RELIABILITY ANALYSIS OF A CONCRETE COLUMN BY RESPONSE SURFACE METHOD IN THE ANSYS ENVIRONMENT

Kathleen Guimarães Santana

João Pedro Franco de Mello

kathleen.vert@gmail.com

jpfdemello@gmail.com

Instituto Federal do Maranhão - IFMA

Av. Getúlio Vargas, nº 4, Monte Castelo, CEP 65030-005, Maranhão, São Luis, Brasil

Rafaella Moreira Lima Gondim

Rodrigo de Azevêdo Neves

rafaellamlima@hotmail.com

rodrigo.neves@ifma.edu.br

Instituto Federal do Maranhão - IFMA

Av. Getúlio Vargas, nº 4, Monte Castelo, CEP 65030-005, Maranhão, São Luis, Brasil

Abstract. *Due to the diverse number of uncertainties in the process of determining stresses and strength in concrete structures, structural reliability, established in probabilistic terms, appears as a good alternative to a better knowledge of the project. According to the literature, this quantity can be measured from a survival probability or a failure probability. The Response Surface Method, used in this work, is basically a design of experiments in order to optimize an output variable, which is influenced by the input variables. This method requires a simulation procedure that provides random sampling using the response surface equations. For this purpose, Monte Carlo Simulations were also applied. Computational analysis was proven to be appropriate in dealing with this sort of problem, due to the quickness and stability of the solutions. In this work, it is shown an example of the use of Response Surface Method to determine the reliability of a concrete column with three random variables. This choice is justified by the difficulty in using other methods when there is an increase in the number of random variables to the problem. The analysis of a probabilistic model with three random variables linked to a simplified mechanical model of a concrete column was performed in this paper. The computational environment used is ANSYS.*

Keywords: *Failure Probability, Structural Reliability, Concrete, Monte Carlo Method, Response Surface Method*

1. INTRODUCTION

The reliability study of a structure intends to predict uncertainties which appear in the system's variables. Its goal is to figure the probability in which a random failure scenario may occur. Statistically, the reliability R is the complementary event to the failure probability P_f and it can be measured by the following equation:

$$R = 1 - P_f \quad (1)$$

It is usual to work with failure probability values, since reliability numbers are considerably bigger and, thus, more difficult to work with.

In the structural engineering field, the necessity to establish an index capable of evaluating a whole structure, a system or an element is "ancient", and the reliability theory, formalized since the first half of the last century, came to try to fulfill these urges. At first, this theory presented a possibility to consider the uncertainties existing amongst the many variables of a structure, in a more realistic manner. In addition, the recent popularization of computing enabled a great progress in numerical simulation of structures.

In this work, the module used was a column with cross sectional dimensions 20 x 20 cm and 40 cm long. The characteristic compressive strength of concrete, fck, adopted was equal to 32 MPa; this value is a result of the mean resistances obtained by testing of 28 days old specimens in a construction site, located in São Luís-MA. The proposal of this work is to use the software ANSYS 15.0 in order to obtain solutions for a reliability problem in a concrete column. The stochastic module is constituted of random variables which statistical distribution was obtained by adjustment of the data gathered in a construction site located in São Luís – MA.

2. MECHANICAL MODEL

2.1 Analyzed column

The model consists of a short column, with dimensions 20x20x40 (length x width x height). The mechanical non-linear analysis is a necessary step for the following probability investigation to determine the probability of failure. All analysis were performed using the Finite Element Method software ANSYS 15.0.

Elements Used

The concrete was modeled using the element SOLID65. This is a tridimensional element with eight nodes. This element is proper to concrete modelling; it is able to fissure while submitted to tensile forces and to crush while submitted to compressive forces. Furthermore, it exhibits plastic deformation and fluency.

Concrete

Concrete elements were analyzed by using two different behavior models: linear elastic and concrete. In addition to these models, the failure criteria that better describes the material's limit states was considered.

a) Linear Elastic

The linear elastic model demands the introduction of two parameters: elasticity module and Poisson's coefficient. The Poisson's coefficient was assumed 0.2, according to the Brazilian standard NBR 6118:2014.

The modulus of elasticity was assumed to be equal to 3100 kN/cm².

b) Concrete

The concrete behavior model is based on the William-Warckne criteria for brittle materials. It demands the input of the following parameters: shear transfer coefficient for open cracks, shear transfer coefficient for closed cracks, uniaxial cracking stress, uniaxial crushing stress, biaxial crushing stress, ambient hydrostatic stress state, ultimate compressive strength for a state of biaxial compression superimposed on hydrostatic stress state, ultimate compressive strength for a state of uniaxial compression superimposed on hydrostatic stress state and tensile crack factor.

The shear transfer coefficients were adopted based on the works of Park and Paulay apud Leonel et al (2003). The adopted values were 0.1, for open cracks, and 0.3 for closed cracks.

The third parameter is related to the tensile ultimate strength of the brittle material. Assuming our material has f_{ck} equal to 32 MPa, and using the formulae suggested by the Brazilian standard NBR 6118:2014, we find the following values:

$$\mathrm{f_{ct,m}} = 0{,}3(\mathrm{f_{ck}})^{2/3} = 0{,}3(32)^{2/3} = 3.02\ \mathrm{MPa} = 0.302\ \mathrm{kN/cm^2} \quad (2)$$

The fourth parameter was deactivated due to conversion problems and assumed to be equal to -1. This procedure is suggested by Kotinda (2006) and Kunzler (2013), once both authors declared to have better results by doing so.

Parameters 5 to 8 were left blank since they can be calculated using the previous parameters. However, these calculations are only valid if the hydrostatic stress is smaller than 1.73 times the material's ultimate compressive strength.

The last parameter reflects the loss of inertia due to cracking in tension. The adopted value of 0.6 is suggested by Kunzler (2013).

Failure Criteria

The failure limit imposed to the concrete was the Maximum Strain Criterion. In this criterion, the strains in the plies of the model are compared with the imposed parameters. Since this model does not use the temperature as a failure parameter, a temperature-independent failure criteria was created for the concrete material. The failure of the concrete was limited by stress and strains, both for compression and tension. Concrete is a material with a low tensile strength, therefore the allowable strain imposed was equal to 0.0001 (1 cm for 10000 cm), and the stress σ necessary to cause this ultimate strain ε was equal to 0.16 kN/cm, based on Hooke's Law.

$$\sigma = E \times \varepsilon \quad (3)$$

with:
$E = elasticity\ modulus$

The limit imposed for the strain in compression was equal to 0.002 (2 cm by 1000cm), according to the Brazilian Standard NBR 6118:2014. The compression stress was calculated similarly to the tensile stress, and equals 3.2 kN/cm.

Loads

The column was subjected to a compressive load distributed over its top surface. The adopted load was equal to 3 kN/cm².

3. PROBABILISTIC MODEL

3.1 Parameters

In our probabilistic model, the random variables were AREA and TENSAOSOL (applied stress). The mean AREA was set to 400 cm² and the standard deviation was equal to 8. This value was obtained by field research of the variation of column sections in a building located in São Luís – MA. The average applied stress was equal to the applied load in the mechanical model (3 kN/cm²) multiplied by a factor correlating the initial area and the area with variations. The standard deviation was set to 0.1.

The effect of the variation of these two random variables in failure limit state was quantified by the parameter EL (limit state), equal to resistant stress minus applied stress. The probability of failure is defined as the probability of the parameter EL being negative.

3.2 Analysis Method

The Wizard Method tool of ANSYS 15.0 was used to find a method that best fitted the problem. Since our data set was smooth and continuous (Gauss distribution), the Response Surface Method was applied, with posterior Monte Carlo Analysis over the results of the first method.

According to NEVES (2004), the Response Surface Method is an approximation method that offers a good estimation on the failure probability value, for it allows reaching a limit state function and determining the project point (P*). P* is the point where the failure has the largest probability to occur, and it is found by substituting the real limit state function for approximating surfaces around the point, in an iteration process. This method substitutes the real surface by a polynomial, which accelerates the procedure. Other failure modes are neglected; hence the study takes under consideration only the probability obtained by finding the project point. Nonetheless, Monte Carlo samples are created using the response surface equations to complete the analysis.

So as to perform a proper reliability analysis, not only a probabilistic model is required, but also a mechanical model that is relevant for the study. The Finite Element Method (FEM) is often adopted for this purpose.

4. RESULTS AND CONCLUSIONS

The analysis generated one response surface set, which consists on an approximation describing a random output parameter as an explicit function of random input variables. The following Gaussian distribution was found for the parameter EL:

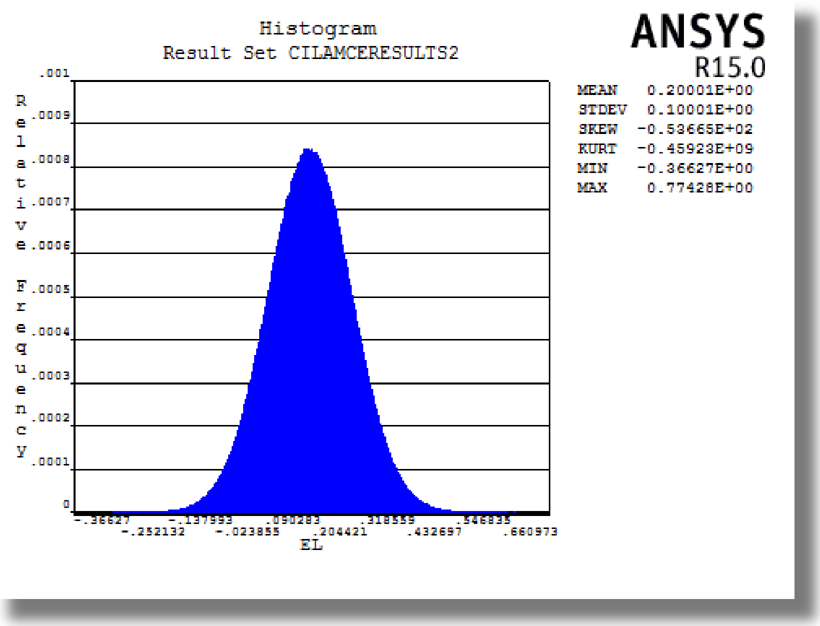

Figure 1: Gaussian distribution for parameter EL

The probability of failure was found to be equal to 2.27%. This high rate can be explained by the small difference between the ultimate compressive stress supported by our material and the applied stress.

REFERENCES

ANSYS, Inc. Theory reference (Version 15.0), 2013.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (2014). NBR 6118 – Projeto de estruturas de concreto - Procedimento. Rio de Janeiro, ABNT.

KOTINDA, T. I. (2006). Modelagem numérica de vigas mistas aço-concreto simplesmente apoiadas: ênfase ao estudo da interface laje-viga. Dissertação (Mestrado). Escola de Engenharia de São Carlos – USP. 114p.

KUNZLER, P. S. (2013). Análise paramétrica por elementos finitos de vigas de concreto armado e protendido pré-tracionadas com abertura na alma. Dissertação (Mestrado). Programa de Pós-Graduação em Engenharia Civil da Universidade Federal do Rio Grande do Sul – UFRGS. 112p.

LEONEL, E. D.; RIBEIRO, G. O.; PAULA, F. A. Simulação numérica de estruturas de concreto armado por meio do MEF/ANSYS. In: Simpósio EPUSP sobre Estruturas de Concreto, 5, São Paulo, 2003. Anais. São Paulo: USP, 2003.

NEVES, R. DE A. (2004). Desenvolvimento de modelos mecânico-probabilísticos para estruturas de pavimentos de edifícios. Tese (Doutorado). Escola de Engenharia de São Carlos – USP. 200p.