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A STUDY ON PROBABILITY FAILURE OF RC BEAM IN PORTAL FRAME FOR VARIYING LIVE LOAD

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Abstract : ***In conventional deterministic design method, it is assumed that all parameters are not subjected to probabilistic variations. However, it is well known that loads coming on structure are random variables. Similarly, the strength of materials and the geometric parameters are subjected to statistical variations. Since load and strength both are random variables, the safety of structure is also a statistical variable. With this view, an attempt is made to compute the safety levels for RC beam in single bay frame ensured by the design methodology of the present code of practice IS 456-2000. For a particular beam statistics and probability distribution for share force and bending moments are generated by digital simulation on a R.C. frame using SAP2000v22 software. The generated data subjected to statistical analysis, probability modelling using program supported on MATLAB. Resistance statistics are generated with the help of relevant equations provided in IS 456-2000. Several design situations corresponding to different material grades, dimensions are considered for 20%, 40%, 60% live load. Probability of failure is computed by Monte Carlo Simulation which establishes the statistics of safety margin M = R – S***

1. INTRODUCTION

In engineering problem, several random variables are involved. In structural engineering problems it may involve material strength, densities, member geometry, applied loads etc. So the involvement of so many parameters changes the behaviour of structural elements to a large extent. However, the computation of the pattern of the behaviour requires a large number of data. The behaviour may include the shear, maximum moment, deflection at critical points etc. As a result, strength calculated by a designer certainly differs from the particular ones. This difference between the performances based values and real values is negotiated in the design members through safety criteria in the design codes Hence, for realistic analysis, it is necessary to seem for expected values and variance of the structural response considering random input parameters. 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 within the probabilistic design situation. Several methods for probabilistic structural analysis are studied within the past years. Monte-Carlo simulation method is the simplest way to achieve the probabilistic studies, in fact Monte-Carlo method is statically consistent and may be computationally very expensive when several degrees of freedom is involved. In this study, the structural response of RCC beam in portal frame is considered especially the flexure and shear. Flexure and shear depends largely on various geometric and material parameters of the associated components. Most of these parameters are of a random in nature, and hence, uncertainty exists in the response of the RC members in terms of the strength. Therefore, a realistic evaluation of the behaviour of the RC frame system that is an assembly of a number of structural components requires a probabilistic approach for an appropriate treatment of uncertain structural properties.

2. OBJECTIVES

To study the probability of failure of RC beam in portal frame incorporating various uncertainties by Monte-Carlo method of simulation.

3 METHODOLOGY

The methodology worked out to achieve the above-mentioned objectives is as follows:

- Modelling the single bay RCC frame in SAP2000 software.
- Validation of the modelling by deterministic approach.
- Validation of the modelling by probabilistic approach using Monte- Carlo simulation technique.
- Fitting of probabilistic distribution responses for different variables.
- Comparing the results of deterministic and probabilistic methods and computing probability of failure

3.1 DETERMINISTIC DESIGN OF BEAM

An RCC single bay frame with the below details is considered

- Column height = 4.0 m
- Beam lengths = 6.0 m
- Live load on Beam = 20 kN/m
- Grade of concrete = M25
- Grade of Steel = fe500
- Size of Column = 300 x 450 mm
- Size of Beam = 300 x 450 mm .

Frame analysis is carried out in SAP2000 and the results obtained are used for deterministic design. Bending moment and shear force are used to check the safety of the beam. The section is found to be safe under various checks in the design as per the provision of IS: 456-2000. If suppose the sections fail it has to be revised in the deterministic design.

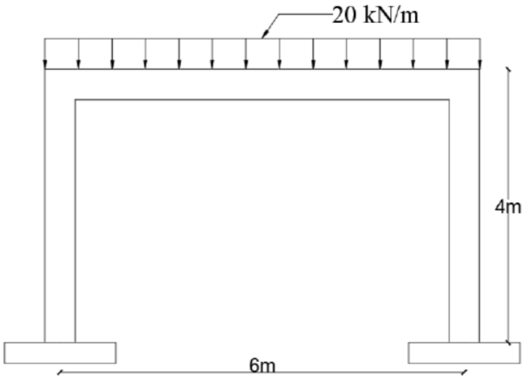


Fig.1: Loading and geometric details of case study frame

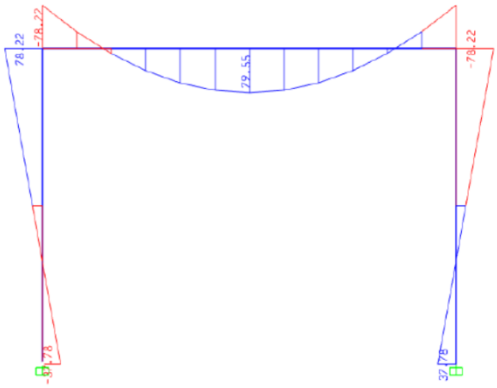


Fig.2: Bending Moment diagram (from ETAB)

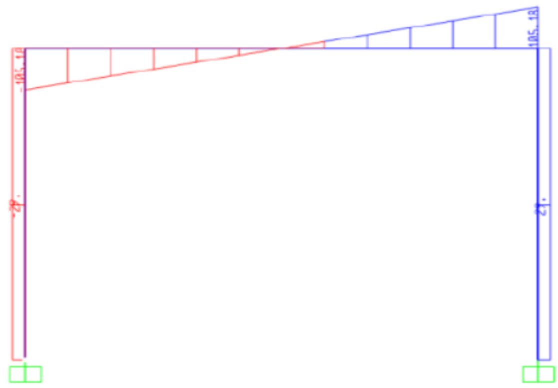


Fig.3: Shear Force diagram (from ETAB)

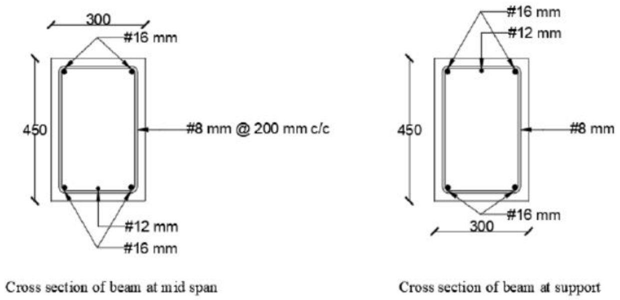


Fig.4: Cross section of beam at different location.

3.2 MONTE CARLO SIMULATION

Monte Carlo Simulation is a powerful engineering tool which enables one to perform a statistical analysis of the uncertainty in structural engineering problems. This particularly useful for complex problems where numerous random variables are related in an experiment which is performed by computer rather than in a structural engineering laboratory.

The Technique consists of following steps
1. Generating a set of values yik for material properties and geometric parameters The suffix i is used to denote the ith variable and suffix k is used to represent the kth set of values (y1k, y2k… yik,... ynk) of the corresponding variables (Y1, Y2,…,Yi,…,Yn)

2. Calculating the values rk corresponding to the set of values yik obtained instep 1, by means of the appropriate response equation for resistance of the section. That is
Rk = g (y1k, y2k,…,yik,…,ynk).

3. Repeating steps 1 and 2 to obtain a large sample of the values of R.

Application: This method has variety of applications, it can be used to study the distribution of a variable, which is a function of several random variables, to simulate the performance or behaviour of a system, and to determine the reliability of probability of failure of a system or a component. The simulation technique has been used in the reliability study of structures by several research works.

The procedure for generating the random deviate from specified distribution generally follows following pattern
1. Generate a random number from the standard uniform distribution.
2. Perform mathematical transformation of the standard uniform random number, which produce random deviate from desired distribution.
3. Use transformed deviates in the experiment as required.

Various methods have been developed for the generation of uniform pseudo-random numbers. Subroutines for this purpose are readily available. Built-in programmes are generally available in computer software like MATLAB to generate uniform random numbers. The transformation of the uniform random number to the random variate of the desired distribution is obtained by the inverse transformation method, if possible. For normal distribution, Box and Muller technique is used to generate normal variates. Here, standard normal deviates are obtained by generating two uniform random numbers v1 and v2 (with a uniform density range between 0 and 1) at a time. Then the desired standard normal variates are given by
$u1=[2\ln(1/v1)]0.5 \cos(2\pi v2)$
$u2=[2\ln(1/v1)]0.5 \sin(2\pi v2)$.

Further we generate Standard normal variates with respect to mean and standard deviation which is given by
$y1=\mu+\sigma*u1$
$y2=\mu+\sigma*u2$

3.3 GENERATION OF LOAD STATISTICS AND RESISTANCE STATISTICS.

For the probabilistic design mean and standard deviation value for distribution of parameters are required. Standard deviation for each parameter is calculated by coefficient of variables. The coefficient of variables is given below table

Distribution of parameters

The basic design variables are identified as,
a) Geometric dimensions
b) Material properties
c) Load

Table.1: Available details of statistical parameters of basic variables

	Variables	Coefficient of variables
Geometric property	**Breadth**	**0.03**
	Depth	**0.04**
Material Properties	f_{ck}	**0.15**
	f_y	**0.1**
Load	**20% live load**	**0.2**
	40% live load	**0.4**
	60% live load	**0.6**

3.4 PROBABILISTIC DESIGN OF BEAM.

In Probabilistic design methods where design parameters are considered as random. It is well known that loads (live load on floors, wind load, ocean waves, earthquake, etc.) coming on structure are random variables. Similarly, the strength of materials (strength of concrete, steel, etc.) and the geometric parameters (dimensions of section, effective depth, diameter of bars, height, length, etc.) are subjected to statistical variations. Hence, to be rational within the estimation of the structural safety, the random variations of basic parameters are to be taken under consideration. Since load, strength and geometric properties are random variables, the safety of the structure is additionally a statistical variable. Probability theory and reliability-based design provide a formal framework for developing criteria for design, which insure that the probability of unfavourable performance is acceptably small. The overall aim of structural reliability analysis is to quantify the reliability of structures into account of the uncertainties related to the resistances and loads. The structural performance is assessed by means of models supported physical understanding and empirical data. Due to idealizations, inherent physical uncertainties and inadequate or insufficient data the models themselves and the parameters entering the models such as material parameters and load characteristics are uncertain. Structural reliability theory takes basis in the probabilistic modelling of these uncertainties and provides methods for the quantification of the probability that the structures do not fulfil the performance criteria. All the following steps are performed in MATLAB software for the probabilistic model 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 depth of beam, and width of beam, characteristic strength of concrete, characteristic strength of steel, live load. For 100 values of standard normal variates the above parameters are applied and 100 number of times frame analysis is carried out in SAP2000v22. Similarly, all the parameters are varied, the moment and shear force are obtained for 20% ,40% and 60% variation in live load. The probability failure for 20%,40% and 60% variation in live load is obtained and compared. Simulate resistance using equation for beam subjected to gravity load specified in IS 456-2000.

4. HISTOGRAM AND PROBABILITY DISTRIBUTION

Histogram provides the range of the data which most frequently occurring values and the degree to which it is scattered The observations are made and noted down as they occur and hence the collected data will be in an unorganizedform. This unorganized data is arranged properly. The values are marked in an increasing.

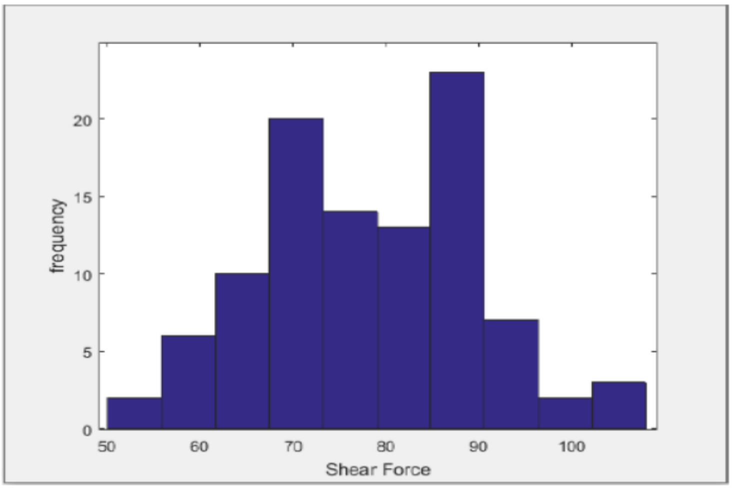


Fig.5 Histogram for Shear Force

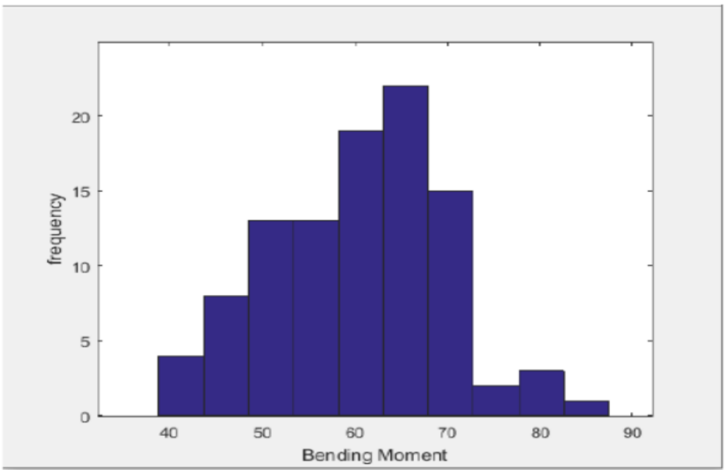


Fig.6 Histogram for Bending Moment

These ordered values are then divided into intervals and the number of observations in each interval is plotted as a bar chart. Histogram and probability distribution curve of the generated sample for maximum moment capacity and maximum shear capacity for beam 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.

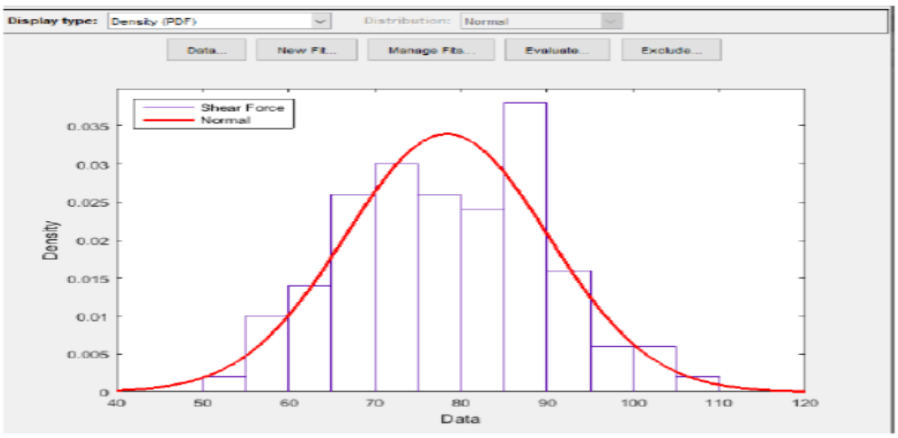
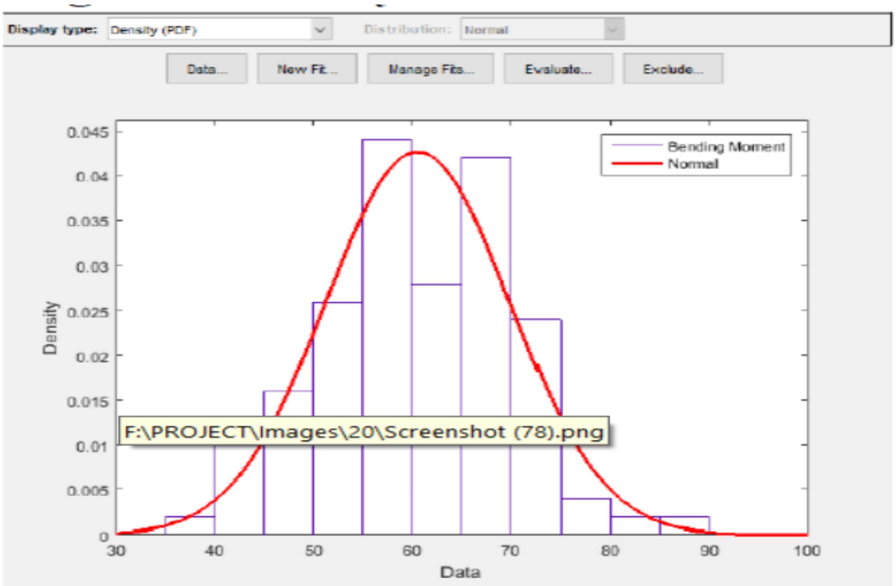


Fig.7 Probability distribution curve for SF



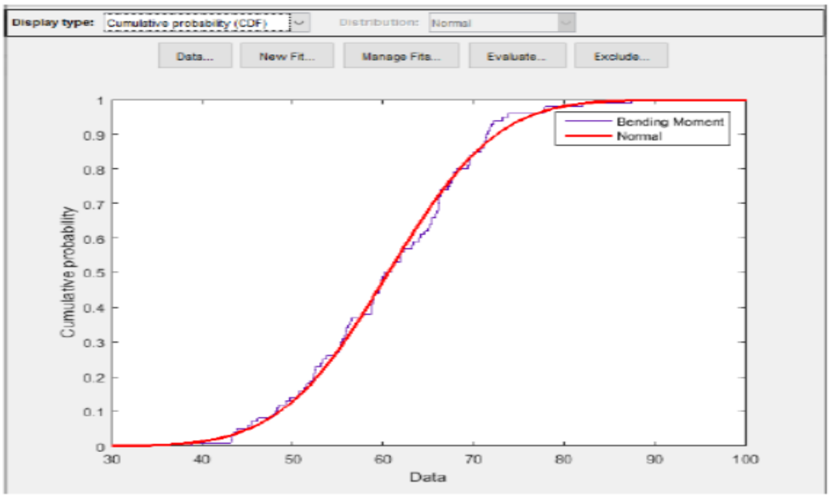


Fig.9 Cumulative density function for SF

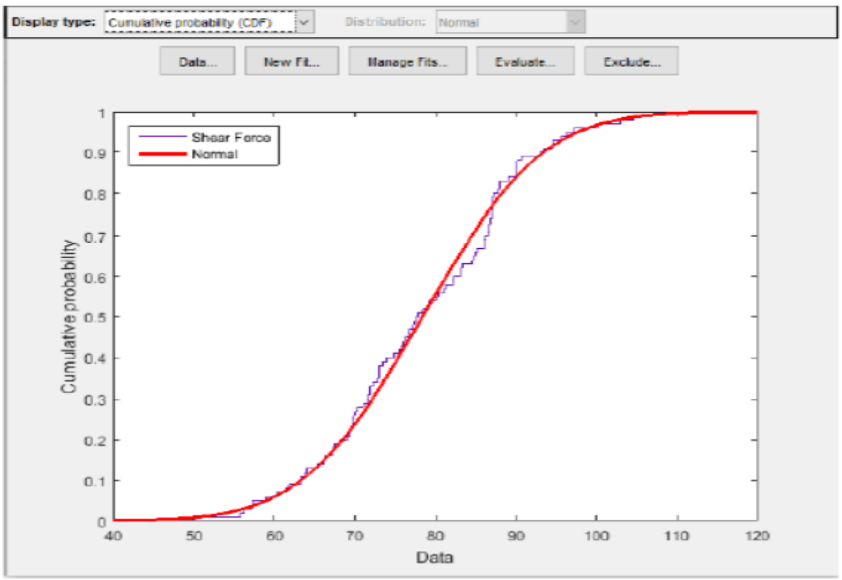


Fig.10 Cumulative density function for BM

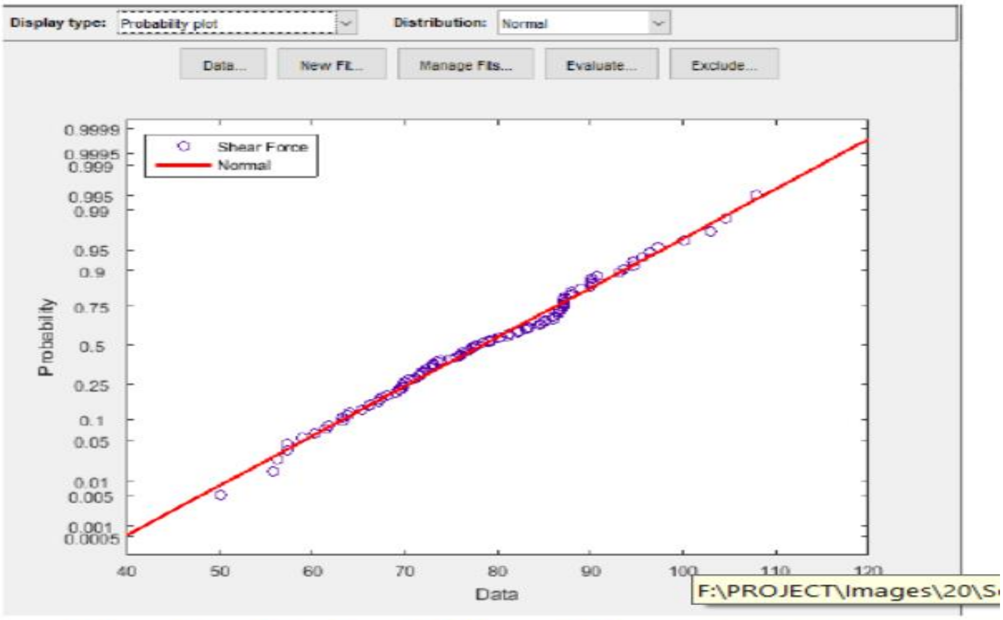


Fig.11 Probability Plot for SF

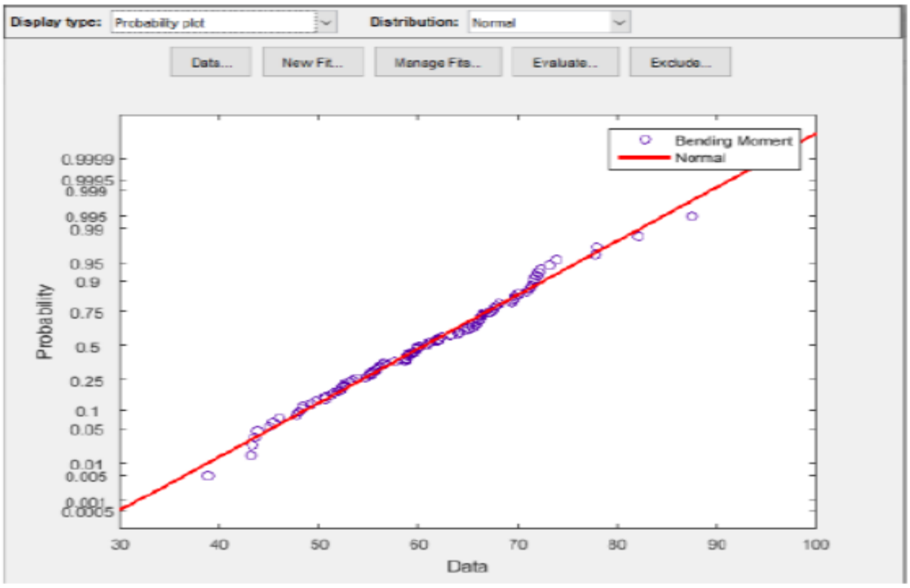


Fig.12 Probability Plot for BM

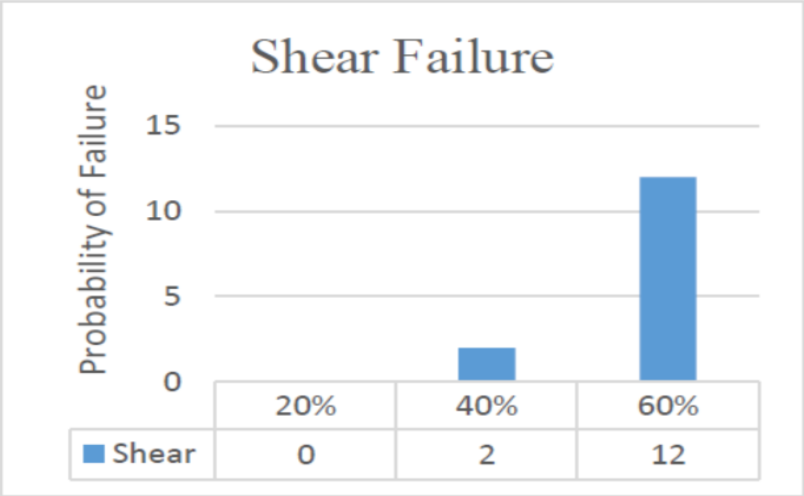
5. RESULTS AND CONCLUSION

The probability Failure of Beam in Shear is as follows

Live Load	20%	40%	60%
P_f	0	0.02	0.12
Reliability	1	0.98	0.88

The probability Failure of Beam in Flexure is as follows

Live Load	20%	40%	60%
P_f	0.01	0.12	0.33
Reliability	0.99	0.88	0.67



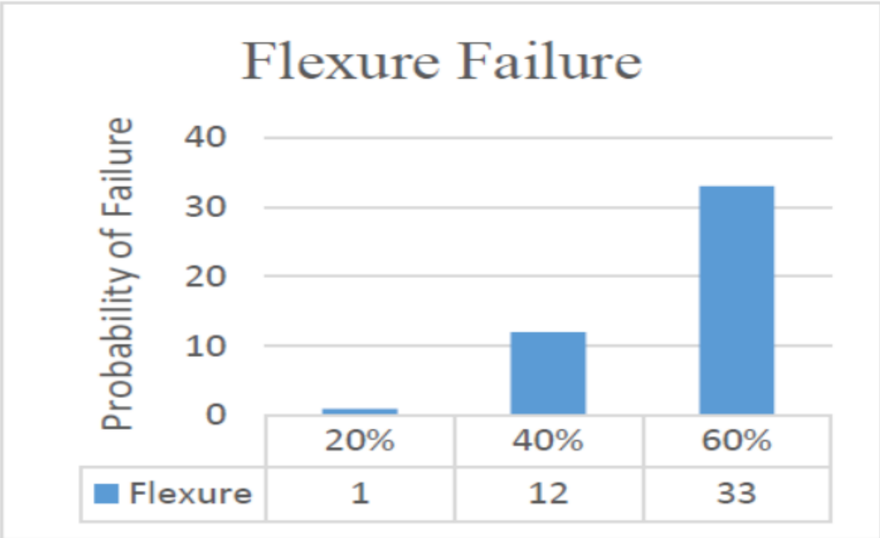


Fig.13 Bar chart showing probability of failure in shear and flexure.

In this study attempt is made to quantify the safety level in terms of probability failure of a reinforced concrete beam in single bay portal frame. Basic design variables are treated as random and their statistics are collected from the literature. The RC frame is analysed using SAP2000v22 software and designed using deterministic approach, as per the provision of IS 456-2000. If the sections fail it has to be revised in the deterministic design. In probabilistic approach design data set varied randomly as a function of statistical models for the variables involved by using Monte-Carlo simulation. The frame is analysed and repeated for 100 times for different live load case in SAP2000v22 software with the help of MATLAB software. Probability distribution like Normal function is tried. It is observed that bending moment and shear force are follow the normal distribution as tested by Chi-Square for goodness-of-fit. K-S test is to check the goodness-of-fit of a given probability distribution to generated data. Using the generated values of design variables as input beam is designed according to the design guidelines given by IS-456 for probabilistic model (S) and it is compared with deterministic model (R). The probability failure of beam is determined by the ratio of number of failure to total number of simulation. The reliability is calculated as Ro = 1-Pf. It is observed that rate of failure of the beam section in shear is about 0 % or probability failure is 0 (20% live load), 2 % or probability failure is 0.02 (40% live load), 12% or probability failure is 0.12 (60% live load) and failure of the beam section in flexure is about 1 % or probability failure is 0.01 (20% live load), 12 % or probability failure is 0.12 (40% live load), 33% or probability failure is 0.33 (60% live load). Probability failure is very low for 20% live load. The designers do not know the explicit level of safety when designed is done by the provision of IS 456-2000.For important structure the pf has to keep as low as possible. The reliability based design aims at the formulation of design procedure for a known level of reliability.

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