PROBABILITY FAILURE OF COLUMN IN STEEL STRUCTURE

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Abstract - ***The evaluation of the safety of structures is a task of much importance. It has been one of the subjects of interest for engineers. The safety of a structure depends on the resistance R, of the structure and the action S (load or load effect) on the structure. The action is a function of loads (live load, wind load, etc.), which are random variables. Similarly, the resistance or response of the structure depends on the physical properties of materials, and the geometric properties of the structure which were also subjected to statistical variations, and are probabilistic.***

The design variables being random, it becomes much more important to assess the level of safety in the probabilistic design situation. Column being the vital most structural element, probability of failure of a column is linked to the overall safety of a structural system. With this in view, an attempt is made to assess the safety levels ensured by the design methodology of the present code of practice IS 800-2007. This requires the information on the probability distributions of the resistance part and action part in each limit state. The work is carried out on the following lines:

In the present study level 2 reliability of the design of steel compression member are carried out as per IS 800-2007.

The statistics and probability distribution of axial load, uniaxial moments and biaxial moments in a particular column are generated by digital simulation on a selected steel frame using ETABS 2013. The generated data on axial load, axial load with uniaxial moments and axial load with biaxial moments is subjected to statistical analysis.

Key Words: *Reliability Analysis, Probability failure, Monte Carlo simulation, Steel structure.*

1. INTRODUCTION

General principles for checking safety define a method for calculating the behavior and strength of structures subjected to loadings. Design methods may be classified in the following ways

a) Permissible Stress Method
b) Ultimate Strength Design and Plastic Design Method
c) Limit State Method
d) Probability-based Limit States Design

1.1 Probability-based Limit State Design

In this design method, probabilistic methods are used to guide the selection of the partial safety factors to loads and resistances of the structure or structural elements or material of the structures, and they result in the desired overall safety. The principal advantages of this design method are:

a) More consistent reliability is attained for different situations as the different variabilities of the various resistances and loads are considered explicitly and independently.
b) The reliability level can be chosen to reflect the consequences of failure.
c) It is a tool for exercising judgement in non routine situations.
d) It provides a tool for updating standards in a rational manner.

The conceptual framework for the analysis of structural reliability and probability-based design is provided by the classical reliability theory.

1.2 Variables in engineering problems

The variables in engineering problems can be classified as

a) Deterministic: An approach based on the premise that a given problem can be stated in the form of a question or a set of questions to which there is an explicit and unique answer is a deterministic approach. Example: material characteristics.
b) Probabilistic: A probabilistic approach is based on the concept that several or varied outcomes of a situation are possible to this approach. Uncertainty recognized as yes or no type of answer to a question concerning structural performance is considered to be simplistic. Probabilistic modeling aims at a study of a range of outcomes to a given input data. Accordingly the description of a physical situation or system includes randomness of data and other uncertainties. The selected data for a deterministic approach would not be sufficient for a probabilistic

study of the same problem. The raw data would provide a meaningful probabilistic analysis.

A probabilistic approach aims in determining the probability p, of an outcome, one of that may occur. Probability would be any percentage between p=0% and probability=100% or any value between p=0 and p=1. In a specific problem the number of likely outcomes may be limited and it may be possible to consider the probability of each outcome. Example: Wind load, ocean-wave height, earthquake etc.

2. DETERMINISTIC DESIGN OF COLUMN

For deterministic design a typical model is considered. A four storey steel frame having, columns of height 3.5m are spaced at 5m centre to centre, beams of length 5m, wall load of 20kN/m, slab of 125mm thick of M25 grade concrete, with live load on slab of 3kN/m^2 are used for modeling.

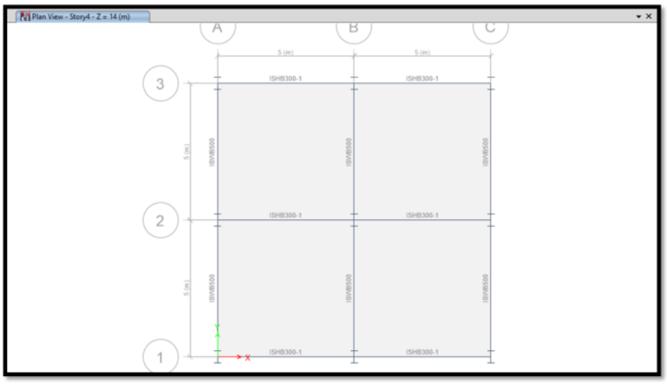

Fig -1: Plan view of steel structure.

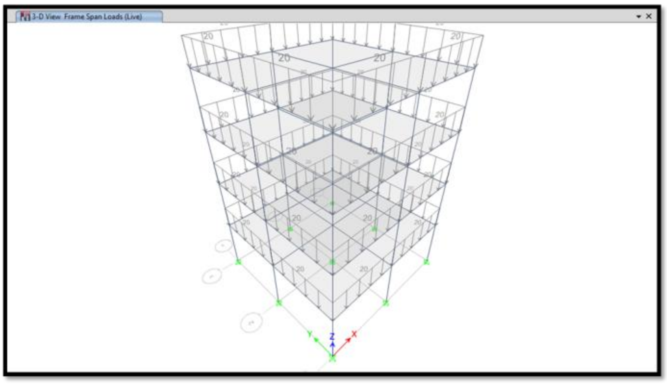

Fig -2: 3D view of steel structure.

Frame analysis is carried out and results are used for deterministic design. Axial load and moments along minor and major axis are used to check the safety of column.
In the present study standard Rolled I-sections ISHB 450 (87.2 kg/m) is taken as trial sections. The axial load and moments for the design are taken from the frame analysis carried out in ETABS.

Data obtained from analysis:

a) Factored axial load = 536.718 kN
b) Factored moment along Major axis
   Mz(top) = 20.892 kN-m
   Mz (bottom) = 8.836 kN-m
c) Factored moment along Minor axis
   My(top) = 12.267 kNm
   My (bottom) = 6.075 kNm

The section is found to be safe under various checks in the design as per the provision of IS: 800-2007.

3. GENERATION OF LOAD STATISTICS AND RESISTANCE STATISTICS

For probabilistic design, standard normal deviates are obtained by generating two uniform random numbers v1 and v2 (with a uniform density range between 0 and 1). Then the standard normal variates are u1 and u2 are calculated.
Here, in present study the variations is applied for f_{ck} characteristic cube strength of concrete in slab, depth of slab, live load on slab, length of beam, live load on beam and height of column.
For 100 values of standard normal variates, the above parameters are applied and number of times frame analysis is carried out in ETABS and the results are used to find the probability of failure of columns of the structure.

3.1 Random variables

The random variable is a numerical variable whose specific values cannot be predicted with certainty before an experiment. The value assumed by a random variable associated with an experiment depends on the outcome of the experiment. This value is associated with every simple event defined on the sample space, but different simple event defined on the sample space, but different simple events may have the same associated value of the random variables, e.g. the strength of concrete, the wind speed observed at a location etc.

3.2 Monte Carlo simulation

Monte Carlo simulation is a type of simulation that relies on repeated random sampling and statistical analysis to compute the results. This method of simulation is very closely related to random experiments, experiments for which the specific result is not known in advance. In this context, Monte Carlo simulation can be considered as a methodical way of doing so-called what-if analysis.
In Monte Carlo simulation, we identify a statistical distribution which we can use as the source for each of the input parameters. Then, we draw random samples from each distribution, which then represent the values of the input variables. For each set of input parameters, we get a set of output parameters. The value of each output parameter is one particular outcome scenario in the simulation run. We collect such output values from a number of simulation runs. Finally, we perform statistical analysis on the values of the output parameters, to make decisions about the course of action (whatever it may be). We can use the sampling

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statistics of the output parameters to characterize the output variation.

3.3 Variations in resistance parameters

The fundamental requirement in the reliability study is the collection of data on the strength and other physical properties of the materials of the structures, and the geometric parameters of the sections and the statistical analysis of the same. In present study the following variations are applied for various parameters of resistance which include

a) Geometrical properties
b) Material properties
c) Loads

4. PROBABILISTIC DESIGN OF COLUMN

Limit state of combined axial load and biaxial moments

a) For random variation in different geometrical properties, length and load, corresponding interaction values are calculated with respect to both major and minor axis.
b) Member subjected to combined axial compression and biaxial bending shall satisfy the following relationship
$P/P_{dy}+K_y\ (C_{my}\ M_y)/M_{dy}+K_{LT}\ M_z/M_{dz}\ \leq 1.0$
$P/P_{dz}+0.6K_y\ (C_{my}\ M_y)/M_{dy}+K_z\ (C_{mz}\ M_z)/M_{dz}\ \leq 1.0$
c) Let iy be the interaction value corresponding to Minor axis.
d) Let iz be the interaction value corresponding to Major axis.
e) If iy > 1.0 or if iz > 1.0, then it is failure.
f) Compute the probability of failure by
g) pf = (Number of such failure)/(Number of simulations).

Table -1: Safety check of the column samples

P (kN)	M_y (Top)	M_y (Bot)	M_z (Top)	M_z (Bot)	Interaction values	
					Y-Y	Z-Z
1091.1	27.03	13.40	45.43	19.63	1.18	1.01
1050.4	25.95	12.86	43.61	18.82	1.12	0.96
1106.8	27.47	13.62	46.16	19.96	1.20	1.02
956.52	23.35	11.58	39.31	16.91	1.00	0.85
1052.2	25.99	12.89	43.68	18.85	1.13	0.96
1089.3	26.99	13.38	45.36	19.60	1.17	1.00
979.17	23.94	11.87	40.29	17.35	1.03	0.88
1106.8	27.47	13.62	46.20	20.00	1.19	1.01
920.36	22.33	11.07	37.62	16.16	1.09	0.95
1058.6	26.15	12.96	43.94	18.96	1.13	0.96

In the present study due the variations applied the samples of the column is found to be unsafe which is decided by the interaction value obtained due to combined effect of axial load and moments as per the provision of IS: 800-2007.

5. PROBABILITY MODELING

Histogram provides an immediate impression of the range of the data, its most frequently occurring values and the degree to which it is scattered. It is the presentation of data in useful form. The observations are made and noted down as they occur and hence the collected data will be in an unorganized form. This unorganized data is arranged properly. The values are marked in an increasing order. These ordered values are then divided into intervals and the number of observations in each interval is plotted as a bar.

Histogram and probability distribution curve of the generated sample of Q and maximum moment capacity Mu3 and maximum moment capacity Mu2 about major and minor axis for column subjected to combined axial load and bi-axial moments are plotted.

The suitability of a probabilistic model to fit the data is arrived after applying any one of the following goodness-of-fit test in MATLAB.

a) Chi-square Test.
b) Kolmogorove-Smirnov (K S) Test.

It is found that Normal distribution fits the generated data well, Based on the Chi-square Test. During the reliability analysis of the present design, the resistance model is calculated by performing Monte-Carlo simulations.The variables included in the study are dimensions, material properties and load. Loads were obtained from ETABS model. The current study assumes a normal distribution for all variables.

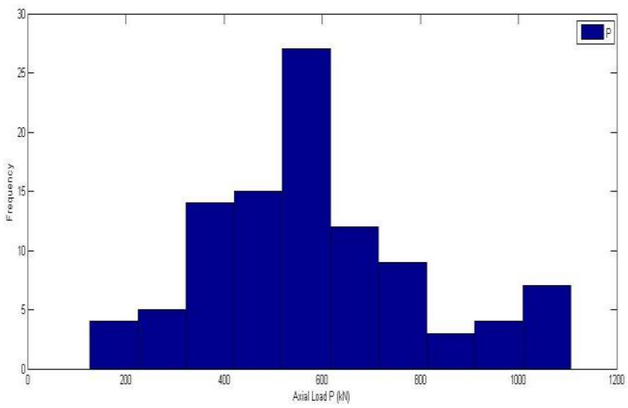

Fig -4: Histogram for Axial Load P of the column

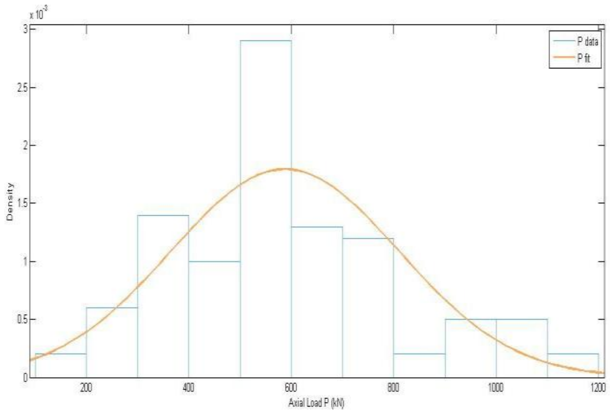

Fig -5: Normal distribution curve for Axial Load P of the column

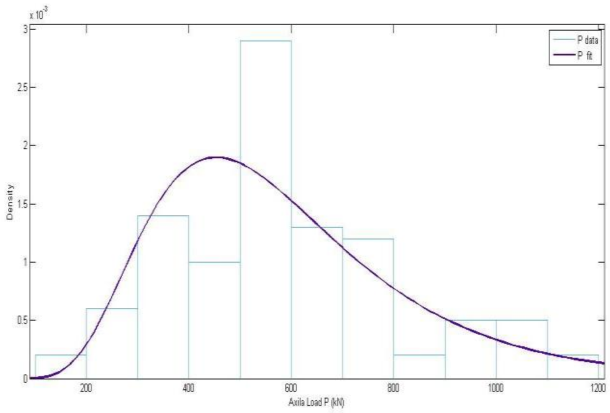

Fig -6: Log Normal distribution curve for Axial Load P of the column

Similarly, Histrogram, Normal and Log normal distribution curve is plotted for moments at top and bottom of the column with respect to both major and minor axis using MATLABS.

3. CONCLUSIONS

a) The deterministic design methodology suggested by IS 800:2007 by adopting limit state method with appropriate partial safety factors is assessed for explicit level of safety by using methods of Reliability. It is done for three different limit of states namely
   - Limit state of Flexure
   - Limit state of Shear
   - Limit state of Deflection.

b) Monte Carlo digital simulation is used to generate random variables by using the statistics of design variables. The statistics of design variables are taken from literature. MATLAB is used to conduct the digital simulation.

c) The statistics of action are generated by repeatedly analysing a multi storeyed steel frame using ETABS software. The randomly generated values of design variables are supplied as input to the program. Similarly, the statistics of resistance are generated using the same technique.

d) The safety margin is defined as the difference between resistance and action. When the random values of resistance (R) and action (S) are generated, check is made if $R < S$. If so, it is counted as failure. The probability of failure is the ratio of (Number of such failure)/(Number of simulations).

e) The probability of failure is found to be 10%, reliability is 90%.

f) It is possible to evaluate the explicit level of safety of steel column design by using the specification of IS 800:2007. The overall factor of safety is implicitly built into deterministic design but it is not explicitly known to the designer. The reliability analysis helps to obtain the explicit level of safety by using a given design philosophy.

g) The present work attempts to demonstrate the procedure for evaluating safety level in terms of probability failure by using the methods of reliability analysis.

h) The advantage of reliability analysis is that it helps to formulate the basis for reliability based design and this will help the designer to design the structural elements for a known probability of failure.

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