CONDITION ASSESSMENT OF STEEL BRIDGES IN SRI LANKA

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Abstract: The majority of steel bridges in Sri Lanka have been built more than 100 years ago. Most bridges have been subjected to changes such as deterioration due to corrosion, mechanical damage due to fatigue and repair due to maintenance. Therefore condition evaluation of such bridges is vital to ensure public safety. This paper presents condition assessment of selected steel bridges in Kaluthara district. The task is pursued through visual observations. Two mathematical models have been developed in this research to evaluate the condition of bridges. The Analytical Hierarchy Process was applied to obtain the priority vector of bridge elements and important factor of bridge elementswere used to obtain the overall bridge condition index. The modified overall bridge condition index is employed to assess the bridge condition. The results obtained from four selected steel bridges are presented in this paper.

Keywords: Steel Bridge, condition assessment, visual observations, Analytical Hierarchy Process (AHP), Modified Overall bridge Condition Index (MOBI).

1. Introduction

A bridge is a structure built to pass over a physical obstacle such as valley, road, river or railway. Bridges can be classified in several different ways which are type of structural elements used, whether bridges are fixed or movable, by what they carry and by what materials that are used. Bridges should be managed and maintained properly to ensure that the road networks can safely and economically operate.

Most steel bridges in Sri Lanka have been built more than 100 years ago. Most of these bridges have been subjected to change such as deterioration, change of use, repair or mechanical damage. Most of these bridges are in a deteriorated condition. Therefore it is necessary to assess the existing steel bridges. (Rathnayaka et al.,)

The aim of bridge condition assessment is to establish the structural reliability of a bridge including evaluation of strength, serviceability, stability and fatigue. The bridge performance depends on two variables which are the load applied and the residual resistance of deteriorating structural members. These variables change with time. (Lima et al., 2008)

Inspections were done on four selected steel bridges in Kaluthara district. Three of these bridges are truss bridges while the other one is a steel arch bridge. This study was carried out to evaluate the current condition of the bridge. This paper presents the inspection procedure, inspection data obtained by visual observations, defects found at all bridges and steel bridge condition rating methods. Two condition rating methods have been developed. The modified overall bridge condition index is employed to assess the bridge condition.

2. Description of bridges

Bridge No. 01 which is located between Narthupana and Kalutaraconsists of a single span 22.5 m steel trusssupported on abutments. The bridge is made of riveted iron members. The abutments have been made of reinforced concrete. Figure 1(a) shows the general view of bridge No. 01.

Bridge No. 02 which is located between Nagoda and Naboda is a single span 31.3 m steel truss. The bridge was constructed 50 years ago. The bridge is made of riveted steel members. The substructure and foundation have been made of dressed stone. The general view of bridge No. 02 is shown in Figure 1(b). (Bridge Inventory, RDA)

Bridge No. 03 is located between Lathpadura and Molkawa. It consists of a single span 35m steel truss supported on abutments. This bridge was completed with Austrian assistance in 2007. Figure 1(c) shows the general view of bridge No. 03.

Bridge No. 04 consists of a single span 75 m steel arch supported on abutments. It is located between Matugama and Horana. It was constructed in 1999 over Kalu River. The abutments have been made of reinforced concrete. The general view of bridge No. 04 is shown in Figure 1(d).

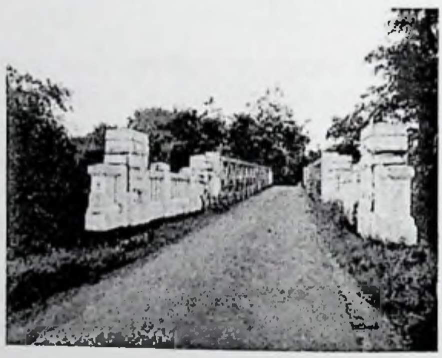
3. Visual Inspection

Visual inspection was carried out in order to evaluate the condition of bridges. The bridge inspection guide was used to inspect the elements of the bridges and defects such as corrosion of the members, joint defects, cracks in the members. The bridge inspection guide was prepared referring existing bridge inspection manuals. The inspection was started from superstructure. Every element of the bridge was inspected and defects were identified and recorded. Other than that the general details of bridges such as span, width, member sizes were also recorded.

4. Development of Condition Rating Method

There are five condition states to categorize the condition of element. These condition states are 1 for very good, 2 for good, 3 for fair, 4 for poor and 5 for very poor. The descriptions of each condition states have been mentioned in the bridge inspection guide. The quantities within the bridge element can be in different condition states. The quantities (unit, length, area) of bridge element were estimated and recorded. Condition is estimated for each element independently. If numbers of deteriorated quantities are high, the condition state value will be increased. The following equation gives the condition state of an element.

(a)



(b)

(c)

(d)

Figure 1: General view of bridges (a) Bridge No. 01, (b) Bridge No. 02, (c) Bridge No. 03, (d) Bridge No.04.

The overall condition state of an element (Cs1)

$$Cs1 = \frac{\sum q \times cs}{\sum q} \text{ ....(1)}$$

Where,

cs= condition state of sub element.
$cs \in (1,2,3,4,5)$
q= quantity of element reported in condition states.

The overall bridge condition index is calculated by combining the different element condition indices. Important factor has to be taken into account to combine the different element indices.

Important factor

Table 1 presents the important factor for different bridge element. Abu Dabous described the structural importance of various bridge elements.(Abu Dabous., 2010). The importance of bridge element is defined considering overall structural integrity and safety of the bridge in this research.

Table 1: Important factors for different bridge elements

Element	Important factor (IF)
Guard rail	1
Wing wall, Bridge surface, Foot path, road drainage	3
Approach road	4
Stems, Expansion Joint	5
Deck, Bearings	7
Top members, Web members	8
Girders, Cross girders, Connections	9

Overall bridge condition index(OBI)

The calculated bridge element condition indices are required to be combined to form the overall bridge index. The bridge condition index represents the overall material and structural condition of the bridge.

$$OBI = \frac{\sum Cs1 \times IF}{n} \text{ ....(2)}$$

n = number of element.
IF = Important Factor.
Cs1 = condition state of an element.

If all elements of a bridge are in very good condition (condition state of all elements is equal to one) the Overall Bridge Index will be 5.467. Also if all element are very poor (condition state of all element is equal to five) the Overall Bridge Index will be 27.333. Therefore the OBI will lie between 5.467 and 27.333. The OBI is divided by 5.467 to obtain the Overall Bridge Index from one to five.

The overall bridge index is modified increasing the range from 10 to 100. The Modified Overall Bridge Index(MOBI) is given by equation(3).

$$MOBI = 22.5 \times \frac{OBI}{5.467} - 12.5 \text{ ....(3)}$$

5. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is popular and widely used in decision making in a wide range of applications. The AHP evaluates decision alternatives by pairwise comparison and allows more accurate judgments than simple weighted product model. Each of this judgment is assigned a number on a scale. One common scale is shown in Figure 2.

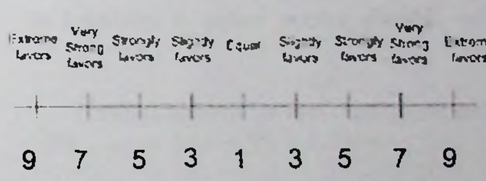


Figure 2: One common scale

There is no exact definition for structural importance of bridge element. The bridge elements are compared in pairs with respect to the structural integrity and safety of the bridge. The results of pairwise comparison are entered in a reciprocal matrix.

The priority vector is obtained by totaling the numbers in each column. Each entry in the column is then divided by the column total. The principal Eigen vector can be obtained by averaging the rows.

The Priority Vector is calculated as follows. The range of priority vector is 1-5.

$$PV = 0.173\mathbf{G} + 0.160\mathbf{CG} + 0.132\mathbf{C} + 0.086\mathbf{D} + 0.022\mathbf{W} + 0.073\mathbf{S} + 0.061\mathbf{B} + 0.032\mathbf{EJ} + 0.033\mathbf{BS} + 0.010\mathbf{GR} + 0.016\mathbf{FP} + 0.072\mathbf{WM} + 0.094\mathbf{TP} + 0.019\mathbf{AR} + 0.018\mathbf{RD}$$

(G-Girder; CG-Cross Girder; C-Connection; D-Deck; W-Wing wall; S-Stem; B-Bearing; EJ-Expansion Joint; BS-Bridge Surface; GR-Guardrail; FP-Foot Path; WM-Web Members; TP-Top Members; AR-Approach Road; RD-Road Drainage)

The priority vector shows the relative weights among the different bridge elements. The λ_{max} value is 16.88 and n is 15.

$$CI = \frac{\lambda_{max}-n}{n-1} = 0.134 \;................(4)$$

The Random consistency Index for n= 15 is 1.59 (Saaty, 1980).

$$CR = \frac{CI}{RI} = 0.084 < 0.1 \;(acceptable) .... (5)$$

The Consistency Ratio is less than 0.1. Therefore above assigned preference is consistent.

The Overall Bridge Condition Index

The overall condition states of elements which were discussed in previous rating system are used to obtain the overall bridge condition index. The overall bridge condition index is obtained by substituting overall condition states of elements to the priority vector.
Then the priority vector value is modified as follows.

$$The\ Modified\ Overall\ Bridge\ Index = 22.5 \times PV - 12.5 \ldots\ldots\ldots (6)$$

The range of the Modified Overall Bridge Index (MOBI) is 10-100. The priority for remedial actions increases as the number rises. The MOBI range can be divided into five condition states as shown Table 2.

Table 2: MOBI ranges for different condition states

Range	Condition State
$MOBI = 10$	Very good
$10.0 < MOBI < 32.5$	Good
$32.5 \leq MOBI < 55.0$	Fair
$55.0 \leq MOBI < 77.5$	Poor
$77.5 \leq MOBI < 100$	Very poor

6. Condition assessment of selected bridges

Case studies are used to verify the proposed mathematical model and assess the condition of bridge according to proposed methodology. The data obtained from bridge inspection report have been used feed the mathematical models. Table 3 shows the condition rating for selected bridges.

Table 3: Condition rating for selected bridges

Bridge	Important Factor Method	Reciprocal Matrix Method (AHP)
Bridge No. 01	63.20	66.29
Bridge No.02	82.32	83.19
Bridge No. 03	16.31	13.59
Bridge No. 04	32.31	32.52

According to results obtained from both methods, Bridge No. 02 is in the worst condition. In comparison to the MOBI of the other bridges, Bridge No. 02 has highest value and therefore should be targeted as a top priority for rehabilitation.
Bridge No. 01 is also in a poor condition. Bridge No. 01 and Bridge No. 02 have been constructed more than 50 years ago. According to above results, Bridge No. 01 and Bridge No. 02 have higher MOBI values than other two bridges. Therefore it is necessary to take immediate remedial action for Bridge No. 01 and Bridge No. 02.
Bridge No. 03 is in good condition. Bridge No. 03 was constructed 5 years ago. Bridge No. 04 is reaching afair condition. That bridge was constructed in 1999. It has however not been subjected to any repair work after the construction. That is the reason for bridge has slightly higher MOBI value. Therefore necessary remedial actions should be taken for bridge No. 04.

7. Conclusion

In this study the important factor method and reciprocal comparison matrix method are used to evaluate the condition of steel bridges. In important factor method, the importance of bridge elementsare defined considering overall structural integrity and safety of the bridge. In reciprocal comparison matrix method, the weightage of different bridge elements have evaluated through AHP. This methodology is adopted for four selected bridges in Kaluthara district in order to assess the condition of the bridge. The MOBI value of bridge should be maintained as less than 21.25 for better condition. Reciprocal matrix method is better than important factor method.

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