Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 9, Issue, 4(C), pp. 25735-25739, April, 2018

ISSN: 0976-3031

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

A REVIEW PAPER ON INCORPORATION OF RELIABILITY FACTORS IN LIMIT STATE DESIGN OF RCC STRUCTURE

Tabish Izhar[1]., Zafar Jawed*[2] and Neha Mumtaz[1]

[1]Department of Civil Engineering, Faculty of Engineering and Technology, Integral University, Lucknow (U.P.), India
[2]Department of Civil Engineering, Masters in Technology, Integral University, Lucknow (U.P.), India

DOI: http://dx.doi.org/10.24327/ijrsr.2018.0904.1920

ARTICLE INFO

Article History:

Received 8th January, 2018
Received in revised form 21st February, 2018
Accepted 05th March, 2018
Published online 28th April, 2018

Key Words:

Reliability Analysis, Probability of Failure, Monte-Carlo Stimulation.

ABSTRACT

Structural engineers are focused on designing a safe structure by following the parameters and factors in the codes and standards that are requested in the project specifications. After finishing the design stage, the structural engineers who work onsite receive the drawings and specifications from the designer and begin their job by performing the project construction. Then their colleagues, who work on the operations and maintenance phase, will start monitoring and maintaining the structural performance during the lifetime of the structure. So, around this project life cycle, all of the structural engineers are focusing on the same target, which is that the structure will maintain the safety throughout its service life according to the design code. The main objective of this Paper is to cover the methods that enable us to have a reliable structure during all the project phases, and also examine that how much the Reliability based design is different from that of the Indian Limit State Design from a practical point of view, the up-to-date methods that predict what the lifetime of the structure will be. Many researchers have been discussing the reliability analysis, which means the same as calculation of probability of structure failure, and this calculation depends mainly on the statistics and theory of probability. Therefore, there is an entire chapter devoted to discussing all of the statistics methods, tools, and probability theory that are used in structural and civil engineering fields from a practical point of view and away from the complicated approach that does not benefit one in a real practical way. It is worth mentioning that there is an increase in research concerning structure reliability as we have innumerable data worldwide from which we can calculate the concrete structure reliability.

INTRODUCTION

Reliability and Its Importance

Reliability is the probability that a system will perform its function over a specified period of time and under specified service conditions. Reliability theory was originally developed by maritime and life insurance companies in the 19th century to compute profitable rates to charge customers. The goal was to predict the probability of death for a given population or an individual. In many ways, the failure of structural systems, (*i.e*., aircrafts, cars, ships, bridges, *etc*.), is similar to the life or death of biological organisms. Although there are many definitions and classifications of structural failure, a distinctive fact is that structural failure can cause tragic losses of life and property.

Reliability analysis is defined as the consistent evaluation of design risk using probability theory. The reliability is the probability of an item performing its intended function over a given period of time under the operating conditions encountered. It is important to note that the above definition stresses four significant elements namely,

1. Probability
2. Intended function
3. Time
4. Operating conditions

The study of *structural reliability* is concerned with the calculation and prediction of the probability of limit-state violations at any stage during a structure's life. The probability of the occurrence of an event such as a limit-state violation is a

Corresponding author:* **Zafar Jawed
Department of Civil Engineering, Faculty of Engineering and Technology, Integral University, Lucknow (U.P.), India

numerical measure of the chance of its occurring. Once the probability is determined, the next goal is to choose design alternatives that improve structural reliability and minimize the risk of failure.

Methods of reliability analysis are rapidly finding application in the multidisciplinary design environment because of the engineering system's stringent performance requirements, narrow margins of safety, liability, and market competition. In a structural design problem involving uncertainties, a structure designed using a deterministic approach may have a greater probability of failure than a structure of the same cost designed using a probabilistic approach that accounts for uncertainties. This is because the design requirements are precisely satisfied in the deterministic approach, and any variation of the parameters could potentially violate the system constraints.

METHODOLOGY

This chapter presents methods for two significant reliability measures: safety index and probability of failure. Because of the iterative nature of calculating these measures, use of limit-state function approximations is a necessary aspect.

In the United States the term Load and Resistance Factor format is currently used (Ravindra and Galambos, 1978; Ellingwood, 1980) (1. 8, 1. 9). From the viewpoint of reliability-based optlmality, it appears, however, that the most powerful characteristic of the new method Is the flexibility that the presence of many adjustable factors gives. For this reason all these methods are jointly called multiple-factor formats.

Basic Probabilistic Description

There are many ways to specify probabilistic characteristics of systems under uncertainty. Random variables are measurable values in the probability space associated with events of experiments. Accordingly, random vectors are sequences measurements in the context of random experiments. Random variables are analyzed by examining underlying features of their probability distributions. APDF indicates a relative probability of observing each random variable x and can be expressed as a formula, graph, or table. Since the computation of the PDF is not always easy, describing the data through numerical descriptive measures, such as the mean and variance, is also popular. In this section, elementary statistical formulas and several definitions of probability theory, random field, and regression analysis are briefly described in order to facilitate an introduction to the later sections.

Characteristics of Probability Distribution

Random Variable

A random variable X takes on various values x within the range $-\infty < X < \infty$.A random variable is denoted by an uppercase letter, and its particular value is represented by a lowercase letter. Random variables are of two types: discrete and continuous. If the random variable is allowed to take only discrete values, X_1 , X_2 , X_3 , X_{nit} is called a discrete random variable. On the other hand, if the random variable is permitted to take any real value within a specified range, it is called a continuous random variable.

Structural Reliability Assessment

If, when a structure (or part of a structure) exceeds a specific limit, the structure (or part of the structure) is unable to perform as required, then the specific limit is called a *limit-state*. The structure will be considered unreliable if the failure probability of the structure limit-state exceeds the required value. For most structures, the limit-state can be divided into two categories:

Ultimate limit-states are related to a structural collapse of part or all of the structure. Examples of the most common ultimate limit-states are corrosion, fatigue, deterioration, fire, plastic mechanism, progressive collapse, fracture, etc. Such alimit-state should have a very low probability of occurrence, since it may risk the loss of life and major financial losses.

Serviceability limit-states are related to disruption of the normal use of the structures. Examples of serviceability limit-states are excessive deflection, excessive vibration, drainage, leakage, local damage, etc. Since there is less danger than in the case of ultimate limit-states, a higher probability of occurrence may be tolerated in such limit-states. However, people may not use structures that yield too much deflections, vibrations, etc.

Generally, the limit-state indicates the margin of safety between the resistance and the load of structures. The limit-state function, $g(.)$, and probability of failure, Pf , can be defined as

$$g(X) = R(X) - S(X) \quad (1)$$

$$Pf = P\,[g(.) < 0]$$

Where R is the resistance and S is the loading of the system. Both $R(.)$ and $S(.)$ are functions of random variables X. The notation $g(.) < 0$ denotes the *failure region*. Likewise, $g(.) = 0$ and $g(.) > 0$ indicate the *failure surface* and *safe region*, respectively.

The mean and standard deviation of the limit-state, $g(.)$, can be determined from the elementary definition of the mean and variance. The mean of $g(.)$ is

$\mu_g = \mu_R - \mu_S$

where, μ_R and μ_S are the means of R and S, respectively. And the standard deviation of $g(.)$ is

$$\sigma_g = \sqrt{\sigma_R{}^2 + \sigma_S{}^2}$$

where,

σ_R and σ_S are the standard deviations of R and S, respectively.

The *safety index* or *reliability index* β, is defined as

$$\beta = \frac{\mu_g}{\sigma_g} = \frac{\mu_g + \mu_S}{\sqrt{\sigma_R{}^2 + \sigma_S{}^2}}$$

Probailistic Analysis

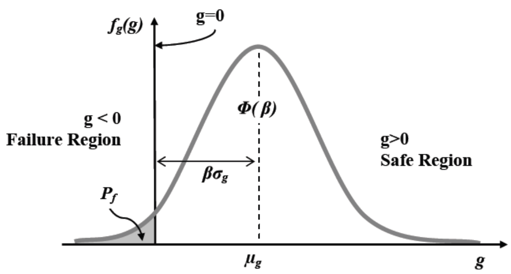

Figure 1 Probability density for limit state g(.)

Monte Carlo Simulation Method

Simulation is the process of replicating the real world problem based on the set of assumption and conceived models of reality. It may be performed theoretically or experimentally. The simulation process yields a special measure of performance or response. Through repeated simulations, the sensitivity of the system performance to variation in the system parameters may be examined. By this procedure, simulation may be used to determine optimal designs. One of the usual objectives in using the Monte Carlo technique is to estimate certain parameters and probability distributions of random variables whose values depend on the Interactions with random variables whose probability distributions are specified. For engineering purposes simulation may be applied to predict or study the performance and for response of a system. With a prescribed set of values for the system parameters or design variables Monte Carlo simulation is a repeated process of generating deterministic solutions to a given problem; each solution corresponds to a set of deterministic values of the underlying random variables. The main element of a Monte Carlo simulation procedure is the generation of random numbers from a specified distribution. 500 numbers of data sets was randomly generated for each cross section, and each data set varied randomly as a function of statistical models for the variables involved.

Methodology of Finding Probability of Failure of Beam

1. For random variations in different grades of concrete, dimensions and live load, corresponding bending, moment values are obtained from ETABS software.
2. Simulate resistance using equation for beam subjected to transverse load specified in IS 456-2000, i.e., flexure resistance equations:

$$Mu = .87\, f_{ck} A_{st} d [\frac{A_{st} f_y}{f_{ck}\, bd}]$$

Compare Resistance (R) and Load (S).

3. If R < S then it will be considered as failure.
4. Compute probability of failure by equation

$$\text{P.F.} = \varphi\left(\frac{\mu_g + \mu_S}{\sqrt{\sigma_R{}^2 + \sigma_S{}^2}}\right)$$

5 Reliability index (β) = β = Φ-1 (Pf).

LITERATURE REVIEW

Prediction of Reliability Index and Probability of Failure for Reinforced Concrete Beam Subjected To Flexure Salma Taj1, Karthik B.M, Mamatha N.R, Rakesh J, Goutham D.R- **May 2017**

The present method of designing rectangular reinforced concrete beam is based on limit state design philosophy which makes use of partial safety factors for material strength and load. The design variables being random, it becomes much more important to assess the level of safety in the probabilistic design situation. Beam being the vital most structural element, the probability of failure of a beam is linked to the overall safety of a structural system. With this in view, an attempt is made to assess the safety levels in terms of reliability index and probability of failure of the beam. A reinforced concrete frame is modelled in ETABS software, the moment and area of tension reinforcement values are extracted from the same software for statistical analysis. Resistance statistics for rectangular reinforced concrete beam are generated using the equations provided in IS 456-2000 code. The variables relating to geometry, material properties and loading are considered as random. Probability of failure is obtained by Monte Carlo Simulation technique which establishes the statistics of safety margin that is Resistance(R) > Action (S). The study investigates the reliability index and probability of failure of the rectangular reinforced concrete beam and plotting of the histogram and probability distribution curve. The entire reliability analysis was implemented through developing a program in MATLAB software.

It is observed that the reliability index varies from 8.8312 to 14.0142 for meshing (span) size of (11 x11) m in flexure which corresponds to a probability of failure of 5.25 x 10-19 to 6.6574 x10-45 for characteristic strength of concrete of 20 N/mm2 & 25N/mm2 with varying depth of beam. It can be seen that as the depth of beam increases irrespective of fck, there is an increment in reliability index which leads to lesser value in probability of failure.

Analysis of Beam Failure Based on Reliability System Theory Using Monte Carlo Simulation Method- Mohammad Masoud Azhdari Moghaddam. In this paper, failure probability of a specified beam in several moment, displacement, shearing stress and web diametric buckling is analyzed. As the results show, failure probability for all modes is negligible and its maximum value does not exceed 10-5. The lowest and highest failure probability belong to shearing stress and lateral torsion buckling respectively. As a conclusion when failure probability is low, we can use element critical failure probability; safety of structure for low failure probability is very sensitive.

A Study on Probability of Failure of a Column in RC Framed Building by Changing Orientations Rahul M, Dr. K Manjunath, Sandeep Kumar D S, Manjunath J- 2016.

Attempt is made to quantify the safety level in terms of probability failure of a corner column in RC framed building. Basic design variables are treated as random and their statistics are collected from the literature. A typical RC framed building is selected and designed using deterministic approach, as per the provision of IS 456-2000. The generated values of Mu & Pu at a given section are used to generate further non-dimensional parameters Pu/(fck*b*D2) and Mu/(fck*b*D2) , using these non-dimension parameters P/fck is obtained appropriate interaction curve from SP-16. Thus the value of P required is obtained. If this value of P required is greater than P provided by the deterministic design, it is considered as failure. Such failures are counted during simulation. The reliability of column section as 1-Pf. Same procedure is repeated for different orientations of corner column. It is observed that rate of failure of the column section is about 39 % or probability failure is 0.39 (40% live load), 32% or probability failure is 0.32 for 20% live load for orientation I and 48 % or probability failure is 0.48 (40% live load), 37% or probability failure is 0.37 for 20% live load for orientation II respectively.

The application of a probabilistic method to the reliability analysis of longitudinally reinforced concrete beams. By - Marta Sowika, Izabela krzypczak, Renata Kotynia, Monika Kaszubska.

The failure in longitudinally reinforced concrete beams without transverse reinforcement is the most often observed in a support zone due to bending moment and shear force acting simultaneously in a cross section. The experiments focused on determining shear capacity and observing the failure process in longitudinally reinforced concrete beams without stirrup of a rectangular and a T-shape cross section. The obtained experimental results were used to calculate the difference of safety margins of the designed shear resistance calculated on the basis of the formula from Eurocode 2 according to reinforced concrete beams without transverse reinforcement of different cross sections.

Reliability assessment of deteriorating structures using Bayesian updated probability density evolution method (PDEM)- By - WenLiang Fan, Alfredo H.-S. Ang , Zheng Liang Li - 20 December 2016

The inspection of engineering structures is important to ensure performance; in this regard, the Bayesian updating process based on inspection data plays an essential role in the life-cycle management of engineering systems. In this paper, the probability density evolution method (PDEM), a universal approach for dynamical systems, is extended for the analysis of deteriorating structures with inspection by combining with the Bayesian updating process.

Complex and comprehensive method for reliability calculation of structures under fire exposure- By - Tamás Balogh, László Gergely Vigh - 22 September 2016

To justify the applicability of the proposed methodology, reliability analysis for a tapered steel frame protected by intumescent coating is presented as an illustrative numerical example. Probability of its failure is calculated by using First Order Reliability Method; the computed failure probabilities are verified by using Monte Carlo Simulation. FORM approximation underestimates the failure probability, the observed error is within -1% to -34%. Based on the results, it has been found that for low and moderate consequence classes the calculated reliability indices are in better agreement with the recommendations of ISO 2394 standard and Joint Committee on Structural Safety than with the values recommended in EN 1990:2002 standard.

Probabilistic reliability assessment of a heritage structure under horizontal loads – By Maria L.Beconcini, PietroCroce, FrancescaMarsili, MartinaMuzzi, ElisaRosso - 13 January 2016

This paper proposes a methodology for the probabilistic reliability assessment of heritage buildings. The procedure addresses investigation and tests on the structure and it considers the implementation of Bayesian updating techniques for a rational use of the collected information. After having described the peculiarities of ancient buildings, it is shown how probabilistic methods can be adapted to evaluate their safety.

Reliability assessment of aging structures subjected to gradual and shock Deteriorations – By Cao Wanga, Hao Zhangb, Quanwang Lia,- 2006, Australia Civil structures and infrastructure facilities are susceptible to deterioration posed by the effects of natural hazards and aggressive environmental conditions. These factors may increase the risk of service interruption of infrastructures, and should be taken into account when assessing the structural reliability during an infrastructure's service life. Modeling the resistance deterioration process reasonably is the basis for structural reliability analysis. In this paper, a novel model is developed for describing the deterioration of aging structures. The deterioration is a combination of two stochastic processes: the gradual deterioration posed by environmental effects and the shock deterioration caused by severe load attacks. The dependency of the deterioration magnitude on the load intensity is considered.

Updating reliability models of statically loaded instrumented structures – By V.S. Sundar, C.S. Manohar - September 2012. The case of linear systems with Gaussian uncertainties and linear performance functions is shown to be exactly solvable. FORM and inverse reliability based methods are subsequently developed to deal with more general problems. The proposed procedures are implemented by combining Matlab based reliability modules with finite element models residing on the Abaqus software. Numerical illustrations on linear and nonlinear frames are presented.

A General Solution Framework for Time-variant Reliability Based Design Optimization – By C. Jiang, T. Fang, X.P. Wei, Z.L. Huang In this paper, a general solution framework called time-invariant equivalent method (TIEM) is proposed to solve the time-variant reliability based design optimization problems, which provides an efficient tool for reliability design of many complex structures or systems considering their whole life cycles. In each cycle, the proposed method constructs an equivalent time-invariant RBDO problem according to the time-variant reliability analysis results and then updates the design point by solving this problem.

Calibration methods for reliability-based design codes – By N. Gayton, Mohamed, J.D. Sorensen, M. Pendola, M. Lemaire The scope of this paper is to underline the advantages and disadvantages of the classical methods, to define their domain of validity and to propose new efficient methods. In our approach, the accuracy is balanced with time efficiency by the mean of iterative scheme using approximate methods. The presented ideas are clarified by four numerical examples of parabolic performance function, column buckling, stability of submarine shells and structural elements.

Structural reliability under monotony: Properties of FORM, simulation or response surface methods and a new class of Monotonous Reliability Methods (MRM) By - E. de Rocquigny.

This paper has established a few properties for the classical reliability algorithms in that context. Monotony increases to a certain extent the confidence in FORM owing to the precluding of some disturbing situations, such as multiplicity of design-points, although not being theoretically sufficient to guarantee their results. Certain bounds for FORM probability can always be computed although they become very loose as input dimension increases; a more interesting upper bound is made available when additionally assuming that the FORM reliability index is robust, in the sense that no point of the limit state can lie closer to the origin.

Thesis on Reliability-based Structural Design- By Seung-Kyum Choi, Ramana V. Grandhi and Robert A. Canfield - March 2006

As modern structures require more critical and complex designs, the need for accurate and efficient approaches to assess uncertainties in loads, geometry, material properties, manufacturing processes and operational environments has increased significantly. Reliability assessment techniques help to develop initial guidance for robust designs. They also can be used to 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.

Reliability-based optimal load factors for seismic design of buildings – By - Juan Bojórquez, Sonia E. Ruiz, Bruce Ellingwood, Alfredo Reyes-Salazar, Edén Bojórquez. A reliability-based development of load factors for the combination of seismic and gravity loads is presented. The procedure aims at minimizing the total expected life-cycle cost of buildings, having as a constraint a maximum value of the mean annual failure rate. The loads considered are dead, live and earthquake loads. The methodology is applied to a large inventory of reinforced concrete frames and steel frames buildings located at a soft soil region of Mexico City.

Benchmark study of numerical methods for reliability based design optimization By - Younes Aoues · Alaa Chateauneuf. The present paper aims at giving an overview of various RBDO approaches which are tested on a benchmark constituted of four examples using mathematical and finite element models, with different levels of difficulties. The study is focused on the three main approaches, namely the *two-level approach*, the *single loop approach* and the *decoupled approach*; for each category, two RBDO formulations are discussed, implemented and tested for numerical examples. The benchmark study allows us to give comprehensive overview of various approaches, to give clear ideas about their capabilities and limitations, and to draw useful conclusions regarding robustness and numerical performance.

Implementation

From the above case studies it is found that Reliability Based Design has played a major role in the design of RCC structures .Now a days in many parts of the world this design is used whether it is Truss design or it is an off shore structure . It has shown a remarkable bridge design as those are totally dependent upon the probability.

It is seen in the previous study cases that Reliability Based design is used all over the world with such successful results but then to in LIMIT STATE DESIGN is playing a major role so a direct way can be established to Incorporate Reliability Factors in limit state design of RCC structures in the following parameters-

1. Beam
2. Column

So it is an advance step in design to introduce reliability factors to Limit State function in which proper failure can be judged and that one may use the directly put the limit state loads and resistance in the equation and results of Reliability Based Design

Acknowledgement

Authors of this paper would like to extent their gratitude to Integral University for supporting this research work (IU/R&D/2018-MCN000325).

References

1. R.Ranganathan, Reliability analysis and design of RCC slabs, Beams and columns and frames-code calibration, DS and T Report no. 4/1/83/STP-111/5, Civil Engineering Department, IIT Bombay (1987).
2. R. Ranganathan, *Reliabilirv Analysis and Design of Structures.* Tata McGraw-Hill. Delhi (1990).
3. Mohammad Masoud Azhdari Moghaddam, "Analysis of Beam Failure Based on Reliability System Theory Using Monte Carlo Simulation Method".
4. Hassan Baji and Hameed Reza Ronagh, "Reliability Analysis of Moment Redistribution in RC Beams".
5. Renjian Lu.*et.al*, "Reliability evaluation of Reinforced concrete beams".
6. Reliability Methods in Civil Engineering by Dr Srinivasan Chandrashekhran, Department of Civil Engineering, IIT Kharagpur. For more details on NPTEL visit http://nptel.iitm.ac.in
7. Ravindra P. Patil and K. Manjunath, "An Empirical Expression for Reliability Index of Flanged RC Beams in Limit State of Deflection".
8. Dr. B. C. Punmia, Ashok Kumar Jain and Arun Kumar jinn – Limit State Design of Reinforced Concrete – First edition, Laxmi Publications (p)-limited.
9. Limit state Design of Reinforced Concrete, 2nd edition, by P.C.Varghese, Prentice- Hall of India Pvt.Ltd. New Delhi, 2002.
10. IS 456:2000 "Indian Standard Code of Practice for Plain and Reinforced Concrete" (Fourth revision), Bureau of Indian Standards.
11. Dr. K. Manjunath and Meghana Bharadwaj, "Reliability analysis of Flanged RC Beams in Limit State of Cracking".
12. Andre J. Torii and Roberto D. Machado, "Reliability analysis of Nonlinear Reinforced Concrete Beams".
13. A.SriVidya and R. Ranganathan. Automatic generation of stochastically dominant failure modes in frame structures for reliability studies. *Reliab. Engng System Safety 37, 15-23 (1992).*
14. Ravindra, M.K. and T.V.Galambos, "Load and Resistance FactorDesign for Steel", *Journal of Structural Division, ASCE*, Vol.104, 1978, PP.1337-1353.
15. Ellingwood, B. *et al*.," Development of a Probability Based Load Criterion for American National Standard A58," *NationalBureau of Standards PublIcatI on* 577, Washington, D.C., 1980.
16. H.O.Madsen, S.Krenk, N.C.Llnd, *Methods of Structural Safety* Prentlce-Hall, Inc., Englewood Cliffs, NJ 07632, 1986.

****