Sukanti Rout, Santosh Kumar Sahoo, Bidyadhar Basa / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 5, September- October 2012, pp.1825-1830

Monte Carlo Simulation Technique For Reliability Assessment Of R.C.C. Columns

Sukanti Rout*, Santosh Kumar Sahoo, Bidyadhar Basa*****
*(Department Civil Engineering, SOA University, Bhubaneswar-30)
** (Department Civil Engineering, SOA University, Bhubaneswar-30)
*** (Department Civil Engineering, SOA University, Bhubaneswar-30)

ABSTRACT

Efforts have been made since several years to improve the engineering decision and minimize the uncertainty, thus preventing the failure of the structure. Several probability theories have been developed in this regard to ascertain the actual behavior of the structure or to determine the reliability of the structure as load and resistances are random variables. This paper presents the usefulness of "Monte Carlo Simulation technique", for checking the safety of R.C.C columns subjected to combined axial load and biaxial moments.

A simple program for this method of reliability analysis of R.C.C columns is developed which will benefit the designers and site engineers to define safety of the building in absolute terms.

Keywords: Reliability; Monte Carlo method; Simulation; R.C.C Column Design

INTRODUCTION

Every engineering structure must satisfy the safety and serviceability requirement under the service load over it; which means it must be reliable against collapse and serviceability, such as excessive deflection and cracking. In the present study an attempt has been made to study the reliability of a structural system and its component using Monte Carlo Simulation Technique, which is a static, stochastic and continuous simulation model. In this study the focus is distribution of a variable to simulate the performance or behavior of a structural system. The main reason for adopting Monte Carlo Simulation Technique in the present work is to estimate the parameters and probability distribution of random variables whose values depend on the interaction with specified probability distribution. The relative advantage is that, this method avoids the complicated closed form solution. The method can also be used to study the statistical properties of resistance.

MONTE CARLO METHOD

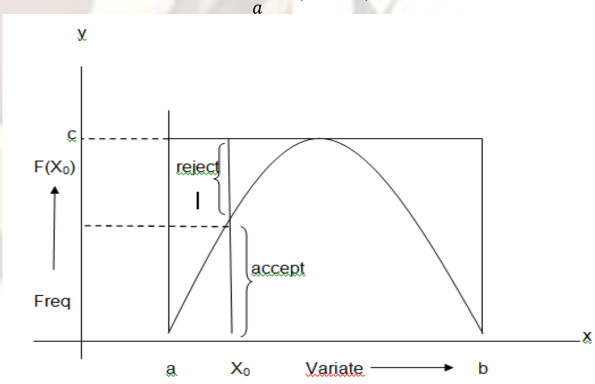
It is a simulation technique in which statistical distribution functions are created by using a series of random numbers. This approach has the ability to develop many data in a matter of a few minutes on a digital computer. The method is generally used to solve problems which cannot be adequately represented by the mathematical models or where solution of the model is not possible by analytical method.

MONTE CARLO SIMULATION yields a solution which is very close to the optimal, but not necessarily the exact solution. However, it should be noted that this technique yields a solution that converges to the optimal or correct solution as the number of simulated trials lead to infinity.

For example , the integral of a single variable over a given range corresponds to find the area under the graph representing the function .Suppose the function f(x) is positive and the lower and upper bounds are a and b ,respectively and the function is bounded above by the value 'c'. The graph of the function is then contained within a rectangle with sides of length c, and (b-a).

If the points are picked up at random within the rectangle and determine whether they lie beneath the curve or not, it is apparent that, provided the distribution of selected points is uniformly spread over the rectangle, the fraction of points falling on or below the curve should be approximately the ratio of the area under the curve to the area of the rectangle. If N points are used and n of them fall under the curve, then, approximately,

$$\frac{n}{N} = \int_a^b \frac{f(x)\,dx}{c(b-a)}$$



Lower bound and upper bound of frequency

The accuracy improves as the number N increases. When it is decided that sufficient points have been taken, the value of the integral is estimated by multiplying the area of the rectangle c(b-a).

For each point, a value of X is selected at random between a and b, say X_0. A second random selection is made between o and c to give Y. if Y less than equal to $f(X_0)$, the point is accepted in the count n, otherwise it is rejected and the next point is picked. This method is often powerful when used on integrals of many variables by using a random number for each of the variable. Although random numbers have been used, the problem being solved is essentially determinate.

Column with axial load and biaxial moment

Creation of random numbers:

For normal distribution, Box and Mullar technique is used to generate normal variates. Standard normal deviates are obtained by generating two uniform random number v_1 and v_2 (with a uniform density range between 0 and 1) at a time. Then the desired standard normal variates are given by

$u_1=(2 \ln 1/v_1)^{1/2} \cos 2\pi v_2$

$u_2=(2 \ln 1/v_1)^{1/2} \sin 2\pi v_2$

then two normal variates y_1 and y_2 are given by

$y_1=\mu+\sigma[(2 \ln 1/v_1)^{1/2} \cos 2\pi v_2]$

$y_2= \mu+\sigma[(2 \ln 1/v_1)^{1/2} \sin 2\pi v_2]$

where y_1 and y_2 are values of fck and fy respectively and μ= Mean and σ= standard deviation (Already obtained from test results for fck and then for fy)

Thus 400 normal variates of fck and 400 normal variates of fy are generated using above normal distribution equations.

Theoretical models or prediction equation for moment of resistance (R_x and R_y)

Step-1

Start with K_u=1

$x_u = K_u d = d$

(a) Calculation of ϵ_i

$\epsilon_i = (0.0035/a_i)/ x_u$

where $a_i = x_u-(D/2) +y_i$

(b) Calculation of f_{ci}

If $\epsilon_i < 0$, then $f_{ci} = 0$

If $0< \epsilon_i < 0.002$ then $f_{ci} = 446 f_{ck}\, \epsilon_i (1-250\, \epsilon_i)$

For $\epsilon_i>0.002$, $f_{ci}= 0.446\, f_{ck}$

(c) Calculation of f_{si}

If $\epsilon_i<0.00174$, f_{Si} is calculated as = $\epsilon_i.E_S$

But if $\epsilon_i>0.00174$, f_{Si} is obtained from table.

(d) Calculation of P_{u1}

$p_{u1}= P_{uc1} +P_{us1}$

=> $P_{uc1} = 0.36fck.b.x_u$

=> $P_{us1}= (f_{s1}-f_{c1})A_{st1} + (f_{s2}-f_{c2}) A_{st2} + f_{s3} – f_{c3}) A_{st3}$

$= \sum_{i=0}^{n} Asti\ (fsi - fci)$

(e) Comparison of P_{u1} with given P_u

If $P_{u1} = P_u$

then $M_{uxx} = M_{uyy} = P_{uc1}[(D/2)-0.416d] +$

$\sum_{i=1}^{n} Asti\ (fsi - fci)Yi$

Step-2

But if $P_{u1} > P_u$: Reduce the value of K_u and repeat step-1 i.e, from (a) to (b) till P_{u1} is nearly equal to P_u. And then calculate M_{uxx} (or) M_{uyy}.

Step-3 But if $P_{u1}< p_u$: Increase the value of K_u and repeat the process given below till

$P_{u1}=P_u$ => $x_u= K_u D$

Calculation of ϵ_i

$\epsilon_i = (0.002/a_i)/ (x_u – 3D/7)$ where $a_i=x_u-(D/2) +y_i$

Calculation of f_{ci}

If $\epsilon_i < 0$, then $f_{ci} = 0$

If $0< \epsilon_i < 0.002$ then $f_{ci} = 446 f_{ck}\, \epsilon_i (1-250\, \epsilon_i)$

For $\epsilon_i>0.002$, $f_{ci}= 0.446\, f_{ck}$

Calculation of f_{si}

If $\epsilon_i<0.00174$, f_{Si} is calculated as = $\epsilon_i.E_S$

But if $\epsilon_i>0.00174$, f_{Si} is obtained from table.

Calculation of P_{u1}

$p_{u1}= C_1$ fck b D

=> $C_1= 0.4461- C_3/6)$

$C_3= (8/7)(4/(7K_u-3))^2$

$P_{us1}= (f_{s1}-f_{c1}) A_{st1} +…$

=> $P_{u1} = P_{uc1} + P_{us1}$

When P_{u1} nearly equal P_u Calculate

$M_{uxx}=M_{uyy}= P_{uc1}((D/2)-C_2D) + (f_{s1}-f_{c1}) A_{st1}y_1+…$

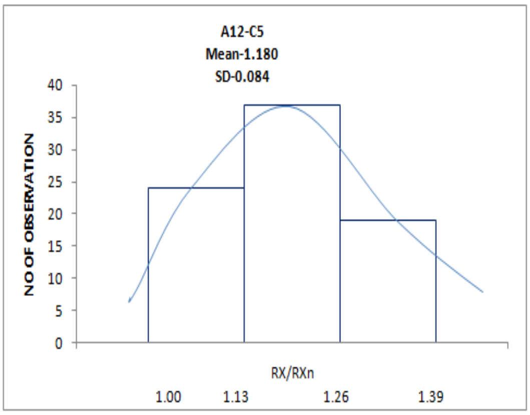
SUMMARY OF RESULTS

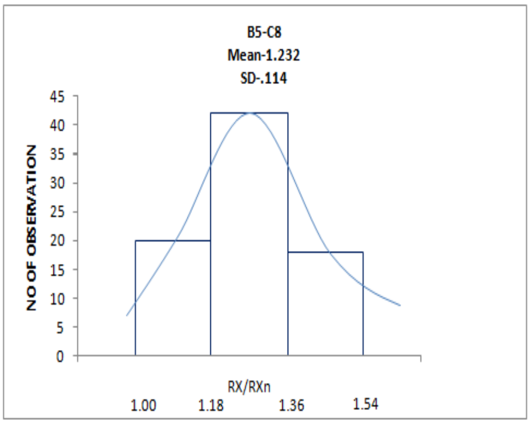
Sl. No.	Column No.	Mean Value of R					
		Rx (Experimental)	Rx (Theoretical)	Error (%)	Ry (Experimental)	Ry (Theoretical)	Error (%)
1	A1-C5	224357583.16	216238054.80	3.6	62839408.85	66512857.33	safe
2	B5-C8	151191989.87	153119732.48	safe	44710047.57	45259232.29	safe
3	A12-C5	143555122.77	145145657.54	safe	43059584.09	43343882.42	safe
4	E1-C9	179191242.79	181193795.76	safe	51433067.99	51538480.79	safe
5	D5-C7	151680987.80	153679880.53	safe	44863460.61	45341398.85	safe
6	E12-C9	181791010.06	180639379.54	0.63	52111320.47	51538480.79	1.09
7	G4-C4	12733645.29	128145997.75	safe	39255146.82	39589696.31	safe
8	G8-C4	126281498.65	127847050.52	safe	38959885.64	39516766.01	safe
9	H1-C9	205961940.05	210289172.09	safe	4112963.77	59393707.45	safe
11	J8-C8	175160333.22	175556885.38	safe	50498151.52	50992109.49	safe
12	H12-C9	198018302.31	198739468.43	safe	55967507.66	56103010.27	safe
13	K1-C9	215747305.24	215390375.06	0.165	60508199.28	60711559.78	safe
14	K3-C8	158806533.25	157954449.12	0.536	46670876.63	46436553.12	0.5
15	K7-C4	130815021.19	133422381.29	safe	39913836.91	40944299.41	safe
16	L9-C2	68216936.43	69667027.26	safe	29200822.16	29701231.04	safe
17	K13-C3	86049780.18	87140606.06	safe	35157467.47	35626911.64	safe
18	M6-C1	72123318.37	73171549.37	safe	30467776.96	30857820	safe
19	N1-C5	135817427.44	139998858.79	safe	41113902.6	41947696.72	safe
20	P2-C12	184725345.02	18603048.82	safe	33061581.7	89739685.47	safe
21	Q11-C11	152896009.16	150283093.77	1.7	76065152.65	75022759.69	1.37
22	Q14-C14	139621708.82	141793096.40	safe	42035574.25	42464086.75	safe
23	R1-C5	143046684.55	146238147.25	safe	42832494.35	43633058.01	safe
24	R2-C12	196648226.79	200188470.44	safe	94447457.95	96259961.98	safe
25	T1-C4	156679414.41	158213045.24	safe	46264673.91	46798557.42	safe
26	T2-C6	150267826.80	148649950.42	1.03	45014695.6	45037478.69	safe
27	S10-C8	175810064.70	176862750.71	safe	50629950.44	51269322.22	safe
28	T12-C4	146824190.68	148490416.77	safe	43778469.65	44232849.85	safe

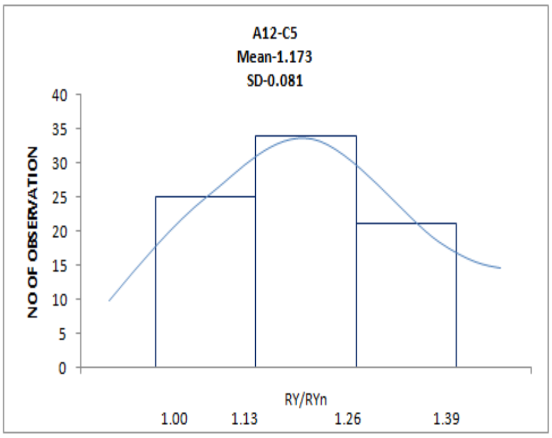
RESISTANCE STATICS OF R/RN

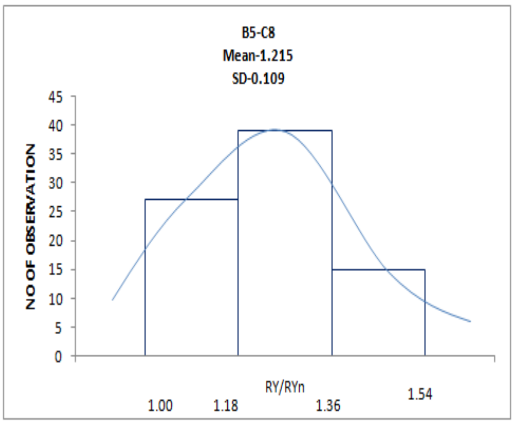
Sl. No.	Column No.	Mean R/RN				Standard Deviation R/RN				γR=Design Value of R/RN			
		RXN (Exp)	RXN (Std)	RYN (Exp)	RYN (Std)	RXN (Exp)	RXN (Std)	RYN (Exp)	RYN (Std)	RXN (Exp)	RXN (Std)	RYN (Exp)	RYN (Std)
1	A1-C5	1.1	1.29	1.09	1.29	0.051	0.152	0.045	0.152	0.654	0.725	0.649	0.725
2	B5-C8	1.23	1.29	1.21	1.29	0.114	0.152	0.109	0.152	0.729	0.725	0.719	0.725
3	A12-C5	1.18	1.29	1.17	1.29	0.084	0.152	0.081	0.152	0.698	0.725	0.694	0.725
4	E1-C9	1.18	1.29	1.18	1.29	0.09	0.152	0.087	0.152	0.699	0.725	0.699	0.725
5	D5-C7	1.23	1.29	1.21	1.29	0.123	0.152	0.116	0.152	0.728	0.725	0.718	0.725
6	E12-C9	1.2	1.29	1.2	1.29	0.084	0.152	0.083	0.152	0.712	0.725	0.712	0.725
7	G4-C4	1.21	1.29	1.2	1.29	0.115	0.152	0.108	0.152	0.72	0.725	713	0.725
8	G8-C4	1.21	1.29	1.19	1.29	0.106	0.152	0.099	0.152	0.716	0.725	709	0.725
9	H1-C9	1.13	1.29	1.14	1.29	0.08	0.152	0.081	0.152	0.671	0.725	0.48	0.725
10	J4-C8	1.18	1.29	1.18	1.29	0.088	0.152	0.086	0.152	0.7	0.725	0.701	0.725
11	J8-C8	1.2	1.29	1.2	1.29	0.093	0.152	0.09	0.152	0.71	0.725	0.711	0.725
12	H12-C9	1.17	1.29	1.15	1.29	0.05	0.152	0.051	0.152	0.692	0.725	0.685	0.725
13	K1-C9	1.15	1.29	1.16	1.29	0.065	0.152	0.066	0.152	0.68.	0.725	0.687	0.725
14	K3-C8	1.24	1.29	1.22	1.29	0.095	0.152	0.092	0.152	0.736	0.725	0.727	0.725
15	K7-C4	1.19	1.29	1.17	1.29	0.097	0.152	0.091	0.152	0.704	0.725	0.697	0.725
16	L9-C2	1.2	1.29	1.18	1.29	0.095	0.152	0.09	0.152	0.713	0.725	0.702	0.725
17	K13-C3	1.15	1.29	1.15	1.29	0.077	0.152	0.077	0.152	0.682	0.725	0.681	0.725
18	M6-C1	1.2	1.29	1.19	1.29	0.084	0.152	0.083	0.152	0.712	0.725	0.709	0.725
19	N1-C5	1.16	1.29	1.16	1.29	0.082	0.152	0.079	0.152	0.69	0.725	0.69	0.725
20	P2-C12	1.21	1.29	2.5	1.29	0.108	0.152	0.73	0.152	0.719	0.725	1.48	0.725
21	Q11-C11	1.25	1.29	1.23	1.29	0.101	0.152	0.096	0.152	0.739	0.725	0.73	0.725
22	Q14-C14	1.18	1.29	1.17	1.29	0.081	0.152	0.076	0.152	0.698	0.725	0.696	0.725
23	R1-C5	1.16	1.29	1.16	1.29	0.074	0.152	0.07	0.152	0.69	0.725	0.686	0.725
24	R2-C12	1.18	1.29	1.17	1.29	0.095	0.152	0.094	0.152	0.699	0.725	0.695	0.725
25	T1-C4	1.16	1.29	1.15	1.29	0.076	0.152	0.075	0.152	0.688	0.725	680	0.725
26	T2-C6	1.18	1.29	1.18	1.29	0.093	0.152	0.09	0.152	0.702	0.725	0.702	0.725
27	S10-C8	1.19	1.29	1.19	1.29	0.086	0.152	0.083	0.152	0.708	0.725	0.708	0.725
28	T12-C4	1.17	1.29	1.16	1.29	0.071	0.152	0.07	0.152	0.695	0.725	0.689	0.725

FREQUENCY DISTRIBUTION CURVE









ANALYSIS OF RESULTS

In the present problem, MONTE CARLO METHOD has been used to study the distribution of a variable (R/Rn) which is a function of two random variables fck and fy to simulate the performance or behavior of a structural system and to determine the reliability of 28 column components. Here R is the moment of resistance of a particular column for which Rn is the nominal value of moment of resistance which has been calculated using the nominal value of fck (characteristic compressive strength of concrete of M25 grade i.e. 25 N/mm^2 and of fy (characteristic yield strength of Fe 415 grade steel i.e. 415 N/mm^2) . Values of R have been normalized with its corresponding nominal value of Rn so that the statistics of R of different designs could be compared. Hence instead of studying the distribution of R the distribution of R/Rn is studied. It is to be noted that Rn is deterministic and is constant for a particular design. The frequency distribution of the generated samples of R/Rn are presented in the form of tables, histograms and frequency polygon curves from which it has been found that the normal distribution fits the generated data well. This is very much consistent with the results obtained by Ellingwood. et al (1997) who have also fitted a normal distribution to the lower tail below 5% fractile of the generated strength distribution result as given in the table "SUMMARY OF RESULTS". It is observed that the resulting values of mean, standard deviation and γR (Ratio of design value of R to Rn) are comparable with standard values of mean , standard deviation and □ R as presented in the table "RESISTANCE STASTICS OF R/Rn" . Also from the comparison drawn between experimental results and theoretical exact values of mean and standard deviation of R it is found that there is a maximum deviation of 3.6% in the values for mean in Rx for column category A1-C5. As the error for mean is below 4%, these category of column can be considered reliable from safety point of view.

CONCLUSION

Evaluation of reliability allows one to formulate a rational design and optimization procedure. In terms of the design problem rather than analysis, a major advantage of reliability based design is the elimination of deterministic design restrictions in the individual members of the structural design. The total structure is only as strong as its "weakest element" which is here the column designated as A1-C5. The members with very high levels of reliability do not contribute to overall structure reliability. As the weakest link i.e. the column designated as A1-C5 is reliable from safety point of view. Hence the total structure is reliable from strength of the column point of view

The error between experimental results and theoretical exact values for all 28 columns show that the design is adequate. i.e. the columns have sufficient strength to resist the applied loads and experimental results well agree with theoretical exact value. Also, the experimental resistance statistic satisfies the standard statistics resistance values.

Hence, it is calculated that the columns of typical floor of the building under consideration are structurally reliable.

REFERENCES

Journal papers

[1] Chikkodi. p. and Ranganathan. R. (1988), "Partial Safety factors for R.C.C. Design", Intl. J.of structures. vol.8,127-149 .

[2] Ellingwood. B.R.(1979), "Reliability Based Evaluation of Design Criteria" J. Str. Div.ASCE.105.ST-4,713-737.

[3] Rashedi M.R. and Moses I. (1988),"Identification of failure Modes in System Reliability", J. Struct. Div. ASCE, 114(2), 292-313.

[4] Val, D.V. and Melchers, R.E.(1997)"Reliability Determination of Deteriorating R.C.Slab Bridge":"Method: First order reliability method.(FORM)", ASCE. J. Struct. Engg. , 123(12).

Books

[1] Ranganathan. R. (1990), "Reliability Analysis and Design of Structures" Tata McGraw Hill.

[2] Verghese. P.c.(1994) " Limit State Design Of Reinforced CONCRETE " Prentice Hall of India ,New Delhi.q

Codes

[1] Bureau of Indian Standard (1978) "Design Aids to IS: 456-1978 for Reinforced Cement Concrete", (sp:16-1980) .

[2] Bureau of Indian Standard (2000) "Indian Standard Code of Practice for Plain and Reinforced Cement Concrete", IS:456-2000.

[3] Bureau of Indian Standard (1980) "Explanatory Hand Book to IS 456-1978",SP-34.

[4] Bureau of Indian Standard (1980) "Hand Book on Concrete Reinforcement and Detailing",sp-34.

[5] Ranganathan. R.(1987), "Reliability Analysis and Design of R.C.C. Slabs ,Beams, Columns and Frames "- code calibration report no. D.S. and T:4/1/83-stp.111/5, Civil Engg.Deptt.,IIT.Mumbai.