Probability of failure of column and beam in steel structure due to plan irregularities

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Abstract - *The evaluation of safety of the structure is an important task for the engineers. The safety of structure depends mainly on the parameters like Resistance denoted by 'R' of the structure and action denoted by 'S' on the structure. Here action is the function of loads, which are random variables such as live load, wind load etc., and resistance of the structure depends on the physical properties of materials used and geometrical properties of the structure which are probabilistic. The concept wherein several outcomes of a situation are possible is used for Probabilistic approach. Probabilistic modelling aims at the study of a range of outcomes for a given input data. The design variables are random hence it is much more important to assess the safety levels in the probabilistic design situation. Column is the vital most component of the structure, probability of failure of column is linked to the overall safety of the structure. Considering the above an attempt is made to assess the safety of the structure ensured by the design methodology of IS 800-2007.*

Key Words: **Column-Beam failure, Reliability, Steel structure, Axial load, Uniaxial moments, Biaxial moments.**

1. INTRODUCTION

The evaluation of safety of the structure is an important task for the engineers. The safety of structure depends mostly on the parameters like resistance (R) of the structure and action (S) on the structure. The action is the function of loads which are random variables such as live load, wind load etc., and the resistance of structure depends on materials used, geometrical properties of the structure which are probabilistic. Even though it was always known that these above parameters are random variables, no serious attempts were made to consider their random variations, till 1960 in analysis, design and evaluation of safety. It was probably due to the reason that engineers and research workers were not confident of applying probability theory. It was only around 1960 that engineers started to realise the need for the evaluation of safety of the structure taking into the consideration of random variations of the design parameters like loads, height etc.

1.1 Scope of study

The structural safety depends on Resistance (R) of the structure and the Action (S) on the structure. The Action is the function of loads which are random variables. The resistance depends on the physical properties of materials used and geometrical properties of the structure which are probabilistic.

The design variables being random it is 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 column is linked to the overall structural safety hence it's important to assess the safety levels ensured by design methodology of IS 800:2007.

1.2 Objective of study

In the present study, an unsymmetrical structural frame is considered and level 2 reliability of the design of steel flexural members and compression members are carried out as per the code of practice IS 800-2007.

The axial load, uniaxial moments and biaxial moments in a particular column and the statistics and probability distribution of moments and shear in a particular beam are generated on selected steel frame using ETABS 2015.

The data generated is subjected to the statistical analysis. The probability modelling is done using MATLAB. Probability of failure is determined by Monte Carlo simulation. Monte Carlo simulation is used to determine the statistical value of resistance of the members and chi-square 'goodness of fit' test is employed to determine the type of distribution for the variables.

2. METHODOLOGY

A two storey building with the below details is considered
Floor height = 3.0 m
Spacing of columns = 4.0 m and 6.0 m
Column height = 3.0 m ISMB-450
Beam lengths = 4.0 m and 6.0 m ISMB-300
Live load on storey 1 = 19 KN/m

Live load on storey 2 = 6 KN/m
Thickness of slab = 200mm
Grade of concrete = M20
Frame analysis is carried out and the results obtained are used for deterministic design. Bending moment and shear force are used to check the safety of the beam. Axial load and moments along minor axis and major axis are used to check the safety of the column. If suppose the sections fail it has to be revised in the deterministic design.

2.1. Generation of load and resistance statistics

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

2.2. RANDOM VARIABLES

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

Table-1: Random variables

V1	V2	U1	U2	V1	V2	U1	U2
0.179	0.738	-0.14	-1.85	0.615	0.324	-0.442	0.881
0.26	0.736	-0.144	-1.635	0.428	0.479	-1.291	0.171
0.8	0.124	0.475	0.469	0.863	0.396	-0.431	0.33
0.112	0.384	-1.561	1.394	0.203	0.175	0.811	1.591
0.746	0.893	0.599	-0.477	0.529	0.213	0.26	1.098
0.191	0.32	-0.775	1.646	0.791	0.59	-0.578	-0.367
0.792	0.776	0.111	-0.674	0.437	0.456	-1.238	0.351
0.842	0.231	0.07	0.582	0.571	0.064	0.974	0.414
0.42	0.645	-0.807	-1.041	0.134	0.285	-0.437	1.957
0.495	0.844	0.66	-0.985	0.81	0.692	-0.231	-0.607
0.683	0.158	0.477	0.731	0.51	0.401	-0.943	0.676
0.569	0.924	0.943	-0.488	0.69	0.351	-0.511	0.694
0.419	0.784	0.28	-1.289	0.807	0.596	-0.539	-0.371
0.974	0.561	-0.213	-0.086	0.667	0.085	0.775	0.458
0.942	0.047	0.331	0.101	0.015	0.276	-0.471	2.86
0.802	0.097	0.545	0.38	0.168	0.047	1.807	0.55
0.878	0.079	0.449	0.243	0.729	0.575	-0.708	-0.361
0.301	0.852	0.927	-1.242	0.139	0.058	1.856	0.708
0.992	0.862	0.082	-0.097	0.435	0.6	-1.044	-0.758
0.658	0.391	-0.709	0.579	0.29	0.684	-0.634	-1.44
0.037	0.894	2.019	-1.587	0.575	0.53	-1.033	-0.197
0.306	0.168	0.758	1.339	0.167	0.736	-0.166	-1.885
0.383	0.117	1.028	0.929	0.938	0.184	0.144	0.327
0.192	0.975	1.794	-0.284	0.773	0.859	0.454	-0.556
0.178	0.077	1.645	0.864	0.53	0.43	-1.02	0.48

2.3. Variations in resistance parameters

The requirements in the reliability study is the collection of data on the physical properties of the materials of the structure, strength of the materials used and the geometric parameters of the sections and statistical analysis of the structure. In the present study, the variations applied for various parameters of resistance which include Geometrical properties, Material properties and loads are as follows:

Table-2: Geometrical and Material Property Variations

SL NO	PROPERTIES	% of variations
1	**Geometrical** Depth of slab Length of beam Height of column	 10 03 03
2	**Material** Characteristic cube compressive strength of concrete	20

2.4. Generation of normal variates

Table-3: Normal variates for slab, beam and column

	SLAB			BEAM				COLUMN
SL NO	fck	D	LL	L(6m)	L(4m)	LL (19)	LL (6)	H
1	19.97	199.99	2.94	5.996	3.996	18.972	5.972	2.996
2	19.97	199.99	2.94	5.996	3.996	18.971	5.971	2.996
3	20.10	200.05	3.19	6.014	4.014	19.095	6.095	3.014
4	19.69	199.84	2.38	5.953	3.953	18.688	5.688	2.953
5	20.12	200.06	3.24	6.018	4.018	19.120	6.120	3.018
6	19.85	199.92	2.69	5.977	3.977	18.845	5.845	2.977
7	20.02	200.01	3.04	6.003	4.003	19.022	6.022	3.003
8	20.01	200.01	3.03	6.002	4.002	19.014	6.014	3.002
9	19.84	199.92	2.68	5.976	3.976	18.839	5.839	2.976
10	20.1	200.0	3.2	6.020	4.020	19.132	6.132	3.020

	3	7	6					
11	20.10	200.05	3.19	6.014	4.014	19.095	6.095	3.014
12	20.19	200.09	3.38	6.028	4.028	19.189	6.189	3.028
13	20.06	200.03	3.11	6.008	4.008	19.056	6.056	3.008
14	19.96	199.98	2.91	5.994	3.994	18.957	5.957	2.994
15	20.07	200.03	3.13	6.010	4.010	19.066	6.066	3.010
16	20.11	200.05	3.22	6.016	4.016	19.109	6.109	3.016
17	20.09	200.04	3.18	6.013	4.013	19.090	6.090	3.013
18	20.19	200.09	3.37	6.028	4.028	19.185	6.185	3.028
19	20.02	200.01	3.03	6.002	4.002	19.016	6.016	3.002
20	19.86	199.93	2.72	5.979	3.979	18.858	5.858	2.979
21	20.40	200.20	3.81	6.061	4.061	19.404	6.404	3.061
22	20.15	200.08	3.30	6.023	4.023	19.152	6.152	3.023
23	20.21	200.10	3.41	6.031	4.031	19.206	6.206	3.031
24	20.36	200.18	3.72	6.054	4.054	19.359	6.359	3.054
25	20.33	200.16	3.66	6.049	4.049	19.329	6.329	3.049
26	19.91	199.96	2.82	5.987	3.987	18.912	5.912	2.987
27	19.74	199.87	2.48	5.961	3.961	18.742	5.742	2.961
28	19.91	199.96	2.83	5.987	3.987	18.914	5.914	2.987
29	20.16	200.08	3.32	6.024	4.024	19.162	6.162	3.024
30	20.05	200.03	3.10	6.008	4.008	19.052	6.052	3.008
31	19.88	199.94	2.77	5.983	3.983	18.884	5.884	2.983
32	19.75	199.88	2.50	5.963	3.963	18.752	5.752	2.963
33	20.19	200.10	3.39	6.029	4.029	19.195	6.195	3.029
34	19.91	199.96	2.83	5.987	3.987	18.913	5.913	2.987
35	19.95	199.98	2.91	5.993	3.993	18.954	5.954	2.993
36	19.81	199.91	2.62	5.972	3.972	18.811	5.811	2.972
37	19.90	199.95	2.80	5.985	3.985	18.898	5.898	2.985
38	19.89	199.95	2.78	5.984	3.984	18.892	5.892	2.984
39	20.15	200.08	3.31	6.023	4.023	19.155	6.155	3.023
40	19.91	199.95	2.81	5.986	3.986	18.906	5.906	2.986
41	20.36	200.18	3.72	6.054	4.054	19.361	6.361	3.054
42	19.86	199.93	2.72	5.979	3.979	18.858	5.858	2.979
43	20.37	200.19	3.74	6.056	4.056	19.371	6.371	3.056
44	19.79	199.90	2.58	5.969	3.969	18.791	5.791	2.969
45	19.87	199.94	2.75	5.981	3.981	18.873	5.873	2.981
46	19.79	199.90	2.59	5.969	3.969	18.793	5.793	2.969
47	19.97	199.98	2.93	5.995	3.995	18.967	5.967	2.995
48	20.03	200.01	3.06	6.004	4.004	19.029	6.029	3.004
49	20.09	200.05	3.18	6.014	4.014	19.091	6.091	3.014
50	19.80	199.90	2.59	5.969	3.969	18.796	5.796	2.969
51	19.63	199.82	2.26	5.945	3.945	18.630	5.630	2.945
52	19.67	199.84	2.35	5.951	3.951	18.673	5.673	2.951
53	20.09	200.05	3.19	6.014	4.014	19.094	6.094	3.014
54	20.28	200.14	3.56	6.042	4.042	19.279	6.279	3.042
55	19.90	199.95	2.81	5.986	3.986	18.905	5.905	2.986
56	20.33	200.16	3.66	6.049	4.049	19.329	6.329	3.049
57	19.87	199.93	2.73	5.980	3.980	18.865	5.865	2.980
58	20.12	200.06	3.23	6.017	4.017	19.116	6.116	3.017
59	19.79	199.90	2.58	5.969	3.969	18.792	5.792	2.969
60	19.80	199.90	2.61	5.970	3.970	18.803	5.803	2.970
61	20.15	200.07	3.29	6.022	4.022	19.146	6.146	3.022
62	19.90	199.95	2.80	5.985	3.985	18.902	5.902	2.985
63	19.74	199.87	2.48	5.961	3.961	18.742	5.742	2.961
64	19.98	199.99	2.97	5.997	3.997	18.983	5.983	2.997
65	20.02	200.01	3.04	6.003	4.003	19.020	6.020	3.003
66	20.08	200.04	3.15	6.011	4.011	19.076	6.076	3.011
67	20.05	200.02	3.10	6.007	4.007	19.049	6.049	3.007
68	19.75	199.88	2.50	5.963	3.963	18.752	5.752	2.963
69	19.98	199.99	2.96	5.997	3.997	18.981	5.981	2.997
70	20.12	200.06	3.23	6.017	4.017	19.116	6.116	3.017
71	19.68	199.84	2.37	5.952	3.952	18.683	5.683	2.952
72	20.27	200.13	3.54	6.040	4.040	19.268	6.268	3.040
73	20.19	200.09	3.37	6.028	4.028	19.186	6.186	3.028
74	19.94	199.97	2.89	5.991	3.991	18.943	5.943	2.991
75	20.17	200.09	3.35	6.026	4.026	19.173	6.173	3.026
76	20.18	200.09	3.35	6.026	4.026	19.176	6.176	3.026
77	20.03	200.02	3.07	6.005	4.005	19.034	6.034	3.005
78	20.07	200.03	3.13	6.010	4.010	19.066	6.066	3.010
79	20.32	200.16	3.64	6.048	4.048	19.318	6.318	3.048
80	20.22	200.11	3.44	6.033	4.033	19.220	6.220	3.033
81	19.93	199.96	2.85	5.989	3.989	18.927	5.927	2.989
82	20.07	200.04	3.14	6.011	4.011	19.070	6.070	3.011
83	20.08	200.04	3.17	6.012	4.012	19.083	6.083	3.012
84	20.39	200.20	3.78	6.059	4.059	19.391	6.391	3.059
85	19.88	199.94	2.76	5.982	3.982	18.879	5.879	2.982
86	20.14	200.07	3.27	6.020	4.020	19.135	6.135	3.020
87	20.14	200.07	3.28	6.021	4.021	19.139	6.139	3.021
88	19.93	199.96	2.85	5.989	3.989	18.926	5.926	2.989
89	20.0	200.0	3.1	6.014	4.014	19.092	6.092	3.014

	9	5	8					
90	20.57	200.29	4.14	6.086	4.086	19.572	6.572	3.086
91	20.11	200.05	3.22	6.016	4.016	19.110	6.110	3.016
92	19.93	199.96	2.86	5.989	3.989	18.928	5.928	2.989
93	20.14	200.07	3.28	6.021	4.021	19.142	6.142	3.021
94	19.85	199.92	2.70	5.977	3.977	18.848	5.848	2.977
95	19.71	199.86	2.42	5.957	3.957	18.712	5.712	2.957
96	19.96	199.98	2.92	5.994	3.994	18.961	5.961	2.994
97	19.62	199.81	2.25	5.943	3.943	18.623	5.623	2.943
98	20.07	200.03	3.13	6.010	4.010	19.065	6.065	3.010
99	19.89	199.94	2.78	5.983	3.983	18.889	5.889	2.983
100	20.10	200.05	3.19	6.014	4.014	19.096	6.096	3.014

3. RESULTS

PROBABILITY OF FAILURE OF BEAM (ISMB-300)

i. Shear = Very low {$<10^{-6}$}
ii. Flexure = Very low {$<10^{-6}$}
iii. Deflection = 6/100

PROBABILITY OF FAILURE OF COLUMN (ISMB-450)
Combined axial force and biaxial bending = 13/100

3.1. Histograms and probability distribution curve for beams

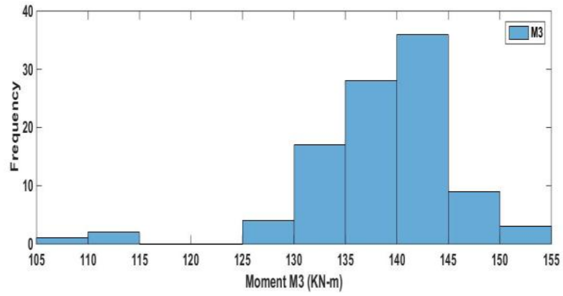

Fig 1. Histogram for Moment M3 of ISMB 300 Beam section

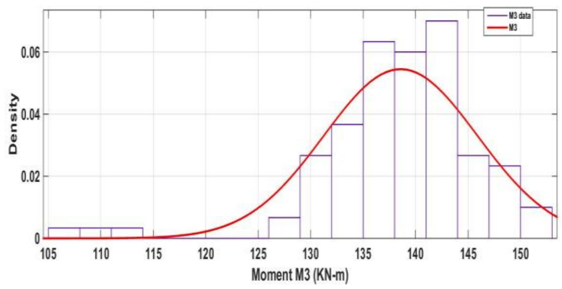

Fig 2. Normal Distribution curve for Moment M3 of ISMB 300 Beam section

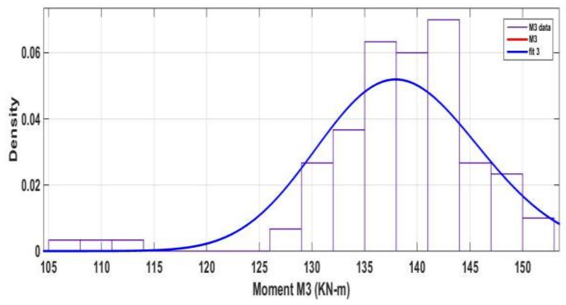

Fig 3. Log Normal Distribution curve for Moment M3 of ISMB 300 Beam section

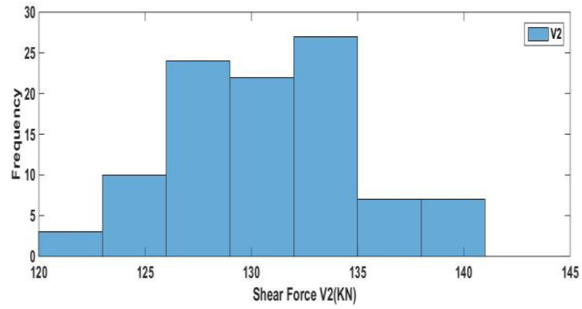

Fig 4. Histogram for Shear V2 of ISMB 300 Beam section

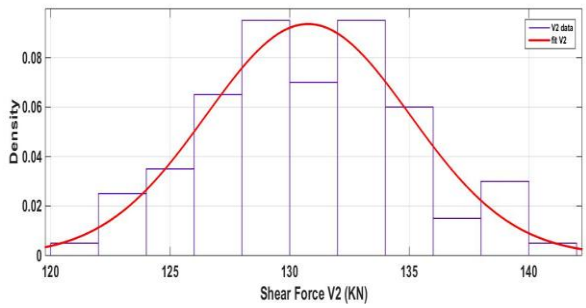

Fig 5. Normal Distribution curve for Shear V2 of ISMB 300 Beam section

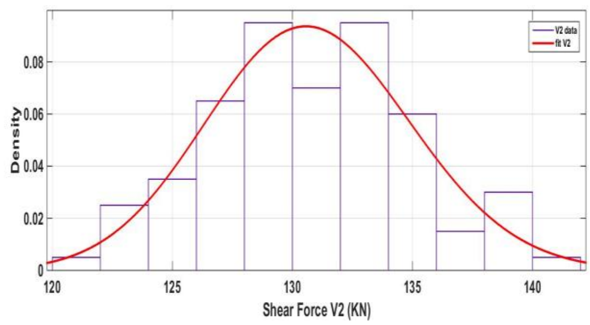

Fig 6. Log Normal Distribution curve for Shear V2 of ISMB 300 Beam section

3.2. Histograms and probability distribution curve for columns

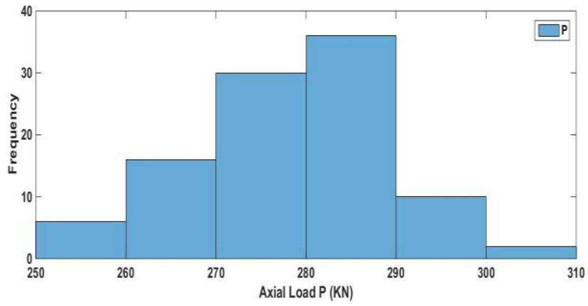

Fig 7. Histogram for Axial Load P of ISMB 450 column section

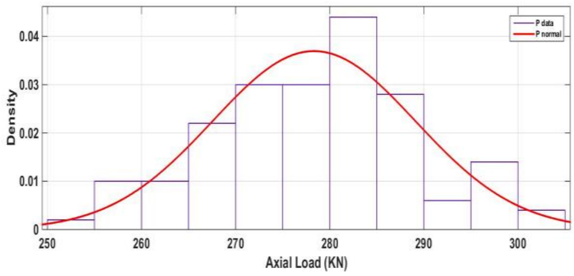

Fig 8. Normal Curve for Axial Load P of ISMB 450 column section

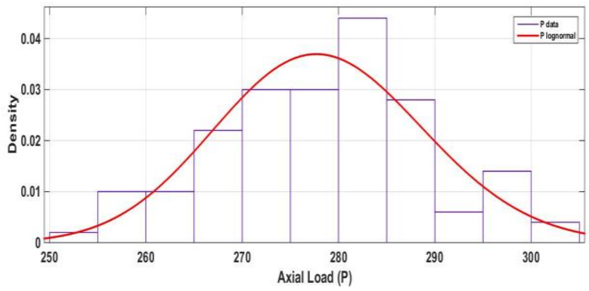

Fig 9. Log Normal Curve for Axial Load P of ISMB 450 column section

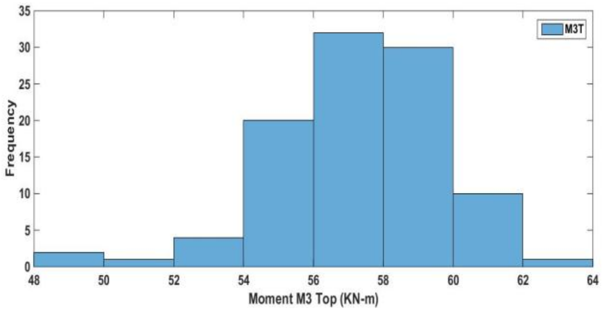

Fig 10. Histogram for Moment M3 (Top) of ISMB 450 column section

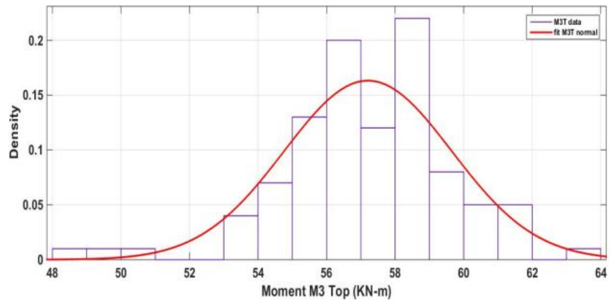

Fig 11. Normal Curve for Moment M3 (Top) of ISMB 450 column section

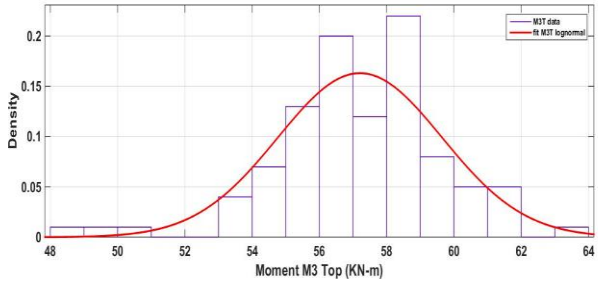

Fig 12. Log Normal Curve for Moment M3 (Top) of ISMB 450 column section

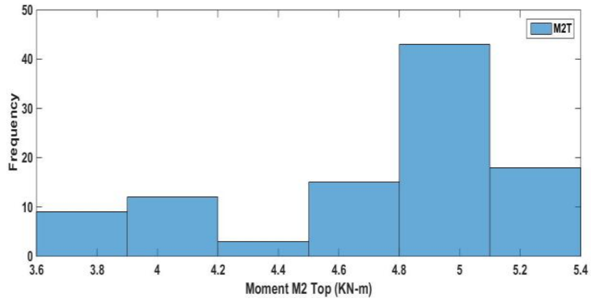

Fig 13. Histogram for Moment M2 (Top) of ISMB 450 column section

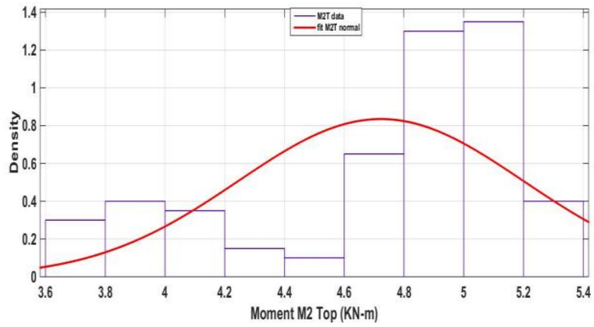

Fig 14. Normal Curve for Moment M2 (Top) of ISMB 450 column section

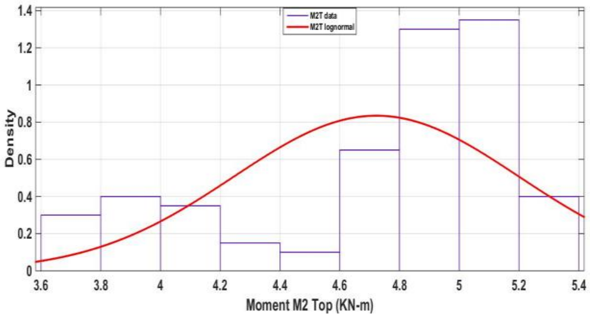

Fig 15. Log Normal Curve for Moment M2 (Top) of ISMB 450 column section

4. CONCLUSIONS

- 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.
- 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.
- 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.
- The safety margin is defined as difference between Action and Resistance. 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

$$\frac{\text{Number of such failures}}{\text{Number of simulations}}$$

- With the above listed procedure, the probability of failure in each limit state is listed below

Limit State of	Flexure	Shear	Deflection
BEAMS	Very low ($<10^{-6}$)	Very low ($<10^{-6}$)	(6/100) = 0.06

Limit State of	Combined Axial force and Bending
COLUMNS	(13/100) = 0.13

- It is possible to evaluate the explicit level of safety of a steel beam and a 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.
- It may be concluded that probability failure in limit state of Flexure and Shear for a beam is very low and is of order of 10^{-6} which is almost equal$_{2\times10}$to zero. However, probability of failure in limit state of deflection is found to be 2 x 10^{-2}.
- The present work attempts to demonstrate the procedure for evaluating safety level in terms of probability failure by using the methods of reliability analysis.
- 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.

REFERENCES

1) R. Ranganathan, Reliability Analysis and Design of Structures, Tata Mc Graw hill Publishing Company limited.

2) S. Ramamrutham, Design of Steel Structures, Dhanpat Rai Publishing Company limited.

3) Ravi G, (1987), "Reliability studies of Steel Structures in Flexure, Tension and Compression", MTech Thesis, Indian Institute of Science, Bangalore.

4) Yadunandan C.N, Sundararju Iyengar K.T, (2000), "Partial Load Safety Factor for Strength Design of Steel Structures", IE(I) Journal-CV, Vol.81, pp 33-36.

5) Andrzej s. Nowak, Kevin R. Collins, (2000), "Reliability of Structure's", McGraw Hill Publishers, United States of America.

6) CIRIA – Construction Industry Research and Information Association (1977), Report 63, "Rationalisation of Safety and Serviceability factors in structural codes", London.

7) Idrish A., Edache P, (2007), "Reliability Analysis of Simply Supported Steel Beams", Australian Journal of Basic and Applied Science 1(1), INSInet publications pp 20-29.

8) N Subramanian, Design of Steel Structures, Oxford University press.

9) Samik Raychaudhuri, INTRODUCTION TO MONTE CARLO SIMULATION, Indian Institute of Technology, Kharagpur, India.

10) Dr. Vasant Matsagar, Design of Steel Structures, Indian Institute of Technology Delhi

11) V.N. Vazirani, M.M. Ratwani, Vineet Kumar, Design and Analysis of Steel Structures, Khanna Publishers.

12) IS: 800-2007, "General construction in steel - Code of practise", Bureau of India Standards, New Delhi.

13) SP: 6(1) – 1964, "Handbook for Structural Engineers", Bureau of Indian Standards, New Delhi.

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