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Variability in Deflection of Reinforced Concrete Beams

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Abstract – This paper addresses an attempt made to capture the inherent variability in the deflection of reinforced concrete beams. For the study practical range of reinforced concrete beams with the span ranging from 3m to 10m and live load of 2kn/m2 to 5kn/m2. All the beams are sized for the required span and loading as per the directions of IS 456:2000.Eexpression for deflection given in IS code is used as basic deterministic expression. Using statistical details mainly coefficient of variation and distribution model of various random variables involved in deterministic expression large number of deflection samples say ten thousand samples per beam are developed using Monte Carlo Simulation technique. Various statistical tests are conducted on sample developed and noticed that variability in deflection of reinforced concrete beam follows the lognormal distribution and coefficient of variation is consistent.

Key Words- Monte Carlo Simulation, Distribution Model, Statistical Tests, PDF, CDF.

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1. INTRODUCTION

With the present day use of higher strength concrete and higher grade reinforcing steel, refined /computerized method of designs of reinforced concrete beam for limit state of safety resulting sections are slender or shallower , the problem of predicting and controlling deflections of reinforced concrete flexural members under service load is becoming increasingly important. The Universally accepted verification method for structures serviceability is based on deterministic criteria and on definite initial parameters, which are variables in reality. Uncertainties exists in geometrical properties of the member like cross sectional dimensions of the member, amount of steel reinforcement, also in material properties particularly of concrete consequently structures response differs considerably in serviceability.Many researchers suggested an empirical expression for prediction of beam deflection based on large number of experimental work and further compared the calculated value of deflection from theoretical or codal expression with actual deflection of the beams. Sample results of ratio of computed /experimentally obtained deflection values are given in table 1[1]. Values in the table clearly indicate that theirexists large variation in actual deflection and computed deflections. This is mainly because of variability present in parameters contributing to deflection of reinforced concrete beams. Hence it is required to develop probabilistic approach to quantify variability in deflection of reinforced concrete beams. Literature survey on probabilistic analysis have focused on ultimate strength rather than serviceability limit states, very few probability deflection design provisions have been developed these have primarily been for structures with steel and timber[Galambos 1986, Philpot TA 1993] and on reinforced concrete [E.H.Khor 2001].

In this paper an attempt is made to suggest a distribution model for variability in deflection of reinforced concrete beams and to study the coefficient of variation. Outline of the work is as follow

- Deterministic expression for deflection
- Collection of statistical parameters involved in deflection expression
- Fool of practical range of beams
- Generate sufficient number of deflection samples using deterministic expression and variability in parameters using Monte Carlo Simulation
- Statistical analysis of generated samples for suggesting a distribution model

- Study the coefficient of variation

2. PRESENT WORK

For present work expression for deflection given in IS 456:2000[6] is used as deterministic expression for computation of deflection. Practical range of beams with span ranging from 3m to 10m,center to center spacing of 3m,3,5m and 4m,live load of 2kn/m2 to 4kn/m2 and with /without wall load are designed as per the guidelines of IS code. In all seventy-two reinforced concrete beams are considered for the present work. Literature survey is carried out for the statistical parameters of the different variables contributing for deflection and same is presented in table 2.

Table 1 Mean and coefficient of variation values for the ratio of theoretically computed/experimentally obtained deflection values for the beam specimens

Sl. No	Author	No. of beams	fc'	$\Delta_{(cal)}/\Delta_{(exp)}$							
				IS 456		ACI 318		CEB-FIP		Nayak*et.al.*	
				Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Lakshmikantha	20	40-100	1.38	23.3	1.35	22.6	1.63	30.2	1.4	25.4
2	Anima	4	45-60	1.22	8.9	1.16	8.7	0.76	8.6	1.29	9.3
3	Ko& Kim	8	65-80	1.14	9.7	1.02	21.6	1.36	13.1	1.15	15.5
4	Keith E Leslie	3	70-80	1.32	11.4	1.3	19.0	1.41	13.5	1.31	15.5
5	Wafa&Ashour	3	75-90	1.36	18.5	1.28	13.5	1.76	25.1	1.13	21.3
6	Ahmad &Barkar	5	60-80	1.09	25.6	1.09	26.7	1.59	34.2	1.1	24.8
7	Bernardo & Lopes	18	65-85	1.19	24.4	1.21	22.4	1.22	23.1	1.26	22.3
8	Ahmad &Batts	3	65-90	1.41	27.6	1.00	14.4	1.56	10.6	0.99	27.5
9	Ghosh	4	>100	1.36	20.7	1.29	23.5	1.77	12.2	1.19	17.5
10	Sarkar	12	75-110	1.12	16.6	1.13	15.8	1.3	19.7	1.11	17.9

Table 2. Available detail of statistical parameters of basic variables

Name of Variable	Coeff. of variation	Type of distribu-tion	Source
Width(bw)	0.03	N	Ref[7],Darwin et al(1998)
Depth(D)	0.05	N	Mirza and Macgregor
Concrete strength(fck)	.15	N	Mirza et al(1979)
Reinforce-ment cover	.10	N	Ref.[7],Mirza et al(1979)
Amount of steel reinforcement (Ast,Asc)	.10	N	
Length (L)	.03	N	
Live load (Wl)	.20	N,LN Type I	Ellingwood et al (1980), Ref [7].
Dead load(Wd)	.10	N	Darwin et al(1978).
Width of flange	0.05	N	
Depth of flange	0.03	N	

Using deterministic expression for deflection and statistical parameters of variables generate large number say ten thousand samples for each beam. Specimen values of selected beam are given in figure 1(a) and (b)

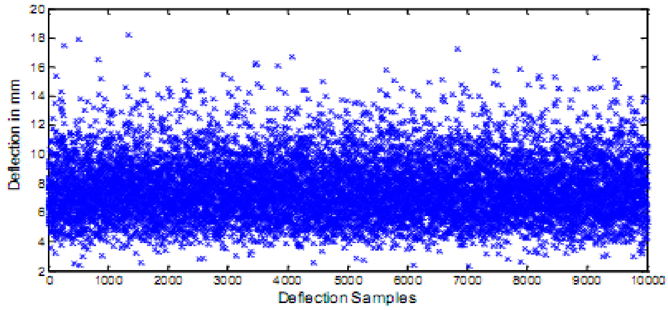


Figure 1(a) deflection samples for beam 1

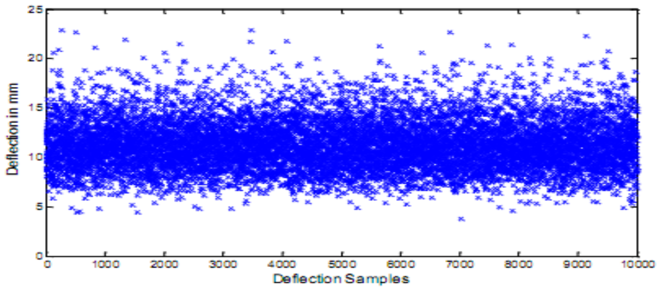


Figure 1(a) deflection samples for beam 2

From figure 1(a) and (b) it is seen that deflection in the reinforced concrete beam is a random variable as we can see large scatter in the values of deflection.

3. ANALYSIS OF GENERATED DEFLECTION SAMPLES

Sample Histograms are constructed based on the generated samples to know the range of deflection sample nature of spread etc. Specimen histograms for selected beams are shown in figure 2(a) and (b)

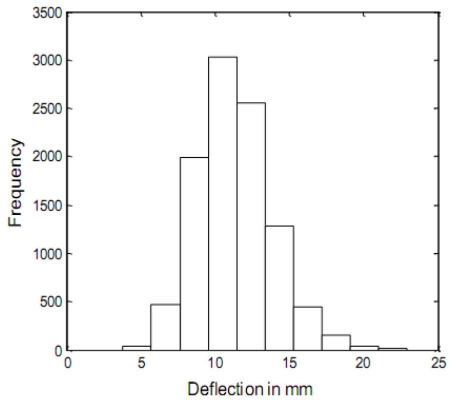


Figure 2(a) histogram of deflection sample (beam68)

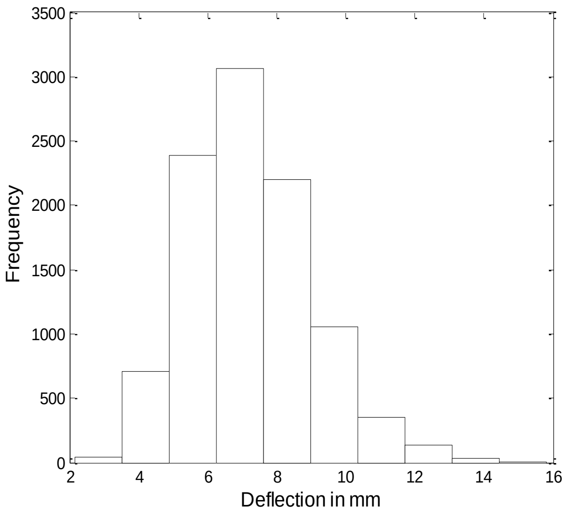


Figure2 (b) histogram of deflection sample (beam2)

Studies of histograms of the deflection samples give us an idea of maximum and minimum values of deflection samples, nature of frequency distribution. Histograms clearly indicate that frequency distribution is not a normal distribution as it is skewed to left.

Now the PDF of deflection samples is overlapped with PDF curves of normal and lognormal distribution having same mean and standard deviation as that of deflection data. Results for selected beams are shown in figure 3(a) and (b)

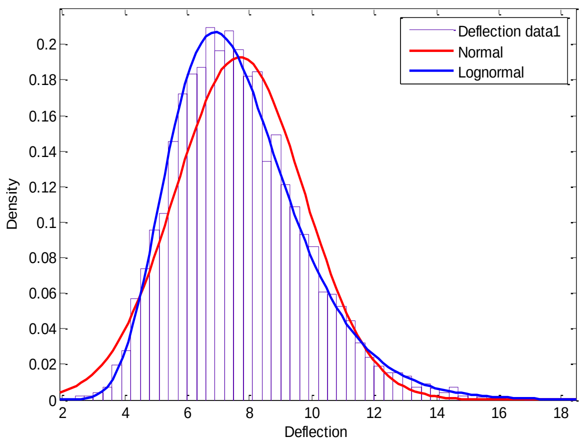


Figure 3(a) Mapping normal and lognormal distribution PDF with PDF of deflection data for beam 1

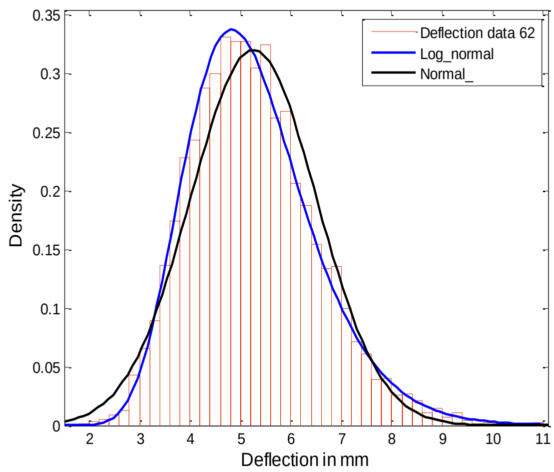


Figure 3(b) Mapping normal and lognormal distribution PDF with PDF of deflection data for beam 62

In above figures it is observed that PDF deflection data matches more closely with PDF of lognormal distribution model than that of normal distribution model .Now further test is carried out by overlapping CDF of deflection data with the CDF of normal and lognormal distribution models having same mean and standard deviation as that of deflection data and results for some selected beam are presented in figures 4(a) and (b).

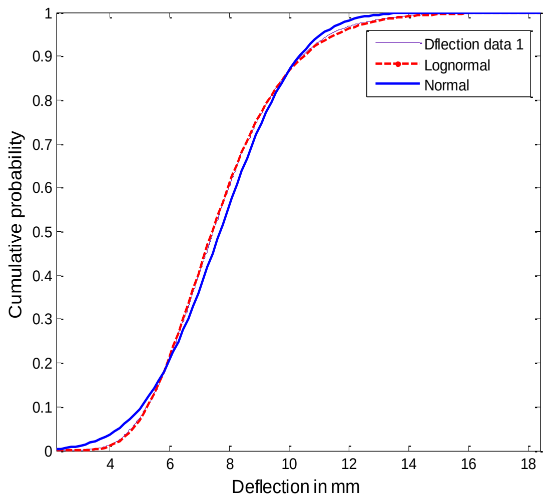
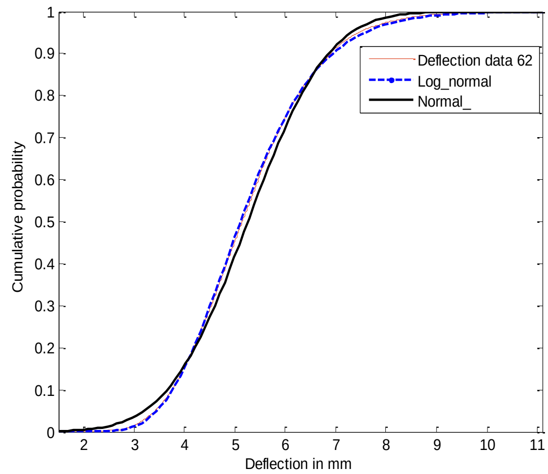


Figure 4(a) Mapping normal and lognormal distribution CDF with CDF of deflection data for beam 1



.**Figure 4(b) Mapping normal and lognormal distribution CDF with CDF of deflection data for beam 62**

Above figures it is clearer that CDF of deflection data matches more closely with CDF of lognormal distribution indicated by dotted line in the figures. Further probability plot of deflection data are matched with probability p[lots of normal and lognormal probability plots .results are presented in figures 5(a) and (b)

Based on study of figures 3 to figure 5 and Chi-Square goodness of fit test it is concluded that randomness in deflection follows lognormal distribution model.

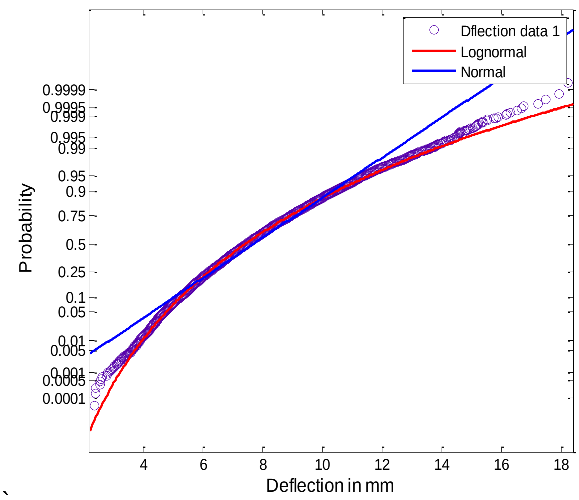


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Figure 5(a) Mapping normal and lognormal probability plots with probability plot of deflection data for beam1

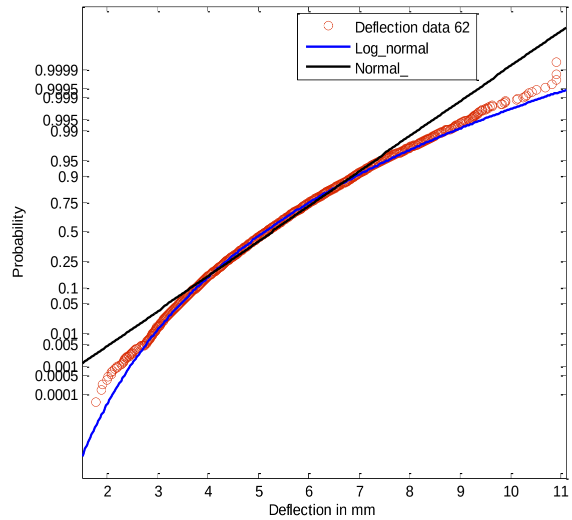

Figure 5(b) Mapping normal and lognormal probability plots with probability plot of deflection data for beam62

4. COEFFICIENT OF VARIATION

After finding probability distribution model one more important parameter controlling variability of deflection of the beam is coefficient of variation for various beams are presented in Table 3.

Table 3 Computation of coefficient of variation

Beam No.	Mean Deflection	Std. Deviation	Coeff. Of variation
1	7.684	2.068	0.269
2	7.241	1.795	0.248
3	7.602	2.070	0.272
4	9.712	2.455	0.253
5	8.251	1.966	0.238
6	8.733	2.252	0.258
7	8.380	2.099	0.251
8	7.018	1.693	0.241
9	7.759	1.974	0.254
10	15.842	3.979	0.251
11	5.658	1.444	0.255
12	13.606	3.273	0.241
13	7.541	1.980	0.263
14	6.480	1.593	0.246
15	6.725	1.801	0.268
16	7.202	1.838	0.255
17	5.971	1.459	0.244
18	10.268	2.472	0.241
19	6.767	1.900	0.281
20	4.211	1.126	0.267
21	5.577	1.595	0.286
22	5.633	1.560	0.277
23	4.788	1.230	0.257
24	5.445	1.505	0.276
25	5.311	1.430	0.269
26	4.441	1.133	0.255
27	4.701	1.283	0.273
28	12.975	3.227	0.249
29	10.239	2.419	0.236
30	11.406	2.913	0.255
31	8.543	2.007	0.235

32	9.610	2.264	0.236
33	10.250	2.597	0.253
34	11.044	2.664	0.241
35	39.951	8.670	0.217
36	9.677	2.392	0.247
37	15.186	3.702	0.244
38	7.023	1.537	0.219
39	13.298	3.327	0.250
40	13.695	3.305	0.241
41	11.742	2.750	0.234
42	6.253	1.499	0.240
43	13.094	3.086	0.236
44	6.132	1.339	0.218
45	5.691	1.323	0.232
46	26.409	5.785	0.219
47	7.555	1.664	0.220
48	9.648	2.262	0.234
49	16.730	3.981	0.238
50	6.665	1.456	0.219
51	8.343	1.960	0.235
52	8.590	1.925	0.224
53	5.666	1.219	0.215
54	6.623	1.527	0.231
55	19.267	4.556	0.236
56	8.442	1.840	0.218
57	7.616	1.886	0.248
58	10.622	2.492	0.235
59	6.986	1.496	0.214
60	3.593	0.824	0.229
61	14.023	2.980	0.213
62	5.259	1.247	0.237
63	9.699	2.240	0.231
64	24.252	5.677	0.234
65	12.327	2.736	0.222
66	15.956	3.782	0.237
67	36.498	7.902	0.217
68	11.320	2.494	0.220
69	13.473	3.158	0.234
70	13.670	3.092	0.226
71	12.405	2.756	0.222
72	10.314	2.430	0.236

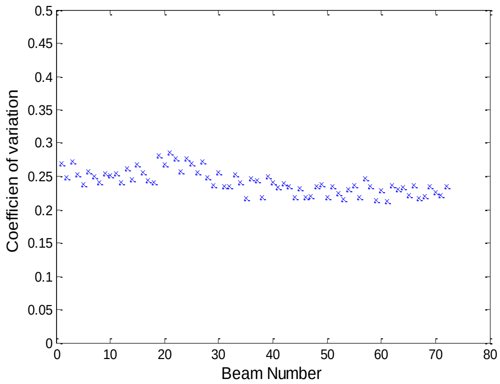

Fig 6 Beam Number Vs Coefficient of variation.

From the Table 3 it is observed that the coefficient of variation for practical range of beams varies from 0.231 to 0.286 with mean coefficient of variation 0.2419

5. CONCLUSION

From this experimentation it is observed that the deflection in the reinforced concrete beams is a random variable. The randomness in the deflection can be modeled as lognormal distribution. The coefficient of variation is consistent for practical ranges of beams with an average value of 0.2419.

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