Serviceability Condition Assessment of I Girder Concrete Bridge Decks

Department of Civil and Environmental Engineering, Ehime University — Kazuhiro Taniwaki (Member)
Department of Civil and Environmental Engineering, Ehime University — Mitao Ohga (Member)
Graduate School of Science and Engineering, Ehime University — I.M.S Waruna Kumara(Student Member)
Graduate School of Science and Engineering, Ehime University — Kamal Karunananda (Student Member)

1. Introduction

Most of the marvels of civil engineering in the world are about fifty years old and many of these engineering structures are getting older and a large number of these are in need of maintenance or rehabilitation (Kong and Frangopol 2004, Atashi et al., 2007) irrespective of where those are located. Among these, Highways and associated structures play an important role in the ground transportation systems and directly affect the productivity of road transport industry.

The reliability approach on estimation of present condition and remaining lifetime estimation is not common and now only is being developed. (Ranjith Dissanayake et al. 2006) In addition to that, the problem in the available few reliability approaches contain many variable parameters and to obtain these parameters for each and every bridge is an unfeasible task and consumes lot of resources. The other problem is most of available approaches cannot be used for general application and they have been proposed to solve particular problems.

The main objective of this study is to propose a reliability approach to estimate the current serviceability condition of steel I girder concrete bridge decks with more efficiency. The meaning of efficiency is to achieve reasonable accurate with less number of parameters, easiness of application, ability to apply similar type of other bridges rather than to a specific bridge.

2. Methodology

In performing reliability analysis of bridges, the first important step is to identify the possible failure criteria of the particular bridge type. Then, carefully failure modes have to be decided relevant to the each failure criteria. When doing that, it is essential to pay attention towards taking only critical failure criteria and failure modes to avoid accounting unnecessary variables. The proposed main failure criteria for steel I girder concrete bridge decks as girder failure and slab failure. Then, three failure modes have been introduced for each failure criteria separately naming as moment failure, shear failure and displacement failure. Base on failure modes, safety margins or reliability models have been proposed as,

$$M=M_{capacity} - M_{current} \tag{1}$$

$$M=V_{capacity} - V_{current} \tag{2}$$

$$M=D_{allowable} - D_{current} \tag{3}$$

Here, $M_{capacity}$, $V_{capacity}$ and $D_{allowable}$ are resistant variables and $M_{current}$, $V_{current}$ and $D_{current}$ are load variables. The main objective of this study is to improve the methodology to obtain probabilistic parameters for these resistant variables (R) and load variables (S).

The elementary failure probability calculations for moment failure are shown in below as an example. Both random variables for the reliability failure model for moment failure as shown equation (1) are taken to be normally distributed.

$$M_{capacity} \sim N(\mu_{(M)\ capacity}, \sigma_{(M)\ capacity})$$

$$M_{current} \sim N(\mu_{(M)\ current}, \sigma_{(M)\ current})$$

Then reliability index (β) can be found as follows,

$$\beta = \frac{\mu_M}{\sigma_M} \tag{4}$$

As M is a linearly dependent combination of $M_{capacity}$ and $M_{current}$

$$\sigma^2_{(M)} = \sigma^2_{(M)capacity} + \sigma^2_{(M)current} \tag{5}$$

$$\beta = \frac{\left(\mu_{(M)capasity} - \mu_{(M)current}\right)}{\sqrt{\sigma^2_{(M)capacity} + \sigma^2_{(M)current}}} \tag{6}$$

Relevant elementary failure probability for the moment failure at the time considered can be expressed as,

$$P_f = P(M \leq 0) \tag{7}$$

Then, the safety margin M has to be converted in to the standard normally distributed variable. Subsequently a relationship between failure probability and reliability index can be found as,

$$P_f = \phi(-\beta) \tag{8}$$

Where ϕ is the standard unit normal distribution function.

The same procedure has to be followed for the shear failure and deflection failure modes also to obtain elementary failure probabilities.

After obtaining all elementary reliability indices for each failure modes and by considering these are connecting as a series, system failure probability (P_F) for the particular bridge can be found out by using system reliability theory.

$$\underset{i=1}{\overset{n}{Max}}\, P_{f_i} \le P_F \le 1-\prod_{i=1}^{n}\left(1-P_{f_i}\right) \qquad (9)$$

It is suggested to develop a FEM model to represent the current condition of the bridge deck. For loading of the FEM model, general traffic density data has been used. To make easiness of understanding and calculations it is proposed to group whole vehicle types in to two groups according to size and weight of the vehicles as *Small Vehicle* and *Large Vehicle*. Then, the mean (μ) and standard deviation (s) have to be calculated for these two vehicle types separately. By considering possible different types of combinations of above two vehicle types, the critical load combination has to be found using the FEM model.

After critical load combination was found, by applying it to the FEM model it can be identified the critical failure locations where the maximum moment, shear or deflection occurs. Then, the probabilistic parameters for resistant variables can be found by considering limiting factors such as material properties, section properties or design limits with relevant to the critical failure locations. Subsequently, probabilistic parameters for load variables also can be obtained according to the probabilistic parameters of the critical load combination by applying to the FEM model.

3.Case Study

The selected bridge is a single spanned steel I girder concrete composite bridge and it is located in the Route 33, over the *Ono River* (Ono gawa) in the national road network of Shikoku, Japan. The name of the bridge is *Amayama Bridge* and now it is nearly 35 years old. Identified damagers through the field investigation consist of corrosion of the girders, cracks, exposing r/f and section reductions of the slab. FEM model for the bridge has been done using MICROFRAP II FEM program. Grid elements (Fig. 1) were used to model the main girders and cross girders. Plate elements (Fig. 2) were used for modeling the slab. After select the critical load combination according to the traffic density data, elementary reliability indices were calculated. The system reliability indices were found as 9.31 and 9.34 for upper and lower bound respectively.

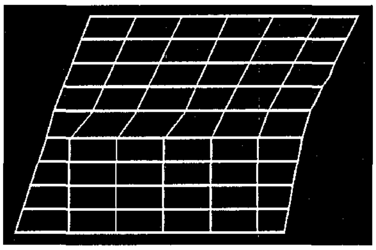

Fig. 1: Grillage of the Model

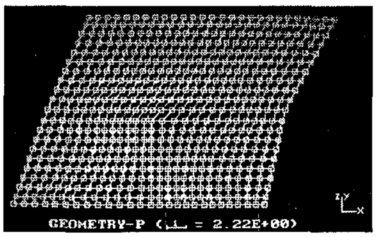

Fig. 2: Plate Mesh of the Model

Table 1: Results

Failure Mode	Reliability Index (β)	Failure Probability (P_f)
Girder Failure		
Moment	9.34	0.6359×10^{-20}
Shear	71.0	$<0.1998 \times 10^{-22}$
Deflection	9.84	0.4044×10^{-20}
Slab Failure		
Moment	44.04	$<0.1998 \times 10^{-22}$
Shear	43.0	$<0.1998 \times 10^{-22}$

4. Conclusion

This methodology can be used to evaluate serviceability condition of steel I girder concrete composite bridge decks with a reasonable accuracy. It is a general approach and can be used for similar type of other bridges also. It is simple, can easily apply and cost effective. For bridge failures, there are many failure parameters are involving. Since, this approach comprises of only limited necessary failure parameters, if only the results are near to failure limits it is recommend to do a detailed study else no need to do such expensive and time consuming test. Considering the case study, the girder failure is more likely than the slab failure. Since the reliability indices are well above the failure limit where ß = 4, there is no need of urgent repair or maintenance. However, continues attention should be taken on corrosion of the steel girders.

References

Atashi M., Lachemi M. and Kianoush (2007). Numerical modeling of the behavior of overlaid slab panels for reinforced concrete bridge decks, *Journal of Engineering Structures*, pp. 271-281.

Hitoshi Furuta (1998), Bridge Reliability Experience in Japan, *Journal of Engineering Structures*, Vol.20, No.11, pp. 972-978.

Kong, J.S. and Frangopol, D.M., (2004), Prediction of reliability and cost profile of deteriorating bridges under time and performance-controlled maintenance, *Journal of Structural Engineering*, 130 (12), pp. 1865-1874.

Ranjith Dissanayake and Kamal Karunananda, (2006), Condition Assessment of Reinforced Concrete Deck Bridges under Corrosion Attack, *Concrete Durability and Service Life Planning: Curing, Crack Control, Performance in Harsh Environments,* Dead Sea, Israel.