Reliability Analysis of an R.C corner Footing subjected to Bi-axial Bending

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Abstract - *An attempt is made to analyse the safety of an R.C corner footing, subject to biaxial bending, under various limit states. The footing is designed using the deterministic approach as per the provisions of present code IS 456-2000. The statistics of basic design variables are taken from the literature. The statistics of loading (axial load and moments) is not readily available in the literature. The same is generated using ETABS. A typical representative building is selected & statistics of axial load and moments (Mx & My) are generated for a given load combination. The generated data is statistically analysed and probabilistically modelled.*

The safety of the footing is analysed using AFOSM & Monte Carlo methods. Fiesler algorithm is adopted in AFOSM method. The limit states considered are, flexure, one way shear, two way shear & bearing. The resistance statistics and bias factors are established for different limit-states using Monte Carlo simulation.

The present study forms an attempt for code- calibration towards LRFD format.

Key Words: **RC Corner footing, Bi-axial loading, ETABS, AFOSM, Monte Carlo simulation, Fiesler algorithm, Code-caliberation.**

1. INTRODUCTION

Foundations are the structural elements which transfers the loads from the structure above the ground level to the earth. If the loads are to be transmitted properly, foundations have to be designed to overcome large settlement or rotation, reduce differential settlement and to offer required safety against sliding and overturning. The foundations are categorised as:

1. Isolated footing under single columns. These may be square, circular or rectangle in plan.

2. Wall footings and strip foundations.

3. Footings that supports two or more columns are known as Combined footings.

4. Mat or Raft foundation is a continuous foundation which supports all the columns of the building.

5. Pile caps are used to tie the piles together in Pile foundations. These load bearing walls or isolated columns or group of columns.

The type of the foundation to be used is based on many factors, namely,

a) Soil strata
b) Bearing capacity
c) Type of loads
d) Type of structure
e) Permissible differential settlement
f) Economy
g) Value of Standard penetration test

2. OBJECTIVES

The main objective of the work is to establish the probability of failure or margin of safety of an R.C corner footing subjected to biaxial bending in various limit states. As the basic variables in the design of a R.C corner footing have inherent- randomness, the probability of failure can be assessed through reliability analysis. Reliability index β is established for various limit states using Advanced First Order Second Moment (AFOSM) method.

The reliability index β is computed for the limit states of flexure, one way shear, two way shear, and bearing strength. Eleven basic design variables are considered in the reliability analysis. The statistics of these variables are collected from the literature.

3. LITERATURE REVIEW

Satyanarayana Murthy Dasaka, Rajaparthy Seshagiri Rao and G L Sivakumar Babu have performed Reliability analysis of allowable pressure of Strip Footing in spatially varying cohesion less soil. This paper investigates the variability of qc using Random field theory. They concluded that transformation model plays a major role in evaluation of variability of design parameter. It neglects the spatial averaging, results in lower allowable pressure than that obtained from advanced probabilistic analysis.

Carsten Ahner and Dmitri Soukhov have carried Reliabilty Aspects of Design of Combined piled-Raft Foundations (CPRF).This paper investigates the reliability aspects of structural behaviour of CPRF. But the problem is with the stochastic model of soil properties. Here the autocorrelation for the stiffness modulus is considered. Using First Order Reliability Method according to Level II of reliability analysis calculations are carried.

John D. SORENSEN, Svend Ole HANSEN, and Torben A. NIELSEN have authored Calibration of partial Safety Factors and Target Reliability Level in DanishStructural Codes. The obtained partial safety factors result is of same average reliability level as in the previous codes, but a much more uniform reliability level has been obtained.

Honjo.Y and Amatya.S have performed reliability-analysis to determine partial- safety factors for square-footings, for highway-bridges on granular soils. The uncertainties in the bearing-capacity are examined by literature review. The probability-failure and reliability-index is found using FORM analysis and Monte-Carlo simulations.

4. METHODOLOGY

The main parameters of action for reliability analysis of footing are Axial load and the moments. It is required that the statistics and probability distribution of these variables are known. In practice it is near to impossible to get the statistics of the axial load and moments without using a software package. Moreover such values are not available in the literature too. For this purpose ETABS is used. The mean and standard deviations of the basic design variables are taken from the literature and using Monte Carlo method, one hundred values for each variable are generated, writing a suitable program in Matlab. The simulated values from the MATLAB are then used in the ETABS model. The model is analysed and the resulting axial load and moments for footing are stored for each case. Statistical analysis is conducted and probability modelling is done to establish the type of distribution, mean and standard deviation of the Axial load and moments on a selected footing. This exercise is repeated for four different footings. The details of ETABS modelof the building selected for the present study are presented. The statistics of basic design variables used in the Monte Carlo simulation are listed in table.

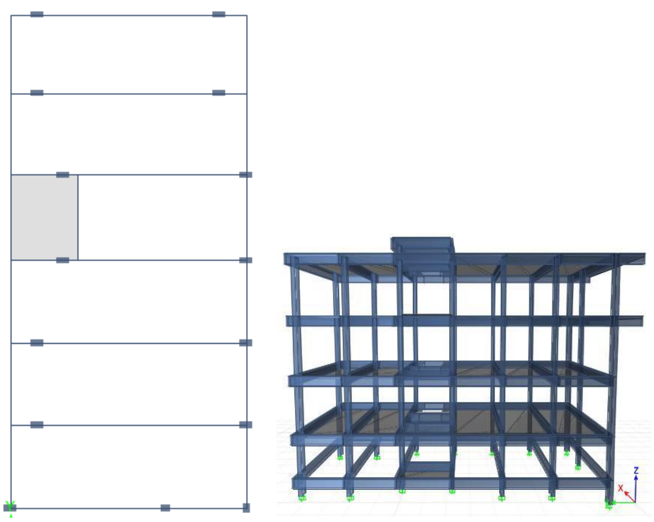

Fig 1: Plan and 3D View of the Building

Parameter	Nominal Value	Mean Value	COV (%)	Type of Distribution
Size of Column / Beam	600mm	618 mm	3	Normal
	300 mm	309 mm	3	Normal
	450 mm	463.5 mm	3	Normal
Density of Concrete	25kN/m²	25kN/m²	5	Normal
Compressive Strength of Concrete	20 N/mm²	22 N/mm²	15	Normal
Characteristic Strength of Steel	500 N/mm²	550 N/mm²	10	Normal
Floor Finish	0.5 kN/m2	0.5 kN/m2	10	Normal
Wall Density	20kN/m3	20kN/m3	10	Normal
Wall Thickness	230	230	5	Normal
Overall Depth of Slab	150 mm	154.5mm	5	Normal
Live Load	4 kN/m2	4.08 kN/m2	10	Normal

Table 1: Statistics of Basic Design Variables

The generated values of axial load and moments are probabilistically modelled. The histograms of the axial loads and moments for the selected four footings are presented below.

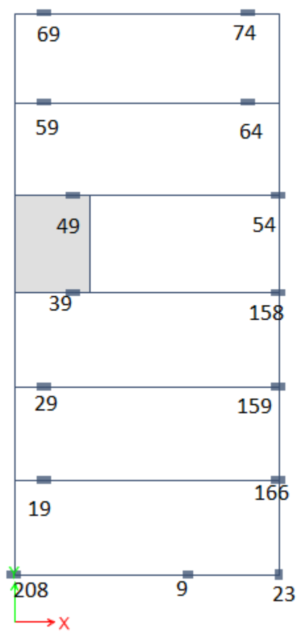

Fig 2: Footing Node Numbers

The overall summary of the statistics of generated values of axial load and moments is presented in Table 2. The footing are so selected that there are two representative samples for each two cases *viz* axial load and uniaxial moment and axial load and biaxial moments.

Node No	Type Of Loading	Axial Load (kN)		Moment Mx (kNm)		Moment Mz (kNm)	
		Mean	COV	Mean	COV	Mean	COV
69	Axial load+ Biaxial Moment	993.29	14.06	5.74	11.76	49.07	7.72
74	Axial load+ Biaxial Moment	966.85	15.18	6.59	12.29	29.38	11.28
29	Axial load+ Uniaxial Moment	1905.38	11.38	---	---	41.19	6.7
19	Axial load+ uniaxial Moment	1609.054	11.23	---	---	51.34	6.44

Table 2: Summary of statistics of axial loads and moments

5. FORMULATION

Steps involved in afosm method (Fiesler method)
An algorithm proposed by Fiesler (1980) can be used with reduced variables and gives the values of β after only one set of iterations. A suitable method is-as follows:
1. An expression for g(X) is determined.
2. Evolve an expression for h(y).
3. All the first derivatives of h(y), hi’ is determined.
4. Set yi = 0 and β = 0.
5. Calculate hi’ values.
6. Calculate h(y).
7. Standard-deviation of Z is calculated using:

$$\sigma_Z = \sqrt{\sum (h_i')^2}$$

8. Calculate new-values for y from:

$$y_i = -\frac{h_i'}{\sigma_Z}\left[\beta + \frac{h(y)}{\sigma_Z}\right]$$

9. Calculate:

$$\beta = \sqrt{\sum y_i^2}$$

10. Steps 5 to 9 are repeated until the values converge.
Using the above discussed methodology the reliability assessment of the footing is made.

6. RESULTS AND CONCLUSIONS:

6.1 Limit State of Flexure

The number of simulations is kept equal to 40000 and the ultimate nominal moment of resistance (Mn) is computed using the nominal values of basic design variables.

Node	Mn(kNm)	Mr		Number of failure cases out of 40000 cases
		Value(kNm)	Bias	
69	865.860	1157.022	1.336	0
74	854.500	1094.152	1.280	0
29	2256.980	2793.129	1.238	0
19	1900.526	2428.529	1.277	0

Table 3: Results of Monte Carlo simulation, for Flexure

6.1.2 Limit State of One way Shear

The number of simulations is kept equal to 40000 and the ultimate nominal Shear resistance (Vn) is computed using the nominal values of basic design variables.

Node	Vn(kN)	Vr		Number of failure cases out of 40000 cases
		Value(kN)	Bias	
69	362.460	385.903	1.065	0
74	350.740	373.398	1.064	0
29	534.968	561.854	1.050	0
19	504.000	536.658	1.065	0

Table 4: Results of Monte Carlo simulation, for One way Shear

6.1.3 Limit State of Two way Shear

The number of simulations is kept equal to 40000 and the ultimate nominal Shear resistance (Vpn) is computed using the nominal values of basic design variables.

Node	Vpn(kN)	Vpr		Number of failure cases out of 40000 cases
		Value(kN)	Bias	
69	3622.430	4053.080	1.118	0
74	3326.150	3722.543	1.119	0
29	3929.889	4395.846	1.118	0
19	4248.530	4751.230	1.118	0

Table 5: Results of Monte Carlo simulation, for Two way Shear

6.1.4 Limit State of Bearing Strength

The number of simulations is kept equal to 40000 and the ultimate nominal bearing resistance (Br) is computed using the nominal values of basic design variables.

Node	Bn(kN/sqm)	Br		Number of failure cases out of 40000 cases
		Value(kN/sqm)	Bias	
69	15973.420	16654.130	1.043	0
74	15260.242	15900.793	1.042	0
29	16686.450	17398.886	1.042	0
19	17399.353	18136.816	1.042	0

Table 6: Results of Monte Carlo simulation, for Bearing Strength

7. CONCLUSIONS

1. The generated statistics on load and moments shows that the COV is about 11 to 16 % for axial load and 5 to 13 % for moments.

2. The safety of a corner footing subjected to moments is assessed in different limit states using AFSOM method. The limit state of flexure is found to be the most critical one as indicated by the lowest value of β.

3. The resistance statistics of the footing in flexure has a bias factor of about 1.336

4. The resistance statistics for one way shear has a bias factor of 1.065

5. The resistance statistics for two way shear has a bias factor of 1.119

6. The resistance statistics for bearing strength has a bias factor of 1.043

7. It may be noted that flexure has the largest bias factor which indicates greater randomness.

8. Probability of failure in each limit state can be assessed by counting the number of

failures (R < = S) cases out of 40000 simulated designs.

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BIOGRAPHY

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