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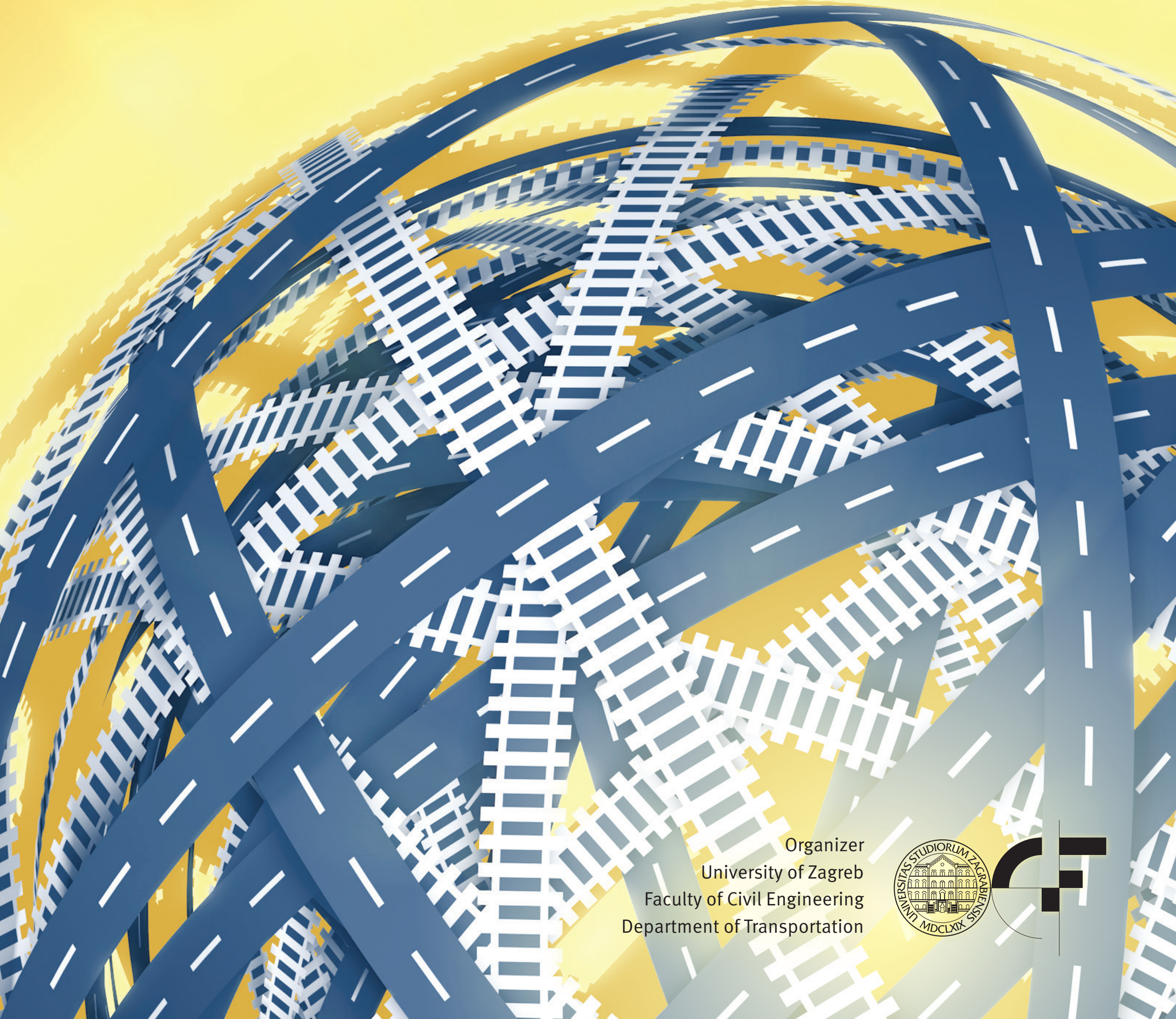
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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ANALYSIS OF THE INFLUENCE OF THE NATURAL ENVIRONMENT ON BRIDGE SOUNDNESS

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Abstract

In recent years, extending the service lives of bridges has become a topic of discussion. As the bridges built during the rapid economic growth period have reached the end of their service lives, replacing these bridges or extending their service lives are being discussed. Within this situation, local municipal governments are also conducting regular inspections once every five years as part of preventative maintenance, rather than performing corrective maintenance. In this study, we will shed light on which bridges are most prone to rapid deterioration by using data from the regular inspection of bridges. We will do this by calculating the deterioration rate from inspection data from two inspection cycles in order to determine the environmental factors that affect the deterioration rate. In regards to analysis methods, we used Hayashi's Quantification Method Type I to grasp the level of influence each factor has on the deterioration rate.

Keywords: bridge, maintenance, regular inspection, bridge soundness, natural environments

1 Introduction

Japan currently has around 700,000 road bridges (at least 2.0 m long). As shown in Figure 1, 18% of these were bridges older than the typical 50-year service life of bridges (older bridges) in fiscal 2013. In another 10 years, this percentage is expected to grow to around 43% [1]. As public works spending continues to decrease yearly, within a few years all of the bridges built in great number during the rapid economic growth period will have been in service for more than 50 years. At this point, dealing with the problem of aging bridges point will be infeasible in terms of both human resources and cost. Should these bridges be closed, the road transportation network could be greatly affected [2].

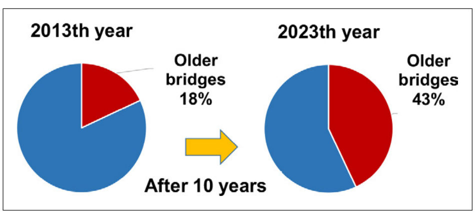

Figure 1 Styles dialogue in Microsoft Word 97-2003 [1]

Given this situation, emphasis has been put on efficient maintenance and operation, and the national government and local municipal governments are engaging in regular inspections of bridges while also actively creating frameworks for asset management. However, there are two main issues with maintenaning and operating bridges through regular inspections. The

first is the issue of the inspector's determination of the soundness of the components of each bridge. The second issue is using the data on the soundness of each component to calculate the overall soundness of the bridges as a whole and determine its priority. In this study, we are dealing with the former; the issue of determining priority.
The state of damage (soundness) and importance of a bridge are considered when its priority is determined. In the case of Ishikawa Prefecture, the BHI (Bridge Health Index), an index of the overall soundness of a bridge, is calculated from the soundness of each component. The BHI is a qualitative index calculated through the weighted average method using the soundness of each component and a weight coefficient between the components. The importance of bridges is evaluated using the BPI (Bridge Public Index), an index of bridge importance that comprehensively evaluates the importance of the route and the traffic volume. Calculated using the weighted average method, BPI focuses on the importance of the route (emergency transportation routes, road and railway overpasses) and the traffic volume (by type of traffic), with a weight coefficient established for each. The priority P for bridge maintenance and replacement is deter-mined by a composite value of these two indices, BHI and BPI.
However, these evaluation methods do not consider the environmental conditions surrounding a bridge. Bridges with different environmental conditions are expected to have greatly different rates of deterioration. Therefore, maintenance and operation that does not consider environmental conditions does not allow the priority of bridge maintenance and replacement to be determined in a manner that is appropriate for the rate of deterioration. Therefore, in this study we will statistically analyze the environmental factors which affect the soundness of bridges evaluated in regular bridge inspections using regular bridge inspections data from two inspection cycles.

2 Data analyzed

In this study, we analyzed the bridges managed by Ishikawa Prefecture. Ishikawa Prefecture is a harsh environment for bridges due to factors including flying salt caused by the meteorological characteristics of its winters, the dispersal of antifreezing agents primarily in mountainous areas to keep roads passable in winter, and fatigue caused by heavy loads and impacts from vehicular traffic in urban areas with high traffic volume.

2.1 Regular bridge inspection data

As shown in Table 1, regular bridge inspection data includes the specifications of the bridges and inspection data. These specifications include the year of construction, superstructure material, bridge length, road traffic census data (daily traffic volume, daily large vehicle traffic volume), location, latitude and longitude, rehabilitation and reinforcement priority, etc. Regular inspections are conducted once every five years, with the items inspected being the main girders, slabs, substructure, expansion joints, bearings, and deck. Their soundness is discretely evaluated using a descending five-point scale with 5 being entirely sound with no apparent damage.

Table 1 Measuring results.

Name of bridge	The year of construction	Superstructure material	Bridge length	Daily traffic volume	Main girders	Slabs	Substructure	Bearings	BHI	BPI	P	Latitude	Longitude
A	1964	RC	34.5	1200	5	3	3	5	70.5	30.0	29.7	36.110	136.688
B	2001	Steel	19.0	1200	5	4	5	5	94.0	30.0	15.6	36.114	136.681
C	1983	RC	7.2	933	5	5	4	5	89.5	30.0	18.3	36.123	136.669
D	1963	RC	3.2	933	5	5	4	5	90.5	30.0	17.7	36.131	136.660
E	1962	RC	5.7	933	5	5	4	5	90.5	30.0	17.7	36.142	136.660
F	1964	RC	5.6	933	5	4	4	5	86.0	30.0	20.4	36.159	136.658
G	1962	RC	2.5	933	5	3	3	5	73.0	30.0	28.2	36.162	136.652
H	1962	RC	4.5	933	5	4	3	5	76.5	30.0	26.1	36.163	136.650
I	1994	PC	14.5	1200	5	5	3	5	78.0	30.0	25.2	36.163	136.650
J	1991	PC	20.0	1200	4	4	4	5	75.0	30.0	27.0	36.165	136.638
K	1991	Steel	30.0	1200	5	4	4	5	84.5	30.0	21.3	36.167	136.633
L	1973	RC	3.8	900	5	3	3	5	73.0	45.0	34.2	36.168	136.621
M	1974	Steel	148.4	702	4	4	4	5	73.0	45.0	34.2	36.170	136.621
N	1975	PC	99.9	702	3	5	3	3	57.0	45.0	43.8	36.173	136.622
O	1977	PC	10.5	2300	3	4	3	5	57.5	50.0	45.5	36.185	136.622
P	1975	Steel	37.8	2300	4	4	3	3	64.0	50.0	41.6	36.184	136.622
Q	1973	Steel	27.5	900	5	2	4	5	77.0	45.0	31.8	36.178	136.624
R	1997	PC	52.0	1000	4	4	3	5	64.5	45.0	39.3	36.200	136.345
S	1964	RC	6.8	100	5	5	4	5	87.5	35.0	21.5	36.204	136.525
T	1996	PC	96.8	200	4	5	4	5	77.0	30.0	25.8	36.209	136.391
U	2003	PC	19.0	1000	5	5	4	5	90.5	45.0	23.7	36.211	136.349
V	1996	PC	38.0	200	5	5	5	5	96.0	30.0	14.4	36.211	136.349
W	1963	PC	5.0	200	5	3	3	5	71.0	30.0	29.4	36.213	136.359
X	1973	Steel	36.0	100	4	3	4	3	70.0	35.0	32.0	36.217	136.530
Z	1970	PC	10.0	100	4	4	3	3	64.0	35.0	35.6	36.222	136.532
AA	1938	RC	7.9	800	3	3	2	5	45.5	30.0	44.7	36.222	136.532
AB	1964	Other	2.0	3500	5	4	3	5	77.5	55.0	35.5	36.222	136.360
AC	1961	PC	31.0	3500	4	4	4	4	75.0	45.0	33.0	36.222	136.360
AD	2003	Other	5.0	1362	5	5	4	5	89.5	50.0	26.3	36.222	136.360
AE	1999	Other	3.5	1362	5	5	4	5	89.5	50.0	26.3	36.222	136.360
AF	1999	Other	4.2	1362	5	4	3	5	77.5	50.0	33.5	36.222	136.360
AG	1995	Steel	35.0	752	4	5	4	3	78.0	45.0	31.2	36.222	136.360
AH	1963	RC	6.4	200	5	3	3	5	73.0	30.0	28.2	36.232	136.437
AI	1964	RC	6.9	200	5	3	3	5	73.0	30.0	28.2	36.235	136.437
AJ	1963	RC	6.1	200	5	3	3	5	73.0	30.0	28.2	36.237	136.437

2.2 Geographical Information System (GIS) data

We conducted an analysis utilizing GIS of the 2086 bridges managed Ishikawa Prefecture (out of 2314) for which location information is included. In actuality, each bridge has bridge length, the regular bridge inspection data only representative location information is included. The "representative location information" we refer to here corresponds the point at which the bridge was inspected, and does not necessarily correspond to the center point of the bridge. In this study, we used the representative location information as the representative point of each bridge. By displaying a bridge's location information in GIS, we can add geographical information not included in the regular bridge inspection data. In this study, we used the National Land Numerical Information as our source of geographical information. The National Land Numerical Information represents numerical data pre-pared from information related to the national lands to support the promotion and formulation of land planning such as the Comprehensive National Development Plan, National Land Use Planning, and National Spatial Strategy [3].

3 Evaluation of the level of influence on the soundness of bridges

In this chapter, we will statistically analyze the bridges managed by Ishikawa Prefecture to determine what level of influence the environmental factors and bridge specifications (bridge length, years in service, superstructure material) on the soundness obtained during regular bridge inspections. As previously stated, Ishikawa Prefecture's regular bridge inspections inspect six components: the main girders, slabs, substructure, expansion joints, bearings, and deck. However, our analysis targets what could be called the two primary components: the main girders, slabs.

3.1 Deterioration index from the soundness of bridges

In Ishikawa Prefecture's regular bridge inspections, the level of damage to bridges is evaluated as soundness using a five-level scale every five years,. Simply using the soundness of bridges as an index of bridge deterioration causes several problems, including the following two. First, this makes it impossible to grasp the deterioration in relation to a structure's real (as opposed to nominal) age, as it only accounts for a bridge's state of damage at one point in time. Second, it makes it impossible to grasp how soundness has recovered after rehabilitation, etc. In Ishikawa Prefecture, data on the regular bridge inspections began being accumulated in 2003. As there are bridges for which two inspections have been performed, we will use the data from two inspection cycles to calculate each bridge's deterioration index. As shown in Formula (1), we defined the deterioration index as the difference between the soundness obtained in the first regular inspection and the soundness obtained in the second regular inspection divided by the time span between both inspections. By using deterioration rate into an index, we can treat deterioration rates larger than 0 as normal deterioration, a deterioration rate of 0 as being no deterioration, and deterioration rates of less than 0 as the possibility of previous rehabilitation or reinforcement. Therefore, even with Ishikawa Prefecture's regular bridge inspection data, which does not contain thorough records of rehabilitation history, we can grasp the real deterioration by excluding samples with a deterioration rate of less than 0 that may have been rehabilitated or reinforced.

$$\upsilon = \frac{s1 - s2}{t2 - t1} \tag{1}$$

Where:
υ – deterioration rate;
s1 – soundness during first inspection;
s2 – soundness during second inspection;
t1 – year of first inspection;
t2 – year of second inspection.

3.2 Analysis methods

We used Hayashi's Quantification Method Type I to analyze the level of the influence of environmental factors on the soundness of bridges. Hayashi's Quantification Method Type I is a method for investigating the relationship between the objective variable and explanatory variables, creating a relational expression, and shedding light on the degree of influence each level of the explanatory variables has on the objective variables, the importance of the explanatory variables, and the predictions of the objective variable. The way it differs from multiple regression analysis is the data format for the explanatory variable. Multiple regression analysis uses quantitative data, while category data is used in the case of Hayashi's Quantification Method Type I. In this study, we have applied Hayashi's Quantification Method Type I by quantifying the levels of each environmental factor as explanatory variables. Further, in order to compare the level of influence that environmental factors and bridge specifications (bridge length, years in service, superstructure material) have, we decided to quantify the bridge specifications (bridge length, years in service, superstructure material) with each level and add them to the explanatory variables.

3.3 Dividing each factor into levels

When conducting our analysis, we divided each factor into several levels. Levels refers to the respective conditions set within each factor. Ideally, these conditions should be set based on standards established to serve as the basis of each environmental factor. However, there are currently no standards to serve as the basis for establishing levels for each environmental factor. Further, determining levels based on nationwide standard values would cause a bias in the sample sizes of the levels for environmental factors more prominent in Ishikawa Prefecture than in the rest of the country. As such, we decided to not set each environmental factor subjectively, and to instead classify each environmental factor into five levels so the sample size of each level would be equal. However, because the data on the dispersal of antifreezing agents only indicates whether or not antifreezing agents had been dispersed, we decided to use two levels: Dispersal and No Dispersal. Further, we established levels for distance from the coastline and daily traffic volume and large vehicle traffic volume based on the standards devised by the authors. For bridge length, we established five levels: 0-5 m, 5-15 m, 15-50 m, 50-100 m, and >100m. For years in service, we established six levels: 0-10 years, 10-20 years, 20-30 years, 30-40 years, 40-50 years, and >50 years. For superstructure material, we established four categories: PC, RC, Steel, and Other.

3.4 Results of analysis

We used the detorioration rate calculated from the soundness of each component as the objective variable, and the environmental factors and bridge specifications as the explanatory variable. Further, in regards to the factors with large ranges obtained through Hayashi's Quantification Method Type I, in other words, the environmental factors that had a large influence on deterioration rate, we shed light on the positive and negative influences that affect the deterioration rate.

3.4.1 Main girder deterioration rate

The sample size we used in our analysis of factors that influence the deterioration rate of main girders was 964 bridges. The multiple correlation coefficient was 0. 33. Figure 2 shows the level of influence each factor had on the deterioration rate of main girders. In it you can see that the factor with the largest influence on the deterioration rate of main girders was superstructure material. It can also be said that the distance from the coastline was a very close second. The category scores for superstructure material and distance from the coastline are shown.

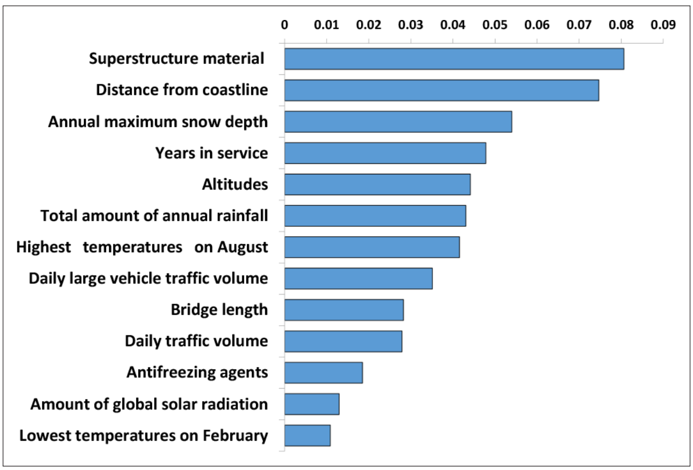

Figure 2 Range of each factor (main girders)

Figure 3 shows the category scores for superstructure material and distance from the coastline. In it we can see that the Steel and PC categories have a positive influence on the deterioration rate of main girders. In other words, they accelerate deterioration. Possible causes for steel bridges are that they may be more easily subjected to damage, or that the damage is more easily noticed. Possible causes for PC bridges include mistaken judgment by inspectors due to the fact that PC materials are intended to tolerate cracking. Excluding distances of 300 m or less, we can see that the deterioration rate grows smaller the greater the distance from the coastline becomes. However, despite the fact that bridges within 300 m of the coastline are the most easily influenced by flying salt, the influence is negative. One possible cause is that measures against salt damage have already been implemented in terms of hardware and/or software for bridges within 300 m of the coastline.

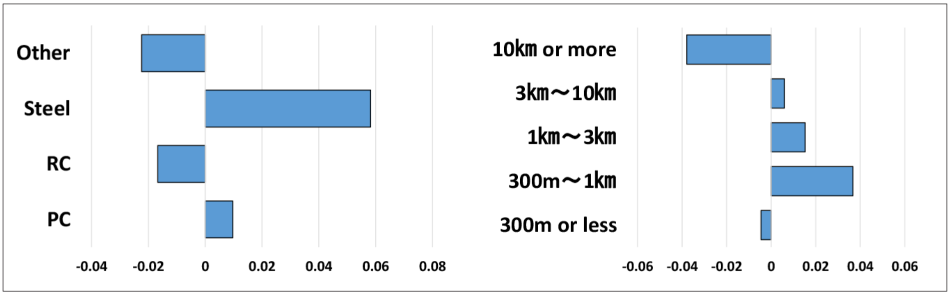

Figure 3 Category scores for superstructure material and distance from the coastline (main girders)

3.4.2 Slab deterioration rate

The sample size we used in our analysis of factors that influence the deterioration rate of slabs was 936 bridges. The multiple correlation coefficient was 0.33. Figure 4 shows the level of influence each factor had on the deterioration rate of slabs. In it you can see that the factor with the largest influence on the deterioration rate of slabs was years in service, and that the second largest influence was that of daily traffic volume. The category scores of the largest influences, years in service and daily traffic volume, are shown. Figure5 shows the category scores for years in service and daily traffic volume. Longer years in service have the effect of accelerating the deterioration rate of slabs. This influence becomes positive at around 40 years in service. Therefore, the slabs of bridges with more than 40 years in service require countermeasures of some sort. In it we can see that, largely speaking, the larger the daily traffic volume becomes, the more the deterioration rate of slabs is accelerated. As the influence becomes positive when daily traffic volume reaches 4000 vehicles/day, the slabs of bridges with a daily traffic volume of more than 4000 vehicles/day require countermeasures of some sort.

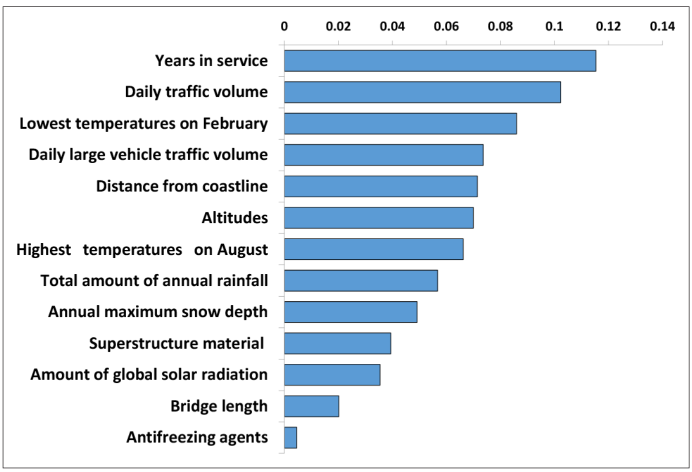

Figure 4 Range of each factor (slabs)

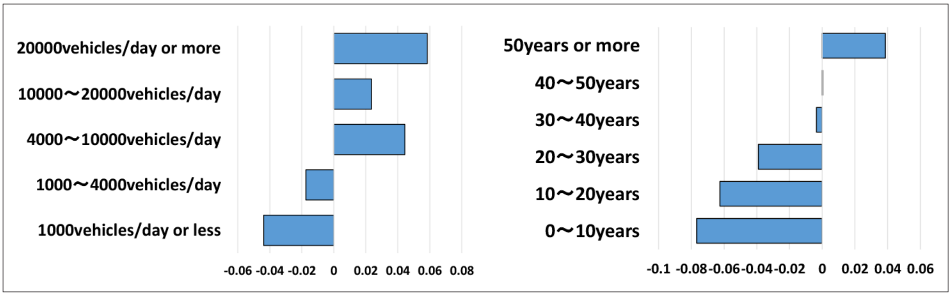

Figure 5 Category scores for years in service and daily traffic volume (slab)

4 Conclusions

In this study, using data from regular bridge inspections conducted as part of the maintenance and operation of road structures, and focusing on the environmental conditions that surround bridges, we analyzed the factors that influence the soundness of bridges obtained during inspections. Calculating an index called deterioration rate using inspection data from two inspection cycles, bridge inspections, we statistically analyzed the level of the influence that factors have on the deterioration rates of bridges using Hayashi's Quantification Method Type I. As it became clear that while bridge specifications (superstructure material, bridge length, year of construction) had a large influence on the deterioration rate of each component, environmental factors also had an influence of equivalent size. As such, there is a need to consider environmental factors when determining the rehabilitation priority of bridges.
Considering the fact that this study focused only on bridges managed by Ishikawa Prefecture, and that there is insufficient basis for setting the levels for each environmental factor in regards to the deterioration of bridges, we are presented with a few issues for the future. The first is conducting a comparison with the bridges of other prefectures with different environments. The second is determining appropriate levels by establishing a number of level patterns in regards to the levels of each environmental factor. The final issue is utilizing the results of this study to propose methods for predicting deterioration and determining rehabilitation priority that take the factors that influence deterioration rates into account.

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