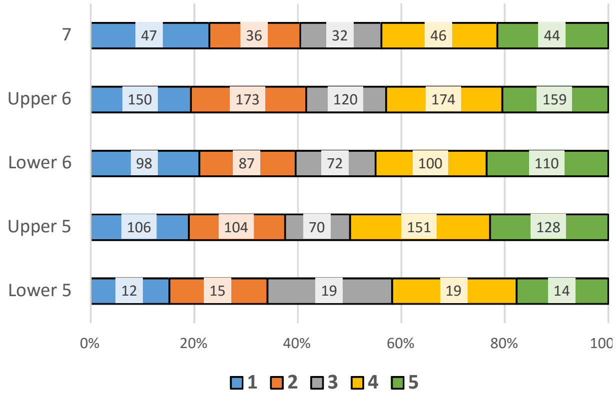

Figure 13 – Existing priority levels by seismic intensity

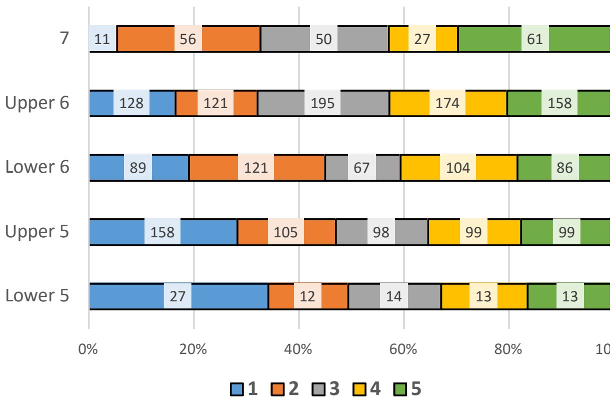

Figure 14 – Priority levels in consideration of seismic risk by seismic intensity

7. Conclusion

The basic analysis of bridges in Ishikawa was examined using the inspection data of Ishikawa Prefecture. The proposal of repair priority determination method considering the seismic risk was carried out using a principal component analysis. When considering the seismic risk, it was confirmed that the priority of the bridge changed in comparison with the existing method.

A further study of generalization of the inspection order determination method that takes into account the seismic risk using the inspection data of the whole country should be conducted. Also, not only earthquake risk, we are going to do a study of consideration of other disaster risk.

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