FATIGUE ANALYSIS OF STEEL BRIDGES USING INTERVAL RELIABILITY

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Introduction

Many bridge infrastructure systems are getting older, and a large number of these structures are in need of maintenance, rehabilitation or replacement (Liu and Frangopol, 2006). Structural reliability analysis has increasingly demonstrated an important role in structural system analysis and design in bridge engineering. However, lack of experimental and field data has been a major concern in bridge assessment and management (Szerszen *et al.*, 1999). Since reliability models depend on statistical data, lack of data produces errors in computed statistical parameters, and such errors propagate to consequent reliability calculations. This can be avoided with combination of structural reliability and interval analysis. Therefore, the main objective of this paper is to propose interval reliability of steel bridges for precise condition assessment when both resistance and load variables are log normal, and to emphasize the importance with a case study.

Interval Reliability Model for Log Normally Distributed Variables

In a general limit state function, the means and the standard deviations of normal distributed resistance (R_i) and load (S_i) can be expressed, respectively as (Christensen and Murotsu, 1986)

$$\left(\mu_{ri}\right)_{normal} = \ln\left[\frac{\mu_{ri}}{\sqrt{(COV_{ri}^2+1)}}\right]$$

$$\left(\mu_{si}\right)_{normal} = \ln\left[\frac{\mu_{si}}{\sqrt{(COV_{si}^2+1)}}\right] \qquad (1)$$

$$\left(\sigma_{ri}\right)_{normal} = \ln\sqrt{(COV_{ri}^2+1)}$$

$$\left(\sigma_{si}\right)_{normal} = \ln\sqrt{(COV_{si}^2+1)} \qquad (2)$$

where $\left(\mu_{ri}\right)_{normal}$ and $\left(\mu_{si}\right)_{normal}$ are the mean values of normal distributed R_i and S_i, $\left(\sigma_{si}\right)_{normal}$ and $\left(\sigma_{ri}\right)_{normal}$ are the standard deviations of normal distributed R_i and S_i. COV_{ri} and COV_{si} are the coefficients of variation of resistance and load variables. In this situation, the mean and the standard deviation respectively of the limit state function can be expressed as (Christensen & Murotsu, 1986)

$$\left(\mu_{Mi}\right) = \ln\left[\frac{\mu_{ri}\sqrt{(COV_{si}^2+1)}}{\mu_{si}\sqrt{(COV_{ri}^2+1)}}\right] \qquad (3)$$

$$\left(\sigma_{Mi}\right) = \sqrt{\ln[(COV_{si}^2+1)(COV_{ri}^2+1)]} \qquad (4)$$

Then, the upper and lower bounds of reliability index are expressed as (Christensen and Murotsu, 1986)

$$(\beta_i)_{max} = \overline{\beta}_i = \frac{\ln\left[\dfrac{\overline{\mu}_{ri}\sqrt{((\overline{COV}^2_{si}+1)}}{\underline{\mu}_{si}\sqrt{((\underline{COV}^2_{ri}+1)}}\right]}{\sqrt{\ln[(\underline{COV}^2_{si}+1)(\underline{COV}^2_{ri}+1)]}}$$

$$(\beta_i)_{min} = \underline{\beta}_i = \frac{\ln\left[\dfrac{\underline{\mu}_{ri}\sqrt{((\underline{COV}^2_{si}+1)}}{\overline{\mu}_{si}\sqrt{((\overline{COV}^2_{ri}+1)}}\right]}{\sqrt{\ln[(\overline{COV}^2_{si}+1)(\overline{COV}^2_{ri}+1)]}} \quad (5)$$

where over bar and under bar represent the upper and lower bounds respectively of each statistical parameter.

Case Study

The Interstate highway I-94 Pierce road Eastbound bridge, Michigan, USA is selected to apply the introduced procedure. There are two previous studies related to this bridge: (Laman and Nowak, 1996), and (Szerszen *et al.* 1999). A reliability analysis of the bridge was carried out by Szerszen. There, the limit state function, *M*, for fatigue failure of a steel girder is expressed in terms of two variables (number of cycles to failure N_F, and number of applied cycles N_n) as (Szerszen *et al.*, 1999).

$$M = N_F - N_n \quad (6)$$

In order to estimate upper and lower bounds of reliability index, the percentage errors occurring in statistical parameters; μ_{NF}, μ_{Nn}, COV_{NF} and COV_{Nn} are considered as $E\mu_{NF}$, $E\mu_{Nn}$, $E_{COV_{NF}}$ and $E_{COV_{Nn}}$, respectively. The upper and lower bounds are expressed as (Christensen & Murotsu, 1986)

$$\overline{\beta} = \frac{\ln\left[\dfrac{(1+E\mu_{NF})\mu_{NF}}{(1-E\mu_{Nn})\mu_{Nn}\cdot t}\right]}{\sqrt{(1-E_{COV_{NF}})^2\cdot COV^2_{NF}+(1-E_{COV_{Nn}})^2\cdot COV^2_{Nn}}}$$

$$\underline{\beta} = \frac{\ln\left[\dfrac{(1-E\mu_{NF})\mu_{NF}}{(1+E\mu_{Nn})\mu_{Nn}\cdot t}\right]}{\sqrt{(1+E_{COV_{NF}})^2\cdot COV^2_{NF}+(1+E_{COV_{Nn}})^2\cdot COV^2_{Nn}}} \quad (7)$$

where t is the time in years. The acceptable reliability index is estimated as 4.26 (Sarveswaren & Roberts, 1999) for fatigue failure of a girder considering brittle failure and not serious failure consequences.

Table 1. Comparison of life prediction using Szerszen and interval approach

Equivalent stress of the girder (MPa)	Expected service life (years)		Reduction in life (%)
	Szerszen approach	Interval reliability approach	
6	218	209	4.12
12	125	115	8.00
18	70	62	11.42

For 10% errors in means of resistance and load variables, the service life was estimated using Szerszen approach and interval reliability approach for three girders as given in Table 1.

Conclusions

Interval reliability based condition assessment of steel bridges was introduced. Interval reliability of a bridge component was obtained when resistance and load were log normally distributed. The introduced interval reliability model was illustrated with a case study. Though the case study was safe, the results indicate that there are significant variations in bridge condition when interval reliability is used.

References

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