International Journal of Information Technology and Knowledge Management
July-December 2010, Volume 2, No. 2, pp. 511-513

COMPUTATIONAL TECHNIQUE FOR RELIABILITY ANALYSIS AND DESIGN OF STEEL BEAM

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Structural systems under reliability-based performance constraints are an important problem now a day. This problem is investigated in this paper. AFOSM method was used for calculating safety index and Limit State Design (LSD) for factor of safety for particular random variables. A computer-automated reliability-based analysis design procedure is presented by which the concept of target reliability analysis with regard to both serviceability and ultimate limit state. The procedure is feasible for application in system optimization of both steel and reinforced concrete structures. The results indicate that the partial factor of safety for material comes out in the range of 1.0 to 1.3 for steel (1.1 as per IS: 800, 2007) and target reliability index in range of 2.93 to 3.80.

Notations: – M_p = Plastic moment capacity; F_y = Yield strength of steel, Z_p = Plastic modulus about major axis; γ_m = Actual strength/ Predicted strength, γ_{m0} = Partial safety factor μ_{Lm} = Load effect due to means of maximum lifetime live load

1. Introduction

Modern structures require more critical and complex designs, the need for accurate approaches to assess uncertainties in loads, geometry, material properties, analysis processes and designing has increased significantly. Reliability assessment techniques help to develop safe designs and identify where significant contributors of uncertainty occur in structural systems, or where further research, testing and quality control could increase the safety and efficiency of the structure. A significant increase in the efficiency of reliability computations is expected from the integration of reliability methods with the discrete and continuum methods of design sensitivity analysis. So far, only the discrete method has been used in the so-called stochastic finite element method. Integration of reliability computations with the continuum method of design sensitivity analysis is proposed in this paper as a new, powerful approach to the probabilistic design of large structural systems. Basic formulations and solution methods of reliability analysis, design sensitivity analysis of reliability indices, reliability-based optimization, and multiobjective reliability-based optimization are reviewed with focus on the sensitivity information necessary to carry out the reliability computations. The most time-consuming sensitivity computations, related to the dependence of structural performance measures on design parameters[1].

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Structural reliability was not routinely evaluated or quantified in the design process. Reliability was accounted for tacitly by the factor-of-safety approach to design in most of the engineering codes ATC(1996), Eurocode-8(2003), FEMA-273(2003))[2] The structural designer/analyst did not perform a formal risk analysis on newly designed structure. The complications that reduce the ability to quantify reliability reside in the stochastic nature of design inputs. The primary purpose for establishing a factor-of-safety for design is to ensure safety. In the field of structural reliability, the performance of a structure is evaluated with respect to a prescribed set of limit states that define acceptable and unacceptable behavior. Performance of a structure is deemed unacceptable if its response violates one or more limit states[3] Design processes might benefit greatly by focusing on reliability targets rather than factors-of safety. Many attempts have been made for loss estimation after an earthquake and also fragility curves have been developed to estimate the probability of failure of different systems as a function of the system characteristics and the frequency content of the ground motions[4].

Structural reliability provides a logical framework for the uncertainties that exist in dealing with problems of structural analysis and design[5]. The uncertainties in structural and load characteristics are quantified using the mathematical theories of probability, random variables, random processes and statistics. The relationship between probability of structural failure to the uncertainty parameters connected with the structural and load characteristics is developed. This facilitates a rational basis for deciding upon optimal structural configuration for a given set of loading conditions consistent with the desired levels of safety and affordable cost. Codes of practice for structural design employ concepts of limit state and partial load and resistance factors that have been calibrated based on probabilistic modeling of uncertainties.

In this paper, reliability study on flexural-torsional buckling of simply supported steel I-beam is presented. ISMB sections were taken as reference with different sectional properties. Minimum six no's of specimens were taken for testing for the study. The variables were chosen to reflect the actual design conditions as closely as possible. To establish the limit state, the variation of different random variable must be known, which are accounted for by a coefficient of variation. The variation can be determined by collecting data on the occurrences of variable and identifying the statistical parameters (standard deviation (σ_x) and mean (μ_x) for the particular random variables[5].

The beams were designed according to IS 800:2007, which deals with limit state design. Rolled steel joists beams of different cross sectional area and length were taken for studying the structural properties and random variables. The depth/ length ratio was maintained less than and equal to 1/ 10 for reliability point of view.

The different values of the random variable were associated with different probabilities of their occurrence. It is necessary to replace a collection of data by a single number used for analysis. Mean value of random variable was collected by using the equation

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Where X_1, X_2……., X_n is the sequence of observed values.

The test data was collected in database i.e. shape data, the mechanical property, sectional property based upon support condition (simply supported) as shown in Table1. The numerical controlled program-generating module was attached with operator for manipulation through a graphic user interface. Program code was given for causing the computer to determine different safety factors for different load combination of live load and dead load ratio which varies from 1.3DL+1.7LL to 1.7DL+1.7LL as shown in Table 2. Probability programmed code for generating failure equation of said element comprising:-Numerical code to generate failure equation of said element was

$$Mp = Fy \times Zp - Q_1 = a_1.Fy.Zp - Q_1$$

a_1 was random variable corresponding to model uncertainties.

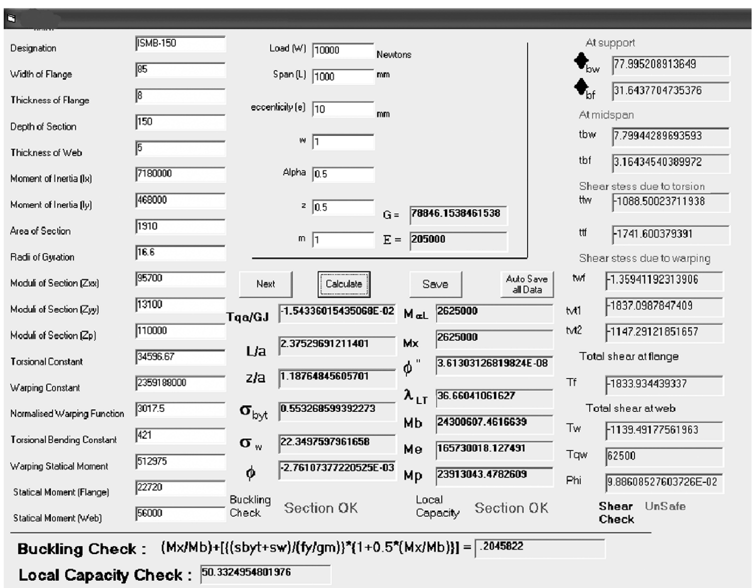
Probability of failure was calculated from the test results data stored in data storage system by using Monte-Carlo method $P_f = n/N$.

n = No of sample value of moment (M) falling below zero

N = Total no of samples. M = Moment due to combined action of bending and torsion.

Constants α for different material property and reliability index were calculated using two different methods separately i.e. Advanced First Order – Second Moment Method (AFOSM) and Limit State Design (LSD).

Advanced First Order – Second Moment Method: The method was employed in finding the design point in a suitable standard space and substituting the actual performance function. All the random variables were transferred in reliability module with zero mean and unit standard deviation.



Following steps were involved in AFOSM method to determine safety index (β)

1. Generalized equation of failure was defined in the form

   $Y = g(x_1, x_2, x_3, \ldots\ldots x_n) = a_0 + a_1x_1 + a_2x_2 + \ldots\ldots a_nx_n = 0$

   where $a_i (i = 0,1,2,\ldots\ldots n)$ were constant x_i term are random variable.

2. Normalize the variables by using the relations $Z_i = \frac{x_i - \mu_i}{\sigma_i}$

3. Guess initial safety index β.

4. Constants was computed using equation $a_i = \frac{g_i(x^*)}{\sqrt{\sum_{i=1}^{n} g_i(x)^2}}$

5. New value of xi was determine from equation $x_i^* = -\alpha_1 \beta$

Repeat steps 4, 5 till the value of β satisfy generalized failure equation on successive iteration differ by small tolerance. Values of random variable and partial safety factor for those variables were calculated by using β as shown in Table 3.

CONCLUSION

Safety aspects study of steel beam in combined action of bending and torsion was undertaken. AFOSM method was used for determining the safety factor (β) and resistance ratio determined by using Monte-Carlo technique. Computation may lead to development of a new evolutionary design support tools which will allow full automation of the structural design. Designer will be able to consider a large number of final and complete designs in a short time with target reliability. These will ultimate lead to novel and economical design with reduced cost.

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