THE RIGHT TIME AND RIGHT BUDGET TO MAINTAIN THE COMPONENTS OF BRIDGE

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ABSTRACT

Usually the status of a bridge is determined by its structural capability and material strength. Consequently a lot of researchers have studied the failure, the fatigue, and the deterioration of the structure in terms of the structural function of a bridge. However, the overall performance of a bridge may be affected simply by the damage of one of its components. Therefore this study utilized a systematic classification and statistical analysis based on the existing bridge inspection data collected in Taiwan to reach the following goals: (1) assess the performance distribution and deterioration rate for bearing and expansion joint of bridge; (2) find out the right time to do the preventive and essential maintenance for the component of bridge with an empirical method, and to decide what time and which component of a bridge will receive preventive maintenance or regular maintenance.

Keywords: Strategy, Safety, Bridge Maintenance, Deterioration, Performance Index, Lifetime.

Symbols

D Degree is defined as the severity of the component defect under consideration

E Extent is the extent to which the defect occurs over the area of the bridge component

R Relevancy is the importance of the defect on the serviceability and structural safety

X Lifetime of the bridge component (year)

Y Performance index

1. INTRODUCTION

In most of Taiwan, bridge inspections are mandatory and are carried out on a periodic basis. These inspection data are utilized to analyze the performance of the inspected bridge. Even so, it remains a challenge to find a reasonable and reliable result for reflecting the level of performance service. In the beginning of the 20^{th} century, bridge maintenance, repair, rehabilitation, and replacement activities in Taiwan were performed strictly on an as-needed basis due to the budget limitation. The Taiwan government was subsequently advised that an optimized bridge management system was urgently needed. Therefore the goal of this paper is to utilize existing site survey data to find a performance trend or a rate of deterioration for each component, and to decide what time and which component of a bridge will receive preventive maintenance or regular maintenance. It is the hope and the intention of this research that the raw inspection data can be processed, and the result can provide us with some valuable information for bridge maintenance. This paper presents a bridge inspection system for Taiwan, and an analysis procedure of the model that was derived, based on data from several counties. Finally the performance, deterioration and expected life span of each component of a bridge can be obtained using this assessment procedure.

Recently researchers have started to focus on a micro point of view to assess the performance of any bridge. Ayaho, Kei and Hideaki [1] tried to develop an overall outline of the Bridge Management System in Japan, but durability and load-carrying capacity of a bridge are the only factors used to determine deterioration, and there is still no mention of the relationship between the performance (health condition) and the age of the bridge.

Table 1: THE PREDEFINED SAFETY COMPONENTS OF BRIDGE

Group No.	Structure Component
1	Abutment /Wing wall
2	Pier & column
3	Bearing
4	Earthquake stopper /restrainer
5	Expansion joint
6	Girder
7	Diaphragm
8	Deck slab

In Taiwan, the traditional Bridge Management System (BMS) includes a module to assist with visual inspection rating. Each of the 8 predefined elements of a bridge (see table 1) is assessed in terms of a 0 to 4 rating for Degree, Extent and Relevancy (DER) (see table 2). The Bridge Inventory in the system format attaches a subjective rating from 0-4 to each portion of the bridge that represents its physical condition. But there is no practical or unified method to measure the deterioration of a bridge based on this 0-4 rated data. Although the bridge is divided into 8 individual components, it is difficult to classify these sections of the bridge comprised of the same material and expect them to deteriorate in the same manner as in other countries. Because of the lack of certain data in Taiwan, the prediction of the deterioration rates can not be processed like the Markov model in Pontis which automatically updates the deterioration rates after historical inspection data are gathered. Therefore, this research will provide a method to solve this issue.

Table 2: THE DEGREE, EXTENT AND RELEVANCY (DER) RATING FOR VISUAL INSPECTION

Index Items	Rating				
	0	1	2	3	4
D (Degree)	No such item	Good	Fair	Poor	Severe
E (Extent)	Cannot be inspected	< 10%	< 30%	< 60%	<
R (Relevancy)	Cannot be decided	Minor	Small	Medium	High

Degree is defined as the severity of the component defect under consideration.

Extent is the extent to which the defect occurs over the area of the bridge component.

Relevancy is the importance of the defect of the component on the serviceability and structural safety.

2. OBJECTIVES

This paper investigates the current practice in Taiwan regarding bridge management systems, which is based on visual inspections and applying a structural performance index during the lifetime of each existing bridge component. Basically this practice will not be able to realize the entire condition, safety, and cost profile of a bridge, unless the deterioration of each component of bridge is analyzed and determined. It would be great to have one simple procedure and set of rules to define the state of health of a bridge, and then, based upon the inspection data and a realistic assumption, determine the maintenance strategy. However, the following are the inspection regulations as required in Taiwan. It shows the raw index of the inspection condition for each of the 8 predefined components of a bridge related to the safety of the bridge (see table 1). The contribution of this research will allow us (1) to assess the performance and deterioration rate for each safety component of a bridge; (2) to find out the right time to do the preventive and essential maintenance for the component of bridge with an empirical method, and to decide what time and which component of a bridge will receive preventive maintenance or regular maintenance.

So, two main topics will be introduced. First, a trial safety performance model for the deterioration rate of each structural component will be introduced. A preventive maintenance strategy will be set up based on the different deterioration rates for each of the components. Finally, the maintenance schedule of each component of bridge is introduced.

3. PERFORMANCE INDEX

The foundation of Taiwan's BMS is also its inventory database. The first step in the implementation of the BMS is to compile a bridge inventory which consists of the listing and recording of all the bridges within the network, complete with comprehensive details as to the type of bridge, DER rating etc. First, from a general perspective it can be assumed that bridges of the same age have a similar functional performance. Therefore, if enough inspection data has been collected for each component of the bridge, at different ages of the bridge, so as to represent a virtual situation of performance of the bridge at any specific age, then it would be possible to figure out the statistical relationship between the age of a bridge and its performance index.

This paper utilized the inspection survey data saved in the department of communication and transportation. Since concrete bridges are very popular in Taiwan, the research model in this paper is primarily focused on concrete bridges. In order to avoid any deviation due to the influence of data from a very large amount of small bridges (less than 10m), this research removed the data of bridges with a span of less than 10m. A basic inventory data and DER inspection data was carried out for each component of these bridges. The functional obsolescence of a bridge is calculated using a comparative standard score table. Any situation for any component of a bridge will correspond to the index value based on the comparative scoring table. The number of data sets is large enough to plot the deteriorating tendency of the component based on the comparative table of bridge performance indexes. The performance of each component of a bridge will be quantified, and when the component has more than one defect, then the most severe defect is chosen for the rating. In other words, after completing the performance index for each component of 1697 sets of bridges, the critical performance index for each sub-item of the 8 safety components is calculated. The distribution of the performance index can be summed up as the static data based on the different ages of the groups, and table 3 shows the performance index of each component of the bridges listed in order of 5 years time intervals, it is evident that the abutment has the worst performance index in any of the lifetime profiles, and that the girder always maintains the better performance situation.

Table 3: THE DISTRIBUTION OF THE SAFETY PERFORMANCE INDEX

Component	Range of bridge age (year)								
	0~5	5~10	10~15	15~20	20~25	25~30	30~35	35~40	40~45
1_Abutment	71.37	69.24	66.57	69.31	68.40	68.70	66.94	65.14	70.67
2_Pier	73.71	73.83	72.23	71.78	72.59	69.89	71.42	64.54	68.67
3_Bearing	82.44	81.41	79.74	79.41	78.80	76.67	76.84	77.71	81.33
4_Earthquake Stop.	82.47	80.15	78.36	77.67	76.98	77.11	76.23	76.36	78.17
5_Joint	80.61	77.44	77.09	77.14	76.36	76.09	76.23	74.11	78.17
6_Girder	92.39	91.21	88.42	85.04	85.09	87.22	92.16	81.96	87.33
7_Diaphragm	87.83	88.29	86.90	87.12	84.90	83.44	87.84	87.14	87.67
8_Deck Slab	91.39	91.23	87.28	84.08	84.39	84.57	84.71	86.32	86.00

4. DETERIORATION

Two deterioration models, as mentioned in the Rijkswaterstaat model [5] and the model by Frangopol [3], have been applied by the Ministry of Transport, Public Works and Water Management in the Netherlands, and the UK Highways Agency respectively. The deterioration in the Rijkswaterstaat's model is determined based on the gamma process with independent increments for one component, while a uniform-distributed deterioration rate is assumed in Frangopol's model while considering more than one component. This paper tries to find the practical deterioration rate with an empirical method to apply it to Taiwan, with different data category, classification and environment conditions.

Rating the degree of the defect of each component separately enables the engineer to obtain actual rates of deterioration. From the previous section, the performance in time series for each component can be displayed as shown in figure 1. Obviously there are three shapes in the different phases; the first shape is deeply drooping curve at beginning, which means that that particular component did not receive any maintenance, and the deterioration happened quickly during that time period. The rate of deterioration for each component is shown in table 4. The second shape is flat or has small upward slope around ages of 20 years old, due to the fact that the management organization carried out preventive maintenance during that time period, and the last shape is steep upward slope, indicating that essential maintenance has been carried out. From figure 1 and table 4, we can see the initial deterioration rate for each component. Based on the description of Tserng and Chung [6], the lowest acceptable performance limit of bridge is 78. Therefore we can derive the proposed lifetime for each specific component if there is no maintenance from the beginning to the end (Please refer to the table 5 and figure 1). The total lifetime for most bridge components are pretty close to 50 years, which is adequate. The 94.3 life span of the diaphragm far exceeds the 50 design years. It seems that the design criterion is too conservative for the diaphragm. However, the lifetime of the abutment and wing/retaining wall is only 16.8 years, the pier is only 37.4 years, and the expansion joint has a life span of only 25.4 years. The only reason to explain the result is that the design criteria of the seismic analysis were developed after 2000 for the high frequency of seismic area in Taiwan. Therefore, the new design criteria consider that all the existing old components of piers, abutment and wing/retaining wall must be upgraded as part of the essential maintenance in the future.

5. MAINTENANCE SCHEDULE

The condition of a structure can only be restored to its original condition through replacement and actual retrofitting. There is evidence of increased deterioration in the past years for 1697 bridges built in different time periods (see table 4). Both the expansion joint and the deck slab of these bridges have a higher level of deterioration rate in the early part of its life (see table 4). Because the failures of those two components are happen fairly readily, their restoration through regular maintenance happens quite readily as well. Approaching the end of their service life, the components with the highest level of deterioration are the pier and girder. In fact the life span of deck slab and earthquake stopper can be extended by rebuilding or replacing them, this will allow the performance index to return to well above the allowable limit for each component. In other words, based on empirical data, the scenario of extension lifetime of each component can be predicted as shown in figure 1, if the maintenance budget and the government policy remain the same in the future as it was for the past 45 years. Except for the deck slab, figure 1 shows a similar phenomenon for all the components. Basically the curved line in figure 1 can be separated into three sections, which are the deteriorating phase (down abruptly), preventive maintenance phase (up slightly), and the essential maintenance phase (jump back up to the higher level). For the deck slab, deterioration occurs rapidly due to the combination of high loading by heavy vehicles and a high traffic flow, but restoration is accomplished relatively fast as well.

Table 4: THE DETERIORATION MODEL FOR EACH COMPONENT OF BRIDGE

Component Item	Deterioration Ratio	
	First Phase	Second Phase
Abutment & Wing wall	Y= - 0.5093X+72.878	Y= - 0.3395X+77.911
Pier & column	Y= - 0.3163X+76.135	Y= - 1.3290X+114.48
Bearing	Y= - 0.2867X+83.349	Y= - 0.4287X+88.281
Earthquake stopper	Y = -0.4335X+83.579	~
Expansion joint	Y= - 0.7238X+82.708	Y= - 0.409X+89.478
Girder	Y= - 0.5861X+95.537	Y= - 1.9687X+155.94
Diaphragm	Y= - 0.2753X+90.294	Y= - 0.3934X+93.943
Deck slab	Y= - 0.6779X+95.985	~

Table 5: THE PROPOSED LIFETIME WITHOUT ANY MAINTENANCE

Group No.	Component Item	Proposed Lifetime (year)
1	Abutment & Wing/ retaining wall	16.8
2	Pier & column	37.4
3	Bearing	66.4
4	Earthquake stopper/restrainer	44.4
5	Expansion joint	25.4
6	Girder	53.3
7	Diaphragm	94.3
8	Deck slab	46.7

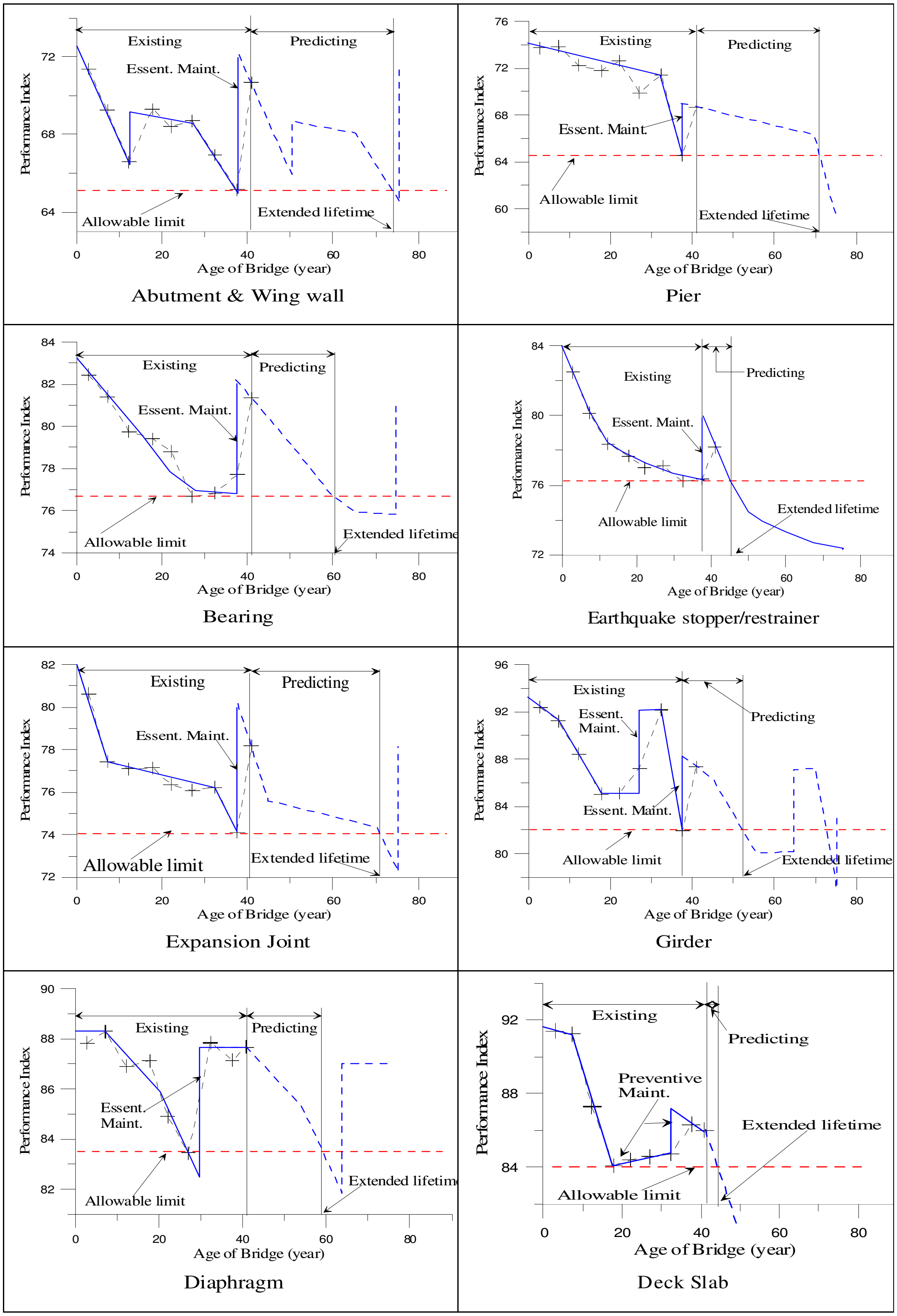

Figure 1. THE PREDICTION OF LIFE EXTENSION FOR EACH COMPONENT

Table 4 shows the ranking of the deterioration rate. The expansion joint and the deck slab are ranked the highest, but the girder and the pier became the highest ranked after 20 years later. It is evident that the expansion joint and the deck slab have the highest deterioration rate in the first 10 years, but the girder and pier reach a deterioration rate 3 times higher than their original rate after 30 years of service. This means that anything can happen in that time period if a strict maintenance schedule is not implemented. As described above, the debris flow, scouring and high occupation rate by heavy vehicles and a high traffic flow are the major contributors. So it is easy for the government to know what are the key components will spend the majority of the maintenance budget on.

Combining the visual inspection data of this group of 1697 bridges will make the performance index value of the bridge condition more accurate, and the deterioration and prioritization strategy will become more practical based on that performance index. Once the cycle period of extended lifetime is defined based on the deterioration rate and recovery ratio (see table 6), the lifetime of a bridge becomes predictable. Basically the government will be able to evaluate their different options: extending the lifetime of a bridge versus maintenance costs, as well as decide which maintenance schedule to implement for components under certain conditions. It will allow them to determine their regular maintenance schedule (between 10 to 25 years in this case study), as well as the special maintenance schedule(after 30 year in this case study).

Table 6: THE PERFORMANCE RECOVERY OF ESSENTIAL MAINTENANCE

Component Item	Lowest allowable limit of performance	Initial index	Restored index	Recovery rate
Abutment & Wing wall	65.14	72.83	72.00	98.86%
Pier & column	64.54	74.25	69.34	93.39%
Bearing	76.67	83.20	82.17	98.76%
Earthquake stopper/restrainer	76.23	83.76	79.78	95.25%
Expansion joint	74.11	82.00	80.00	97.56%
Girder	81.96	93.02	88.186	94.80%
Diaphragm	83.44	88.28	74.37	84.24%
Deck slab	84.08	91.70	86.63	94.47%
			Average	94.66%

6. CONCLUSIONS AND SUGGESTIONS

6.1 Conclusions

This study started with the viewpoint of analyzing the micro-relationship between the component and its performance, and the following practical results were obtained:

- The performance index reflects the degree of impact over a lifetime to each component, and the abutment is the most sensitive and therefore also has the lowest index of all components. On the other hand, the girder has the highest index. It is also pointed out that the substructure is difficult to be maintained, and the government hardly ever does any maintenance on it due to a tight budget.
- The lowest allowable limit of each component is shown in table 6 and figure 1. When the age of a bridge approaches 40 years, the performance index takes a big jump for all the components of bridge. Obviously the performance of the bridge is not acceptable at that time and it is about time to improve the functionality of that component by maintenance.
- It is reasonable to have two deterioration rates in two different time phases for all the components. Most of the deterioration rates are located between 0.2 and 0.5 due to the high frequency of maintenance. The deterioration rate of the deck slab is meaningless because of the frequent repairs. The pier and girder are quite special, since the deterioration rate at the end of their lifetime is almost 3.5 to 4 times as faster than the beginning rate. Particularly the deterioration rates of the pier and the girder of bridges drop very fast after the first 30 years of their lifetime.
- The performance indexes for most of the bridge components show a sudden drop between 30 and 40 years of service. It is evident that after 40 years is a suitable time to carry out some essential maintenance.

6.2 Suggestions

As a result the evaluation of the BMS can be conducted in a realistic engineering environment to obtain practical application experiences to allow for further improvement of the maintenance strategy.

- As described above, the high loading rate of heavy vehicles, typhoon debris flow and seismic activity must be an integral part of the structural design criteria and should be revised to prevent the lifetime of the pier and girder components being shortened more than the other components. Since the approach joint has consistently the lowest performance index, it is necessary to be strengthened so as to bear the particular impact of heavy vehicles in Taiwan.
- This research developed a micro relationship between the age of a bridge and the performance of each bridge component. The administration unit should set up a preventive and essential maintenance schedule for each bridge component. Finally, the government can now estimate their yearly maintenance budget for each bridge component based on the economic analysis.

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