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ABSTRACT

Basically, engineering structures are required to satisfy predefined performance targets such as successfully resisting external load actions. Due to the randomness nature of both the structure property and the external attacks, however, the “absolute safety” of a structure cannot be achieved in engineering practice. Rather, the practical strategy is to control the probability of violating the performance requirements (e.g., structural safety) under an acceptable level. To that end, some probability based approaches are essentially needed to quantify the occurrence possibility of such undesired consequences. Under this context, the mathematical formulation of analytical tools for structural reliability assessment is the topic of this book.

Key words: Bridges; probability of failure; reinforced concrete; reliability; safety; calibration

1 Introduction

For an engineered structure, keeping in mind the performance target of structural safety, it is impossible to achieve a “definitely safe” design, taking into account the uncertainties associated with both the structural performance and the external attacks. On the other hand, a naïve ambition of pursuing an “as-safe as-possible” structure will often result in an over conservative design. In engineering practice, it is more reasonable to examine the safety of a structure from a view of probability (that is, the chance of the occurrence of an event). The structural reliability can be applied in the design of new bridges and evaluation of existing ones. A new generation of design codes is based on probabilistic models of loads and resistance. Examples include: AASHTO LRFD code [1] OHNDC [2], Euro code [3] and CHBDC [4]. In general, reliability-based design can be more efficient. It makes it easier to achieve either

1. For a given cost, design a more reliable structure or
2. Design for a given reliability, design a more economical structure

Reliability can be considered as a rational evaluation criterion. It provides a good basis for the decision about repair, rehabilitation or replacement. The modern reliability analysis methods have been developed since the late 1960s. They are based on theory of probability and statistics. However, current approach to safety in the design and construction is a result of an evolution which took many centuries.

2 Literature Review

Cao Wang, Michael Beer, Dr. Eng and Bilal M. Ayyub, proposed a paper focussing Structural reliability; Time- dependent reliability; Monte Carlo simulation; Analytical



Article Title: Structural Reliability Assessment of Bridges

approach; Resistance deterioration; Load stochastic processes; Resilience: Reliability assessment of engineered structures is a powerful and useful concept to estimate the structural capacity of withstanding hazardous events during their service lives.

The paper gives an overview on the non-empirical assessment methods for time-dependent reliability of deteriorating structures. Generally, these methods can be classified into two types, namely simulation-based and analytical methods. The former is usually brute, and is especially suitable for solving high-dimensional reliability problems. Conversely, analytical solutions may improve the calculation efficiency significantly, and offer insights into the reliability problem that otherwise could be difficult to achieve through Monte Carlo simulation.

Mark G. Stewart Department of Civil, Surveying and Environmental Engineering, The University of Newcastle, New South Wales, 2308, Australia **David V. Rosowsky** Department of Civil Engineering, Clemson University, South Carolina, 29634, USA, proposed a paper focusing on corrosion, deterioration, probability of failure, reinforced concrete, reliability and safety. A structural deterioration reliability model is developed to calculate probabilities of structural failure (flexure) for a typical reinforced concrete continuous slab bridge. Corrosion may be initiated from the application of de-icing salts or atmospheric exposure in a marine environment. They followed an assumption that corrosion will lead to a reduction in the cross-sectional area of the reinforcing steel. Monte Carlo simulation is used to calculate probabilities of failure for annual increments over the lifetime of the structure (75 years). The application of de-icing salts or atmospheric marine exposure is shown to cause significant long-term deterioration and reduction in structural safety. Reducing the cover from that currently specified for design results in a significant increase in failure probabilities.

Andrzej S Nowak and Maria M Szerszen University of Michigan, USA evaluated and given a brief description of application of reliability methods in the development of a load and resistance factor design (LRFD) bridge codes. An important step is the selection of the target reliability index and calculation of load and resistance factors. They have discussed that the Load and resistance factors are derived so that the reliability of bridges designed using the proposed provisions is at the predefined target level.

3 Structural Reliability Assessment

The assessment of structural reliability, i.e., the probability of structural performance not violating the predefined limit state, should be performed, ideally, based on many repeated observations of the outcomes of structural state (i.e., survival or failure). However, this is often not the case in practice; alternatively, the reliability assessment is preferably conducted based on the knowledge of the problem itself, where the probabilistic models are used to describe the randomness of the undeterminable quantities, there may be different types of limit state, depending on the specific performance targets. That being the case, the structural reliability assessment in the presence of different limit states could be solved in a universal



Article Title: Structural Reliability Assessment of Bridges

framework, given that they can be modelled in a similar form. The term structural reliability can be categorized into two types, time-independent (classical) reliability and time-dependent reliability. The former does not consider the time-variant characteristics the uncertain quantities (or simply represent the time-variation with a time-invariant variable), while the latter focuses on the structural performance over a reference period (for example, the service life) of interest. Due to the distinction between the two types of reliability problems, different approaches would be used. Intuitively, the latter would require more skills and computational costs due to the additional consideration of the time scale.

4 Reliability-Based Calibration Procedure

One of the most important applications of the structural reliability methods is the development of the new generation design codes for bridges. The load and resistance factors are calculated so that the reliability of structures is at the predetermined target level. For example, the calibration procedure applied in the development of the AASHTO LRFD Code [1] included the following steps:

- Selection of representative bridges.
- Establishing the statistical database for load and resistance parameters.
- Development of load and resistance models.
- Development of the reliability analysis procedures
- Selection of the target reliability index.

5 Reliability Analysis

Theory

Selection of the reliability analysis procedure is very important. The methods vary with regard to accuracy, required input data, computational effort and special features (time variance). The reliability can be used as an efficient criterion in selection of load and resistance factors. However, the same reliability analysis procedure should be used in calibration, the same for different materials and structural types. Otherwise, calculated β s cannot be considered as a fair basis for comparison. The reliability of the bridge is measured using the reliability index for a single failure element or for the structural system (the bridge). The reliability is assumed to decrease with time due to the deterioration. The failure modes can be stability failure of columns, yielding or shear failure in a number of critical cross-sections of the bridge. If a system modelling is used then it is assumed that the structure fails if any one of these failure modes fails, i.e. a series system modelling is used. It is assumed that uncertain quantities like loading, strength and inspection results can be modelled by N stochastic variables $X = (X_1, \dots, X_N)$. At present the stochastic variables shown in table 1 are used. Further, the structure is modelled by m potential failure modes F_i , $i = 1, 2, \dots, m$. Failure mode i is described by a safety margin

$$MF = MF(X, t)$$

The element reliability index $\beta_i(t)$ at the time t for failure mode F_i is connected to the probability of failure $PR(t)$ by



Article Title: Structural Reliability Assessment of Bridges

$$\beta_t = -\Phi^{-1}(PF, (t))$$

where Φ is the standard normal distribution function. The probability of failure $PF(t)$ in the t time interval $[0, t]$ is determined from

$$PF_t = P(M F_i \leq 0)$$

In a time-invariant reliability analysis the estimate of the probability of failure can approximately be obtained by considering the extreme load in the lifetime TL and the strength.

Stochastic variables: Yield line limit state				
No	Type	Par. 1	Par. 2	Description
1	Normal	550.0	10.0	Thickness of slab [mm]
2	LogNormal	30.0	6.0	Cube strength of concrete [MPa]
3	Normal	23.6	0.4	Density of concrete [kN/m ³]
4	LogNormal	289.0	25.0	Yield strength: longitudinal reinforcement [MPa]
5	Normal	60.0	8.0	Cover on longitudinal reinforcement [mm]
6	LogNormal	289.0	25.0	Yield strength: transverse reinforcement [MPa]
7	Normal	86.0	8.0	Cover on transverse reinforcement [mm]
8	Fixed	10053.0	-	Longitudinal reinforcement area (initial) [mm ²]
9	Fixed	565.0	-	Transverse reinforcement area (initial) [mm ²]
10	Gumbel	0.352	0.026	Static load factor [-]
11	Normal	1.27	0.20	Dynamic load factor [-]
12	Normal	1.08	0.072	Chloride concentration on surface [%]
13	Fixed	0.0	-	Initial chloride concentration [%]
14	Normal	35.0	2.5	Diffusion Coefficient [cm ² /sec]
15	Normal	0.4	0.05	Critical Chloride concentration [%]
16	Uniform	2.5	0.29	Corrosion parameter [-]
17	Normal	1.0	0.05	Model uncertainty variable [-]

Table 1. Stochastic modelling used for the ULS.

7 Conclusions

The structural reliability can serve as rational basis for calculation of load and resistance factors. Reliability based code provide a uniform safety level for various bridges (materials and types). The available statistical database indicates that bridge live loads are strongly site-specific. There is a need for more unbiased truck surveys to verify the validity of the current load models. Further material tests are needed to provide a basis for simulation of the behavior of bridge components and systems. Field tests can be used to verify the current load distribution methods. Current studies are focused on the analysis of individual components (girders). There is a need for consideration of the system behavior. This will allow to quantify the effect of redundancy, ductility, and load sharing in general.

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Article Title: Structural Reliability Assessment of Bridges

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