**M.TECH (STRUCTURAL ENGINEERING)**

**MAJOR PROJECT REPORT**

**On**

# STRUCTURAL RELIABILITY UNDER INCOMPLETE PROBABILITY DATA

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(2K15/STE/06)

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## STUDENT DECLARATION

I hereby declare that the project work entitled "**STRUCTURAL RELIABILITY UNDER INCOMPLETE PROBABILITY DATA"** Submitted to Department of Civil Engineering, DTU is a record of an original work done by ARJUN CHAUDHARY under the guidance of DR. RITU RAJ (ASSISTANT PROFESSOR) Department of Civil Engineering, DTU, and this project work has not been performed for the award of any Degree or diploma/fellowship and similar project.

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# CERTIFICATE

This is to certify that the project entitled "**STRUCTURAL RELIABILITY UNDER INCOMPLETE PROBABILITY DATA"** Submitted by **ARJUN CHAUDHARY,** in partial fulfillment of the requirements for award of the degree of **MASTER OF TECHNOLOGY (CIVIL ENGINEERING)** to Delhi Technical University is the record of student's own work and was carried out under my supervision.

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# CHAPTER 1

# INTRODUCTION

## 1.1. General

The collapse of structural systems in civil engineering is a result of decisions taken under the conditions that are uncertain and failures of varying nature such as temporary failures, design failures and failures resulting from natural hazards that are needed to be addressed.

An art of formulating a mathematical model through which one can get answer to the question: “What is the probability that a structure behaves in a specified way when given that one or more of its material properties or geometric dimensions and properties are of a random or incompletely known nature, and/or that the actions on the structure in some respects have random or incompletely known properties?”

Probabilistic analysis of a structure is an extension to analysis of a structure that are deterministic in nature which leads to formulation of a mathematical model through which one get an answer to the question: “How is a structure behaving when its material properties, geometric properties and actions all are uniquely given?”

The results can help in determining the reliability of a structure which under a configuration of a given load has sufficient load carrying capacity that are predicted down even to the minute detail.

Software are available in the modern era to analyze the reliability of the structure, One of them used in this project is named as COMREL.

Basically any deviation from the maximum load parameter value and any deviation from the carrying capacity values of a structure when expressed through a load parameter value in the limit situation tends to raise a question on the safety of a structure, The analysis help in determining "how much larger than the maximal load parameter - assessed according to the best conviction - should the ultimate load value be chosen in the carrying capacity model in order that the engineer can guarantee that the structure will not fail under service or, at least, that there is an extremely small risk that a failure will occur". The difference between the two values is called the safety margin.

## 1.2. Objectives and basis of study

Following are the foremost objectives :-

- To elaborate the alternate methods of probabilistic structure analysis.
- To study the safety margin problems specifically used for the analysis of a structure.
- To determine the reliability of beams and columns as per Indian Standard codes using different probability distribution curves and methods of reliability.

CHAPTER 2

# LITRATURE REVIEW

## 2.1 RESEARCH PAPER SUMMARY:

From quite a long time, a lot of scholars and researchers have found the concept of structural reliability analysis and design of vast interest. There have been different approaches, analysis and design methodologies that have been devised and worked upon subsequently. During the course of this project, guidance from the research papers of some of the renowned scholars in this field has been taken. The review of their papers has been explained in the subsequent section.

**R.Ranganathan[1999],** The aim is to introduce the probabilistic bases of structural reliability, the techniques and methods of evaluating the reliability of structural components and systems, the methodology in the dovelopment of reliability based design criteria ,and the evaluation of partial safety factors. Probabilistic concepts are used in reliability analysis, and in the design of the existing structures. It can also be used for doveloping a design criterion, that is, calibration of codes and development of partial safety factors, the use of which will result in designs with an accepted level of reliability.

**A.Der Kurighian,** FORM and SORM were used to present the geometry of various random vibrations and solutions. The problems of standard normal random variables which are geometricalrandom vibration problems are identified as obtained from the discretization of the input process. Linear systems when subjected to the excitation as entainled by Guassian, the curiosity problems get characterized by modest geometric forms, which arevector,half space,ellipsoid, and wedge. For responses which are non-Gaussian in nature, the problems are characterized by forms which are non-linearily geometric. The problems which are approximate in nature,solutions to such problems are obtained by use of the first-order and second-order methods of reliability(FORM and SORM).A new outlook for such problems which of random variation has been approximated for their solution.

**A.Der kiureghian, and P.-L. Liu**, The problem of structural reliability is often formulated in terms of a basic random variables vector X = [Xj . . . X,,]T, which representsquantities which are uncertain in nature such as loads, environmental factors, material properties,structural dimensions, and variables that are introduced to account for errors in modeling and prediction, and a performance function *g(X)* that describes the limit state of the structure in terms of X. The performance function is formulated by convention on account that *g(X)* < 0 denotes the failure structure and *g(X)* > 0 denotes the survival of the structureis known as the *limit-state surface*. The boundaries that are betweenthe failure and safe sets theories are Consistent with Ditlevsen's notion which is based on generalized reliability index, under the probability information which is insufficient in nature,Hence we do seek a formal distribution model for *X* and for transformation *T(-)* such that *Y* becomes a standard normal. As per the ground rules based on selection of the transformation and distribution,

The requirements are stipulated which are as follows-:

1. Simplicity - The strength needed to compute the index of reliability shall be appropriate with the information and quality that is accessible.

2. Consistency - The distribution model shall be able to satisfy the probability rules and it must be consistent with the information available.

3. Invariance - The reliability index $\beta$, must be invariant in respect to all conjointly consistent formulations of the transformation and the distribution model.

4. Operability - The distribution model must apply to random numbers and it should

be capable of combining any and all information available.

# 2.2 BRIEF REVIEW OF PROBABILISTIC PARAMETERS

## General

In the conventional deterministic design method, it is assumed that all parameters are not subjected to probabilistic variations. However, it is well known that loads(live load on floors, wind load, ocean waves, earthquake, etc. coming on the structures are random variables. Similarly, the strengths of materials (strength of concrete, steel etc.)and the geometric parameters(dimension of section, effective depth, diameter of bars etc) are subjected to statistical variations. Hence, to be rational in estimation of the structural safety, the random variations of the basic parameters are to be taken into account. Since the load and strength are random variables, the safety of the structure is also a statistical variable.

In overcoming the uncertainities in the design parameters, the safety factor is ensured by taking the smallest value of the strength and the largest value of the load. This way of fixing the safety in design is very conservative and leads to an economical design.

## 2.1.1 Random variables

The performance of an engineering system, facility or installation is modeled in mathematical terms in conjunction with empirical relations. For a given set of model, system performance is determined on the basis of the model. The basic random variables can be defined as the parameter that carries the uncertain parameters that are considered in the model .These variables must be able to represent any type of uncertainty that are to be included in analysis. The uncertainty, that must be considered are physical uncertainty, the statistical uncertainty and the model uncertainty. The physical uncertainties are typically the uncertainties that are associated with certain kind of loading, the structural geometry, the properties of the material and qualities of the repair. The statistical uncertainty arises due to uncertainty in the statistical information as an example smaller number of material tests undertaken. Finally, the uncertainty related to model must be considered so as to take into account the uncertainty associated with the descriptions that are idealized mathematically so as to approximate any behavior of the structure identified physically.

### 2.1.2 Mean and Variance

The central tendency (central value) of any random variable is measured by Sample mean. This is the best statistic so as to numerically summarize a distribution and the center of gravity of data.

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Where $X_i = X_1, X_2, X_3 \ldots\ldots, X_n$.

The variability or dispersion of any data set is a significant characteristic of the set of data. This dispersion may be described by the sample variance given by

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2$$

### 2.1.3 Probability density function and cumulative density function

If there's a record of random function $x(t)$.

The values in between are measured and correspondingly time intervals are evaluated. The ratio is to be given by

$$P(X_1 \le X \le X_2) = \frac{\Delta t_1 + \Delta t_2 + \cdots \Delta t_n}{T}$$

Moreover,P(X) gives the probability for X having the value between $X_1$&$X_2$during the random process.

Similarly, the probability of *X(t)* smaller than value of *X* is expressed as

$$P(X) = P[X(t) < X] = \lim_{t\to\infty} \sum_i \Delta T_i$$

The delta is for the function *X(t)*which has a value smaller than that specified for X. The function *P(X) is* known as the cumulative density function in equation of the function *X(t)*. The cumulative density function when graphically plotted is a function which increases monotonically.

### 2.1.4 Some useful probability distributions

#### Probability distribution

It can be thought of as a mathematical function, that stated in simple terms provides for probability of occurrence of different possible outcomes in an experiment.

In more technical terms, the probability distribution describes a random phenomenon in terms of the probabilities of events. Examples for random phenomena includes the result from an experiment or survey. A probability distribution defined in terms of an underlying sample space, It is the set of all possible outcomes of the random phenomenon being observed.

#### Normal (Gaussian) Distribution

In probability theory,the most common continuous probability distribution function is normal distribution.Physical quantities expected to be the sum of many independent processes often have distributions that are very nearly normal,used as such in measurement of errors.Many results and methods are derived analytically when the variables are distributed normally usually when there is propogation of uncertainity and least square parameters are involved

The probability density of the normal distribution is:

$$P(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{\frac{1}{2}(X-\bar{X})^2}{\sigma^2}}$$

Where:

- $\bar{X}$ – is the mean of the distribution.
- σ - is the standard deviation of distribution
- $\sigma^2$ -is variance

The corresponding CDF is calculated from:

$$P(x) = \int_{-\infty}^{\infty} P(E)d\epsilon = \emptyset\left(\frac{X - \bar{X}}{\sigma}\right)$$

Where

$\emptyset(-)$denotes the standard normal distribution function

$\varphi(-)$ - denotes its probability distribution function

which are defined:

Standard Normal PDF $\varphi(X) = \frac{1}{\sqrt{2\pi}} \int e^{-X^2/2}$

Standard Normal CDF $\emptyset(X) = \frac{1}{\sqrt{2\pi}} \int_{\infty}^{\infty} e^{-U^2/2 dU}$

If variables involved are multivariate in nature

then a multivariate normal PDF will be required.

A vector process is used, and the multivariate normal PDF is stated as,

$$P(x) = \left(\frac{1}{2\pi}\right)^{\frac{P}{2}} \frac{1}{\sqrt{|\rho|}} e^{-\frac{x^2}{2}}$$

Where,

$\bar{X}$ is a vector of p-dimensional random variable,

$\bar{x}$ is a vector of their realizations

$\chi^2$ is a scalar calculated from the product

Scalar:

$$\chi^2 = (\bar{x} - \overline{m})^T \rho^{-1} (\bar{x} - \overline{m})$$

$\overline{m}$ is a vector of mean values and

$\rho$ is the covariance matrix of $\bar{x}$

Modulus of row denotes the determinant of $\rho$

## Lognormal Distribution

This is another commonly used distribution. If the variable $X$ has distribution which is normal with specific mean and variance, then the random variable. $Y = e^x$ is distributed lognormally which is written as exponential function of X:

$$Y = e^X \; and \; X = \ln Y$$

Using equation the PDF of the random variable $Y = e^x$, can be obtained as written

Lognormal PDF:

$$P(X) = \frac{1}{\sigma_x \sqrt{2\pi}} \frac{1}{y} e^{-\frac{1}{2}\left(\frac{\ln y - m}{\sigma_x}\right)^2} \quad \text{for}(y>0)$$

## Gamma Distribution

It represents the sum of R independently distributed exponential random variables, and those random variables which always take the positive values.

PDF and CDF function are defined as below:

Gamma Dist., PDF: $f_X(X) = \frac{\lambda}{\Gamma(R)} (\lambda X)^{R-1} e^{-\lambda X}$ if *(x≥0, λ≥0)*

Gamma Dist., CDF: $1 - \sum_{k=o}^{R-1} \frac{1}{k!} (\lambda X)^k (\lambda X)^k$ if *(x≥0, λ≥0)*

In which Γ(.) represents gamma function as defined:

Gamma function: $\Gamma(x) = \int_0^\infty e^{-u} u^{(x-1)} du$

# CHAPTER 3

# INTRODUCTION TO STRUCTURAL RELIABILITY

## 3.1 Introduction

The failure of civil engineering structures are a consequence of decisions made under uncertain conditions and under different type of failures characterized as temporary failures, maintenance failure, design failure, failures caused due to natural hazards are to be addressed. For example, collapse of a bridge is a permanent failure, however if there is a traffic jam on the bridge, it is a temporary failure. If there is overflow in a filter or a pipe due to heavy rainfall, it is a temporary failure. *Thus failure definition is important. It is expressed as in the terms of failure probability and assessed by structure inability to perform the intended function for a specified period of time.* The converse of failure probability is called reliability which is defined in terms of success of a system, therefore reliability of a system *is the probability of a system so as to perform its required function adequately for specified period of time under the stated conditions.*

For convenience, the reliability $R_0$ is defined in terms of the probability of failure, $P_f$, which is taken as

$$R_0 = 1 - P_f$$

1. Reliability can be expressed as a probability
2. A quality performance is expected
3. It is expected over a desired period of time
4. The performance is expected under specified conditions

## 3.2 Levels of reliability methods

The term '**level**' can be described and is best characterised by the extent upto which the information to the problem associated can be used and provided.The methods of safety analysis suggested can be characterised under four basic "levels" (namely level IV, III, II, and I ) depending upon the degree of sophistication smeared to the treatment of the several problems.

**3.2.1** **level I** methods, Deterministic methods of reliability that uses only one 'characterstic' value to ascertain uncertain variable.This method is analogous to the method of deterministic design.

**3.2.2** **level II** methods,Reliability methods employ two values of specific uncertain parameter (i.e., mean and variance) which is supplemented with a measure of corelation to those parameters usually the covariance.

**3.2.3** **Level III** methods,the joint probability function of density of random variables is extended over safety domain. Reliability as expressed in terms of suitable indices of safety, viz., reliability index, β and probabilities of failure.

**3.2.4** **Level IV** methods the methods compare structural prospects with the prospects that are in reference as per the principles of economic ananlys of engineering which are under uncertainity.

## 3.3 Computation of Structural Reliability

There has been a need for solving complex problems that have led to the development and use of advanced quantitative methods for modeling. For example, the finite element method has been proved as a valuable concept to determine stability, deformation, earthquake response analysis of problems. There has been a rapid development of computers and computing methods that has facilitated the use for any of such methods. , The question of uncertainty of parameters and their randomness is central to design and analysis. However, it is well known fact that the information that has been derived from methods of analysis will be useful only if inputs are available and only if that data is reliable.

Decisions are made on the basis of information which is incomplete. Hence, It is desirable to use those methods and concepts in planning and design that facilitate evaluation and analysis of uncertainty. Probabilistic methods enable a logical analysis for uncertainty made and these provide a quantitative basis so as to assess the reliability of structures. Consequently, these methods are subsequently used to exercise an engineering judgment.

The basic structural reliability problem takes into account load effect (*s)* which is resisted by resistance (*r)*. they are described by a probability density function, $f_S(\ )$ and $f_R(\ )$ respectively. It is essential that rand *s to*be expressed in the same units. For ease, but without any loss of generality,safety of a structural element will be measured and, the structural element will be considered to have failed if its resistance *r*is less than the resultant stress*s* acting on it. The probability $P_f$of failure of the structural element can be stated in any of the following ways,

$$P_f = P(r \leq s)$$

$$= P(r - s \leq 0)$$

$$= P({}^{r}/_{s} \leq 1)$$

$$= P(ln\boldsymbol{r} - ln\mathbf{s}) \leq 0)$$

$or, i$n general

$$= P(g(r, s) \leq 0)$$

Where *G( )* is designated the *limit state function* and the probability of failure is similar with theprobability of limit state violation.

$$P_f = P(r - s \leq 0) = \iint_D f_{rs}(R, S) dR dS$$

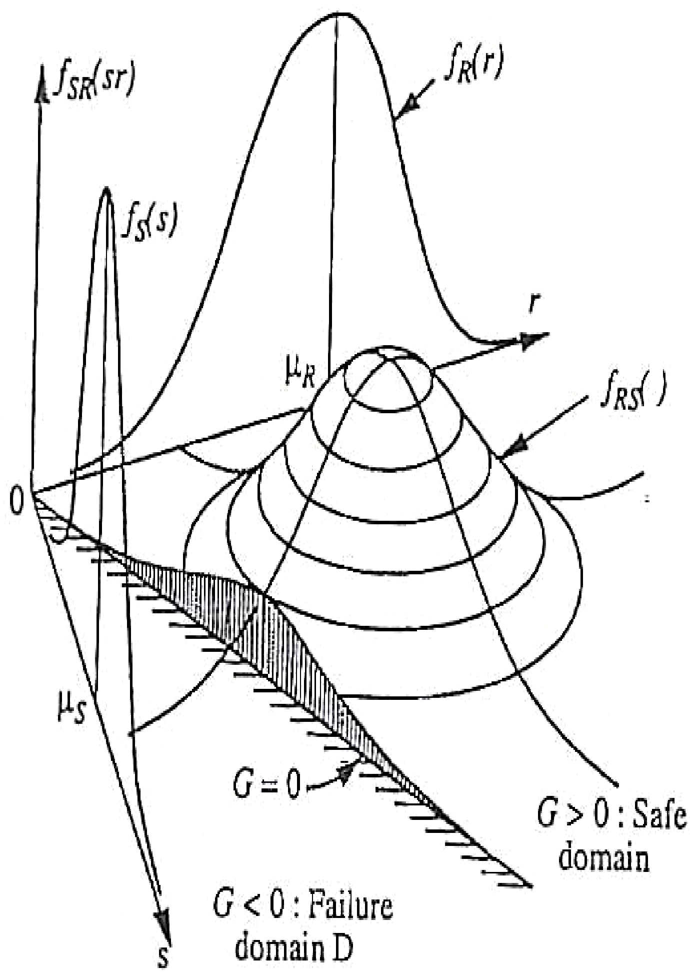



Fig. 1 -Joint density function $f_{RS}(r,s)$, marginal density functions $f_R(r)$ and $f_S(s)$ and failure domain *D*

When $R$ as well as S is an independent function,

$$f_{RS}(rs) = f_R(r) f_S(s)$$

Moreover, equation for probability of failures then becomes:

$$P_f = P(R - S \leq 0) = \int_{-\infty}^{\infty} \int_{-\infty}^{s \geq r} f_R(r) f_S(s) dr ds = \int_{-\infty}^{\infty} F_R(x) f_s(x) dx$$

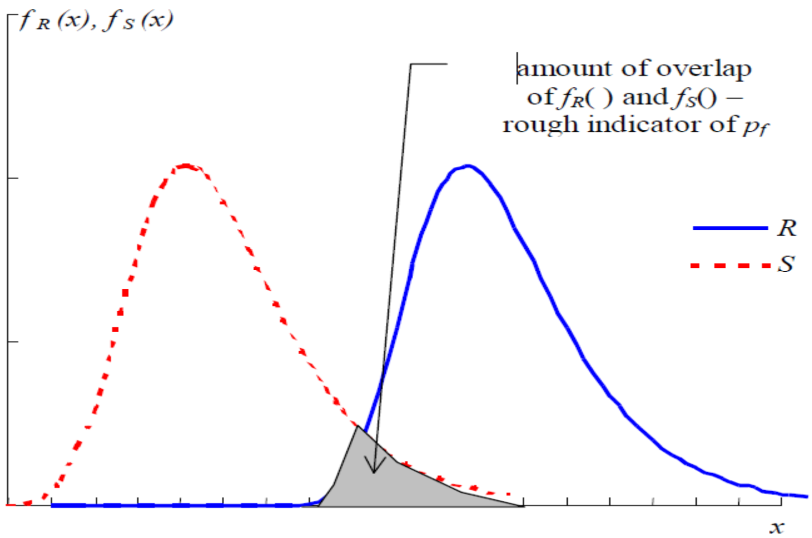



**Fig 2 : Basic *R*-*S* problem: $f_R(\,)\, f_S(\,)$ representation**

## Space of State Variables

For analysis, there’s a need to define state variables of any problem. The *state variables or parameters* are load and resistance parameters used for formulation of the performance function. For ‘n’ number of state variables, the specified limit state function represents function of ‘n’ parameters.

If all loads (or load effects) are represented by the variable Q and total resistance (or capacity) by R, then the space of state variables is a two-dimensional space as shown in Figure 1. Within the space, there is a separation of the “safe domain” from that of “failure domain”; the intersection area between the domains describes the limit state function g(R,Q)=0.

Since both R and Q are some basic random variables, these can be defined as a joint density function $f_{RQ}$ (r, q). A general joint density function is plotted in Figure 2. Again, the function of limit state separates the domains of safe and failure function. The integration of the joint density function over the failure domain represents the joint density function[i.e., the region for which g(R, Q) <0]. It is often very difficult to evaluate this probability, so the concept structural reliability can be quantified by a reliability index.

The standard normal distribution function (zero mean and unit variance) denoted by $\Phi(\,)$.The random variable $Z = R\text{-}S$ as shown in Figure, which is represented by the region $Z \leq 0$ as shown shaded. Using equations above, it follows that

$$P_f = \Phi\left[\frac{-(\mu_R - \mu_S)}{(\sigma_R^2 + \sigma_S^2)^{\frac{1}{2}}}\right] = \Phi(-\beta)$$

Where,$\beta = {}^{\mu_Z}/_{\sigma_Z}$is defined as ***reliability (safety) index***.

If the standard deviations $\sigma_R$and $\sigma_S$or both are subsequently increased, the square bracket term in expression above tends to become smaller which further increases $P_f$. Similarly, The difference between the mean of load effect and the mean of the resistance if reduced, $P_f$ increases. The observations as above can also be deduced from Figure 5 below, taking the overlap of $f_R(\,)$ and $f_S()$ as a rough indicator of $P_f$.

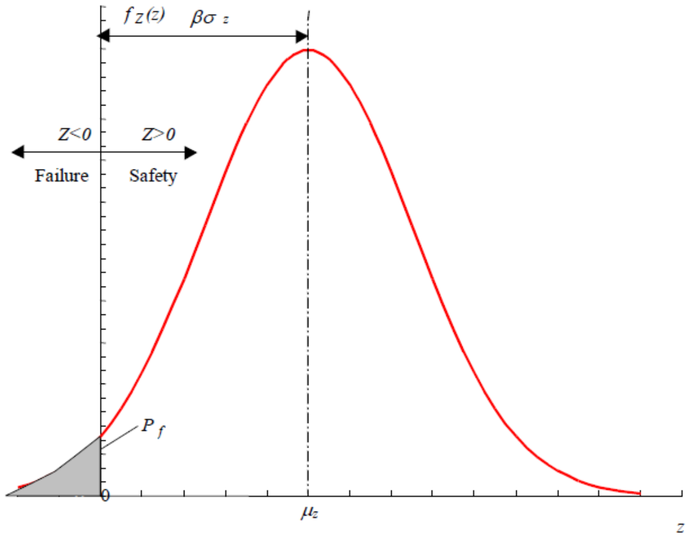



**Fig. 3 - Distribution of safety margin *Z* = *R* – *S***

## Reduced Variables

It is useful in particular situations to transform random variables to their "standard form" which is also a nondimensional form of variables. For variables R and Q which are basic, the standard form can be expressed as

$$Z_R = \frac{R - \mu_R}{\sigma_R}$$

$$Z_Q = \frac{R - \mu_Q}{\sigma_Q}$$

The variables as indicated in the above expression $Z_R$ and $Z_Q$, are called *reduced variables.* By reorganizing Equation, the resistance *R* and the load *Q* can best be expressed in terms ofreduced variables as follows:

$$R = \mu_R + Z_R\sigma_R$$

$$Q = \mu_Q + Z_Q\sigma_Q$$

The limit state function as represented by $g(R, Q) = R - Q$ isstated in terms of the reduced variables and the result obtained is

$$g(Z_R, Z_Q) = \mu_R + Z_R\sigma_R - \mu_Q - Z_Q\sigma_Q = (\mu_R - \mu_Q) + Z_R\sigma_R - Z_Q\sigma_Q$$

The above equation represents a straight line in the space of reduced variables $Z_R$and $Z_Q$. The line corresponding to $g\left(Z_R, Z_Q\right) = 0$that separates the safe and failure domain in the space.

## Reliability Index

Reliability index can be defined as an inverse to the coefficient of variation. The reliability index alternatively is the perpendicular or shortest distance measured from the origin of reduced variables to the failure point also called as design pointwhich is illustrated as in Fig., line $G\left(Z_R, Z_Q\right) = 0$.

The definitionwas given by Hasofer and Lind. Using the geometry one can easily determine the reliability index i.e.(the shortest distance) from the following formula

$$\beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

where $\beta$ repressents the inverse of coefficient of variation of function

$g(R, Q) = R - Q$.

R represents the resistance of the structure

Q represents the action or load on the structure

then the reliability index whenrelated to probability of failure is given by:

$$\beta = -\phi^{-1}\left(P_f\right) \ or \ P_f = \phi(-\beta)$$

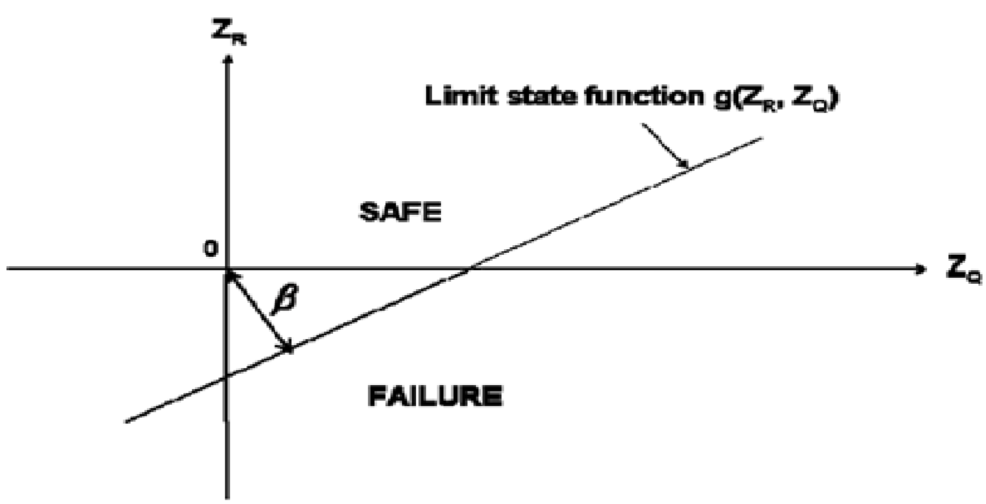



**Fig. 4 Representation of Reliability index for a limit state function**

# CHAPTER 4

# First Order Reliability Method

## 4.1 First order reliability method (FORM)

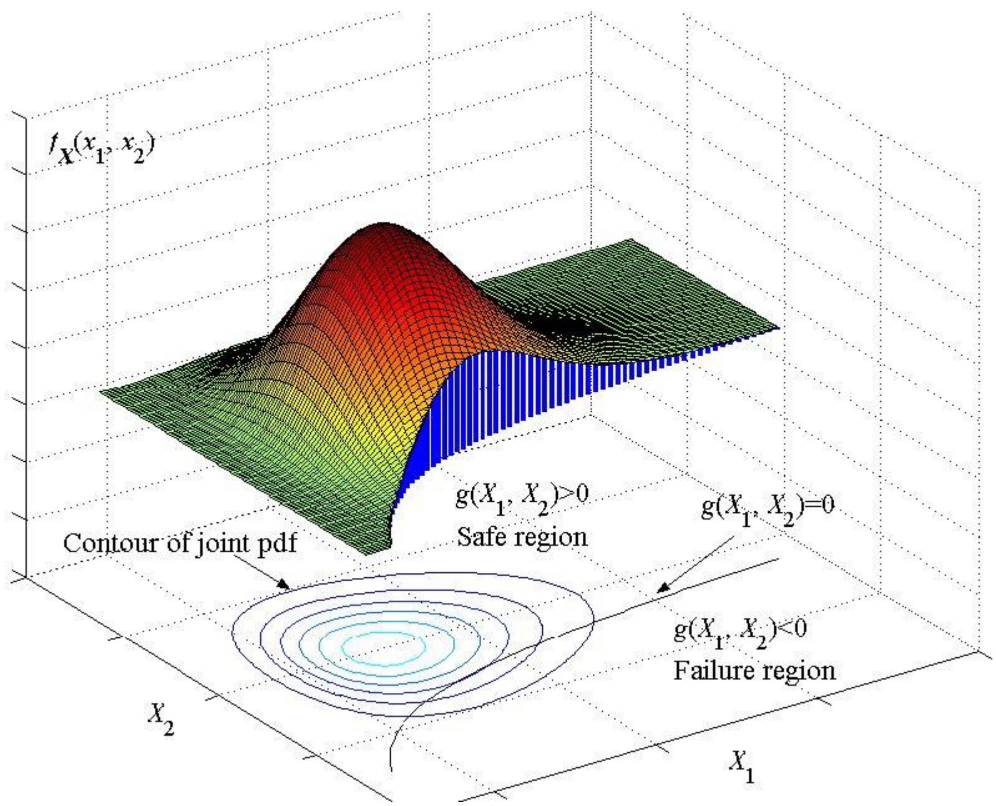



**Fig 5: First order reliability method representation**

This technique of first-order approximation of Taylor series of the function is aimed at linearized mean values of random variable known as first-order second moment (MVFOSM)method;

It therefore uses onlystatistics (i.e.mean & variance) related to second moment of the random variables. Initially approach was based on the basic assumption that the resulting probability of *Z* distribution is normal, The reliability index was defined using the ratio of the expected value of Z over its standard deviation. The reliability index $(\beta_c)$as given by Cornell is an absolute value ofany ordinate of point converging to Z = 0 as normal standardised probability for plot as shown in Figure

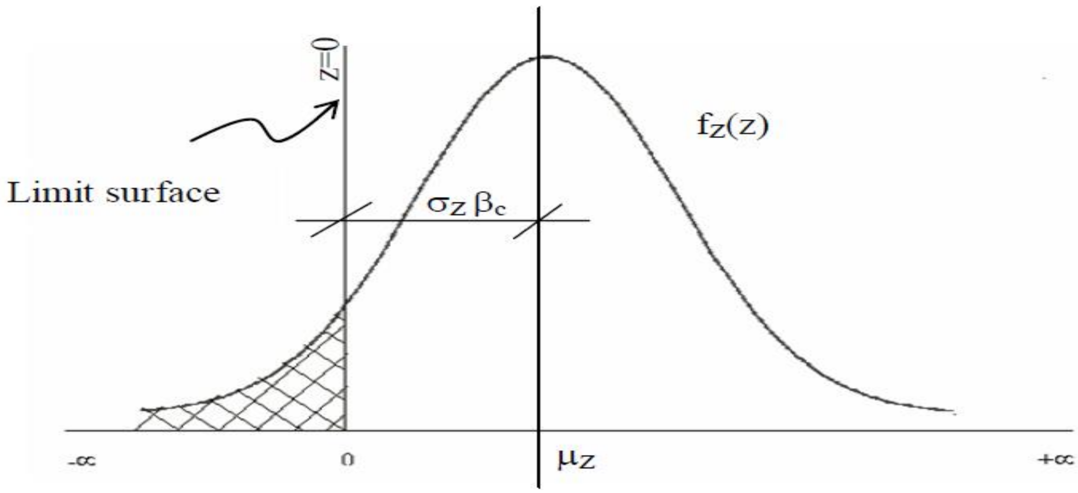



**Fig. 6 – Definition of limit state and reliability index**

And the equation given by:

$$\beta_c = \frac{\mu_R - \mu_S}{\sqrt{\sigma_R^2 + \sigma_S^2}}$$

An approximation can be obtained usingfirst order relaibility method(FORM) approach.

An ideal conditionis approximated for the general case .

where $X$ indicates a vector for Gaussian variables with zero mean and standard deviation as unity,

where *g(X)* is a linear function.

The probability of failure $P_f$ is then

$$P_f = P(g(X) < 0) = P\left(\sum_{i=1}^{n} \alpha_i X_i - \beta < 0\right) = \phi(-\beta)$$

Where,

$\alpha_i$ representsthe cosine direction of random variable

$X_i$, $\beta$ represents the distance between an origin and its hyperplane

*g(X)=0*

*n* represents the number of basic random variables for *X*,

*Φ* represents thestandard normal distribution function.

The above formulations are generalized for many random variables as denoted by vector. Let performance function is given as:

$$Z = g(X) = g\,(X_1, X_2 \ldots . X_n)$$

Using the Taylor series expansion, the performance function for the mean value as given by the equation

$$Z = g(\mu_X) + \sum_{i=1}^{n} \frac{\partial g}{\partial X_i}(X_i - \mu_{X_i}) + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{\partial^2 g}{\partial \mathrm{X}_i \, \partial X_j}(X_i - \mu_{X_i})\left(X_j - \mu_{X_j}\right) + \cdots$$

Where derivatives are given at the mean values of random variables $(X_1, X_2 \ldots X_n)$

$\mu_{X_i}$is the mean value of $X_i$.

The series when expressed in linear terms,

the  mean and variance for first order of Z is obtained as:

$$\mu_Z \approx g\left(\mu_{X_1}, \mu_{X_2, \ldots\ldots\ldots\ldots} \mu_{X_n}\right)$$

And,

$$\sigma_Z^2 \approx \sum_{i=1}^{n}\sum_{j=1}^{n}\frac{\partial g}{\partial X_i}\frac{\partial g}{\partial X_j}var(X_i, X_j)$$

Where $var(X_i, X_j)$ is covariance of $X_i$ and $X_j$. If variances are uncorrelated, then the variance for *z* is given as

$$\sigma_Z^2 \approx \sum_{i=1}^{n}\left(\frac{\partial g}{\partial X_i}\right)^2 var(X_i)$$

The reliability index calculated by taking ratio of mean $(\mu_z)$ and standard deviation of $Z$ $(\sigma_z)$ as:

$$\beta = \frac{\mu_Z}{\sigma_Z}$$

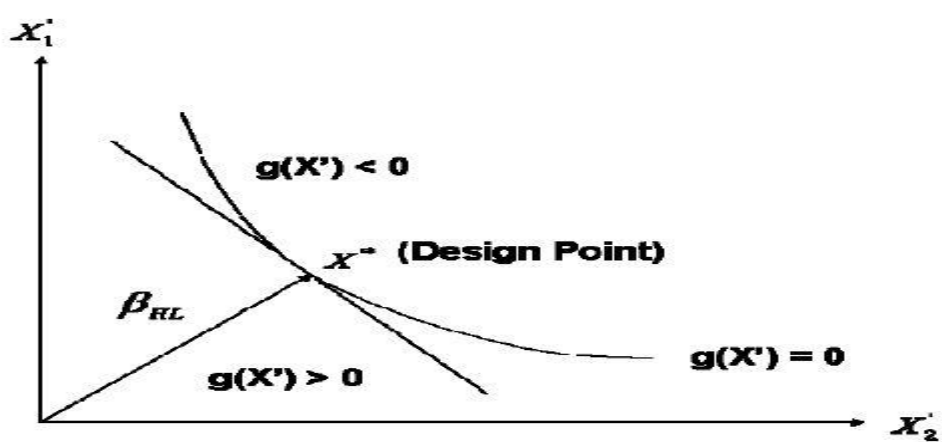



**Fig 7 : Design point representation**

### 5.1.1 Reliability Index proposed by Hasofer and Lind

A modified reliability index was proposed by Hasofer and Lind that did not exhibited the problem of invariance. The "correction" to evaluate the limit state function at a point is known as the "design point" instead of mean values. The design point as defined is a point at the failure surface g = 0. Since this point is not known previously, the technique of iteration must be used (in general) so as to solve for the problem of reliability index.

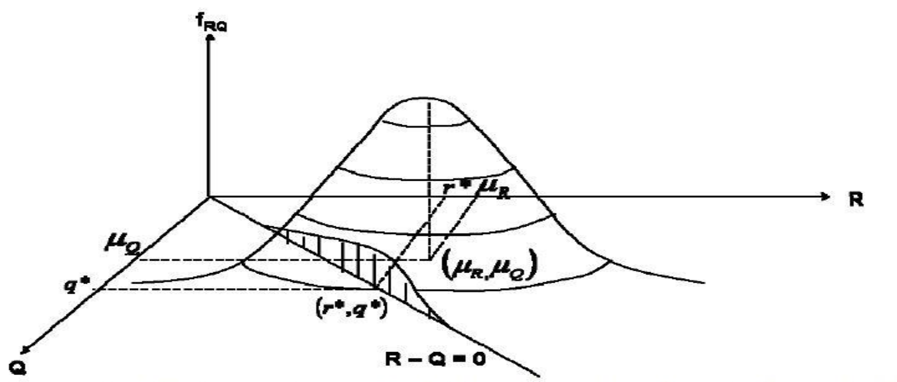



**Figure 10 - Design point on the failure boundary for the linear limit state function g = R – Q**

### 5.1.2. AFOSM Method for Normal Variables

The *Hasofer-Lind* (H-L) method as applicable for normal random variables defines the reduced variables as

$$X_i = \frac{X - \mu}{\sigma} \quad (i=1,2\ldots..n)$$

Where, $X_i$ denotes a random variable with zero mean and unity as standard deviation.

Above equation can be used to transform the original limit state g(X) = 0 to the limit state reduced to g(X`)= 0. The coordinate system of X is referred to as *original coordinate system.* The X` coordinate system can be referred to as the *transformed* or *reduced* system. Note that if $X_i$ is normal. The safety index β can be defined as the minimum distance from the origin of the axes in the reduced coordinate system to the limiting state surface (or the failure surface).

For a failure surface non-linear in nature, the shortest distance of the origin (in normalized coordinate system)is referred to the failure surface that is not unique as in the case of linear failure surface. The computation of failure surface probability involves integration. The tangential plane to the design point is used to approximate the value of $\beta$. If the failure surface towards the origin is concave, approximation will be on the safer side, while for the convex surface it will be on the unsafe side.

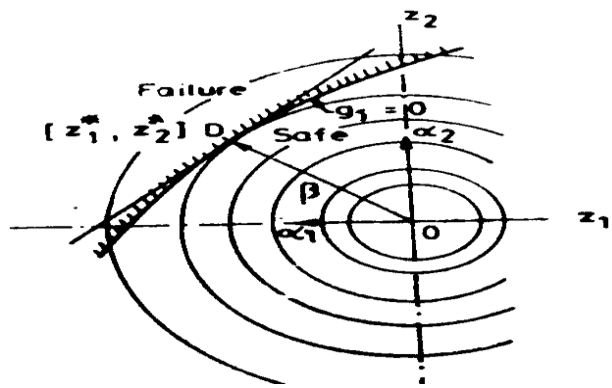



**Fig. 8 – Formulation of safety analysis in normalized coordinates.**

### 5.1.3 Component reliability (COMREL)

COMREL is a software that performs reliability analysis that are time invaraint in nature of various individual failure modes on the basis of advanced methodologies of FORM/SORM. Various algorithms to find the most likely failure point (β-point) are to be implementedthat includes an algorithm that is gradient-free for non-differentiable criteria of failure (state functions). Alternatively other computational options include MVFO(Mean Value First Order),simulation by Monte Carlo, Sampling, Adaptive and Spherical Sampling, other Important Sampling schemes and Simulation by subset method.

Specifically Built-in functions includes all thetrigonometric, logarithmic,hyperbolic, elementary and some other special functions like Gamma functions, Gaussian distribution function and their inverse. It also includes alternatives for differentiation, numerical integration, and finding of a root is available along with testing functions and comparative operators.User-definedfunctions, auxillary as well as reference functions, can also be defined.

### 5.1.4 STAAD.Pro V8i

The most dynamic and popular engineering software product used in structural engineering to carry out analysis of the beams and columns of a structure.It is useful for post printing important and significant results when a structure is subjected to different types of loadings such as joint displacements,supportreactions,deflections,bending moments and shear values,not only these values are helpful in analysis but also these values are specifically used for designing.The software has additional advantages for 3-D model generation and multi-material designing.It is an integration to several modeling softwares and products of design.

# CHAPTER 6

# METHODOLOGY

It is a general tendency of a beam or a column to dovelop moments and shear when subjected to loading either in form concentrated or UDL.

To evaluate or to dovelop an equation for Moment of Resistance of the section there's always a need to have knowledge about various physical parameters of the section.But in normal conditions these parameters are subjected to statistical variation and are probabi -listic in nature.Hence a method must be formulated so as to account for these uncertainities. One of such methods used is given by Hasofer and Lind that gives a theoritical defination of reliability index (β).The method takes into account the statistical variations of physical parameters by using mean and standard deviation values.

STAAD PRO has been used to evaluate critical bending moment values and axial forces.Further,these values are then exported to COMREL for anlysis which through first order and second order reliability methods evaluates the value of reliability index through various iterations and its inverse giving the value of probability of failure.

As an example to the explain the complete methodology a sample beam problem has been expalined further:-

# ANALYSIS OF A SAMPLE BEAM PROBLEM

## 6.1 Reliability of the beam against the limit state of collapse in flexure

Calculate the reliability index of the beam(against the limit state of collapse in flexure) shown in fig., subjected to a self-weight $Q_1$ and a live load $Q_2$.The Flexural resistance moment capacity of the beam is R. It is given that

$Q_1$=wL N L= 4 m

$\mu_{Q1}$= 400 N $\mu_{Q2}$=5000 N $\mu_R$=10000N-m

$\sigma_{Q1}$ = 10 N $\sigma_{Q2}$=2000 N $\sigma_R$=1000N-m

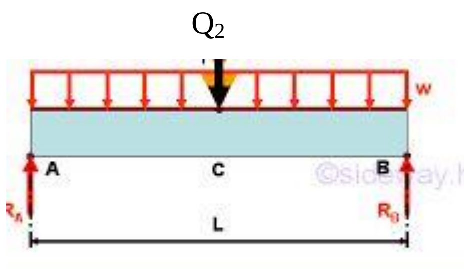



**Fig 9. Simply supported beam Problem**

### 6.1.1 Manual calculation

Solution:

Maximum bending moment due to external loads is

$$M_e = Q_1L/8 + Q_2L/4$$
$$=Q_1(4/8)+ Q_2(4/4)$$

Hence, Action=$Q_1$/2+$Q_2$

The failure function (R-S) is

$$G(Q_{1,}Q_2,R) = R - Q_1/2 - Q_2$$

This is a linear function of variables R, $Q_1$ and $Q_2$

$$M=R - Q_1/2 - Q_2$$

Using Equations. Above

$$\mu_m=\mu_R - \mu_{Q1}/2 - \mu_{Q2}$$

$$\sigma_m^2=\sigma_R^2 + (1/2)^2(\sigma_{Q1}^2) + \sigma_{Q2}^2$$

Substituting the given data, we have

$$\mu_m=10 - (0.4)/2 - 5$$

$$\boldsymbol{\mu_m= 4.8\ KN}$$

$$\sigma_m^2=1^2+(.01)^2/2^2 + (2)^2$$

$$\boldsymbol{\sigma_m = 2.236\ KN}$$

Hence the reliability index β is,

$$\boldsymbol{\beta=(4.8/2.236) = 2.147}$$

### 6.1.2 Solved using COMREL

## $\beta$ and $p_f$ obtained using FORM

```
**********************************************
```

## Numerical Results

```
                   **********************************************
                   ----------- Comrel-TI (Version 9) ------------
                   ---- (c) Copyright: RCP GmbH (1989-2015) -----
                   **********************************************
------------------------------------------------------------------------------
-
   Job name ........... :                                                 maj1
   Failure criterion no. :1
   Comment : reliability index of the beam
   Transformation type   : Rosenblatt
   Optimization algorithm: RFLS
 -----------------------------------------------------------------------------
--
 -----------------------------------------------------------------------------
--

 Iteration No.1; CPU-seconds(cumulative):     0.000
   Scaled St.F(U) =  0.2825E-09; BETA =      0.0000; BETA/||U||=      0.0000
   Multipl.=    9.216    ; Step-length=    1.0000; State Func.calls:    5
------------------------------------------------------------------------------
-

  Iteration No.2; CPU-seconds(cumulative):     0.016
   Scaled St.F(U) = -0.3790E-15; BETA =      2.1466; BETA/||U||=      1.0000
   Multipl.=    9.216    ; Step-length=    1.0000; State Func.calls:    9

                        FORM-beta=2.147;
                        FORM-Pf=1.59E-02;

             --------- Statistics after COMREL-TI ---------
              State Function calls                =       10
              State Funct. gradient evaluations =     2
              Total computation time (CPU-secs.)=     0.03
              The error indicator (IER) was =    0
             **********************************************

Reliability analysis is finished
```

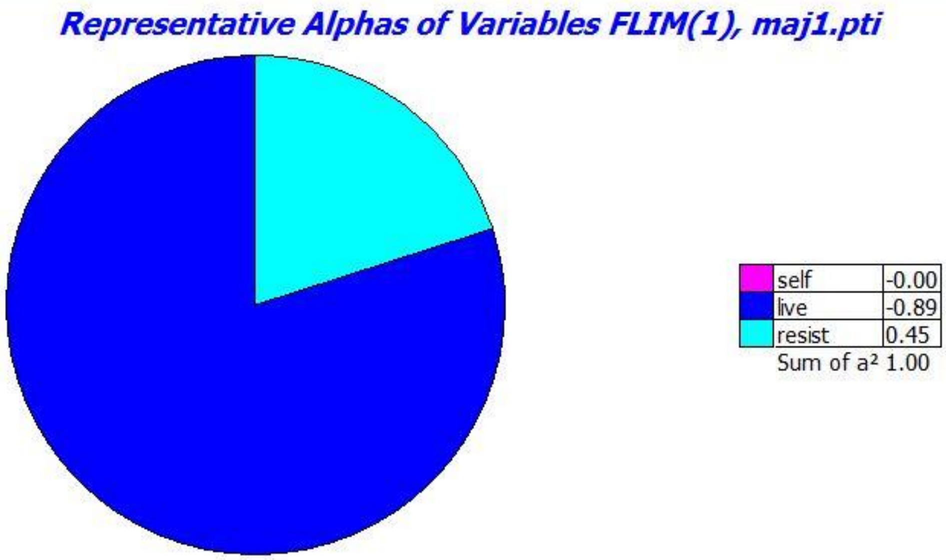
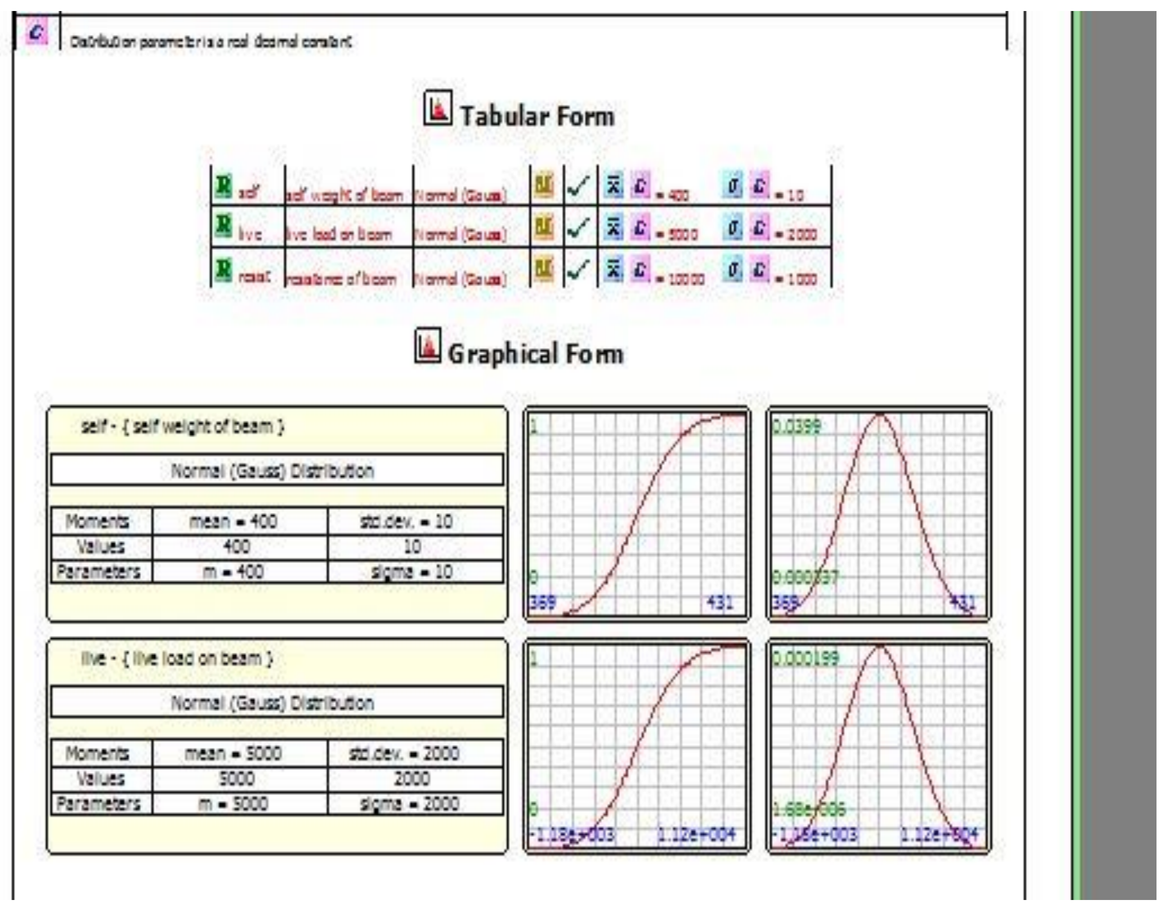
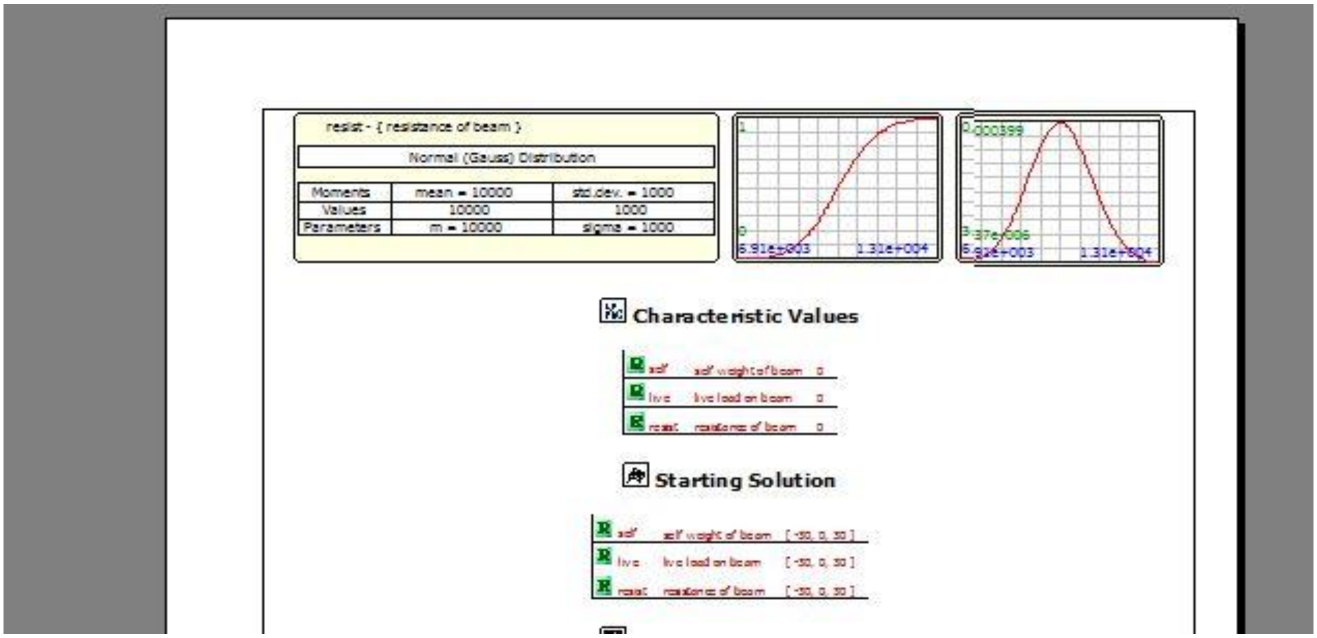



**Fig.11 - α values obtained for all the three variables at design point**






## Limit State Functions

**FLIM**(1){reliability of beam}=
**resist-self**/2-**live**

### Variables in FLIM(1)

| | | |
|---|---|---|
| **Resist** | **R** | R |
| **Self** | **R** | Self weight of beam |
| **Live** | **R** | live load on beam |

## Summary Symbolic Variables

| | | |
|---|---|---|
| **resist** | **R** | resistance of beam |
| **self** | **R** | self weight of beam |
| **live** | **R** | live load on beam |

## Summary Numerical Constants

| | |
|---|---|
| User | -1 |
| User | 2 |

# CHAPTER 6

## 6.1 Reliability of corner and central column for a MULTI-STOREY building under seismic load definition as per IS:1893-2002/2005.

A corner and central column has been analyzed for a multi-storey G+8 steel building model when subjected to an earthquake loading as per IS 1893 2002 seismic load defination for Delhi zone i.e. (zone IV) region .The analysis were performed in STAAD PRO to get the values of most critical axial load and bending moment values acting along Y and Z direction on the column taking into account the different load combinations.

The results obtained in STAAD PRO were then transferred to MS Excel file to clearly study and note values of axial load and biaxial moments. The most critical values for different load combinations were obtained through STAAD PRO analysis that were used for the reliability analysis in COMREL. As per IS: 800-2007, the buckling criteria for the column has been used for axial loading and biaxial bending in Y and Z direction which, is given as:

$$\left(\frac{M_y}{M_{ndy}}\right)^{\alpha_1} + \left(\frac{M_z}{M_{ndz}}\right)^{\alpha_2} < 1$$

The final failure limiting equation is formulated using the above values and formulae which was then used for analysis in COMREL, the analysis were formulated using the different probability density functions such as normal, logarithmic, Gumbel (max.) and they are optimized for achieving the reliability of the structure. The first and second order analysis were performed for the reliability and the failure probability was evaluated.

### 9.3 Combined Axial Force and Bending Moment

Under combined axial force and bending moment, section strength as governed by material failure and member strength as governed by buckling failure shall be checked in accordance with **9.3.1** and **9.3.2** respectively.

**9.3.1** *Section Strength*

**9.3.1.1** *Plastic and compact sections*

In the design of members subjected to combined axial force (tension or compression) and bending moment, the following should be satisfied:

$$\left(\frac{M_y}{M_{ndy}}\right)^{\alpha_1} + \left(\frac{M_z}{M_{ndz}}\right)^{\alpha_2} \leq 1.0$$

Conservatively, the following equation may also be used under combined axial force and bending moment:

$$\frac{N}{N_d} + \frac{M_y}{M_{dy}} + \frac{M_z}{M_{dz}} \leq 1.0$$

where

$M_y$, $M_z$ = factored applied moments about the minor and major axis of the cross-section, respectively;

$M_{ndy}$, $M_{ndz}$ = design reduced flexural strength under combined axial force and the respective uniaxial moment acting alone (*see* **9.3.1.2**);

$N$ = factored applied axial force (Tension, $T$ or Compression, $P$);

$N_d$ = design strength in tension, $T_d$ as obtained from **6** or in compression due to yielding given by $N_d = A_g f_y / \gamma_{m0}$;

$M_{dy}$, $M_{dz}$ = design strength under corresponding moment acting alone (*see* **8.2**);

$A_g$ = gross area of the cross-section;

$\alpha_1$, $\alpha_2$ = constants as given in Table 17; and

$\gamma_{m0}$ = partial factor of safety in yielding.

c) *For standard I or H sections*

for $n \leq 0.2$ $\quad M_{ndy} = M_{dy}$

for $n > 0.2$ $\quad M_{ndy} = 1.56\, M_{dy}\,(1 - n)\,(n + 0.6)$

$$M_{ndz} = 1.11\, M_{dz}\,(1 - n) \leq M_{dz}$$

,

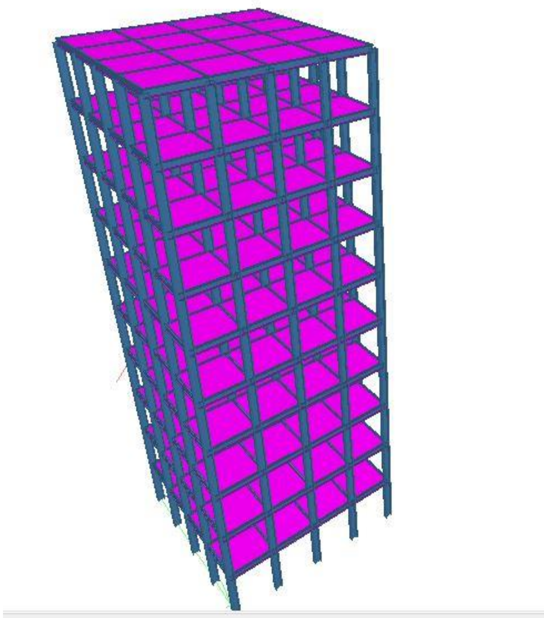
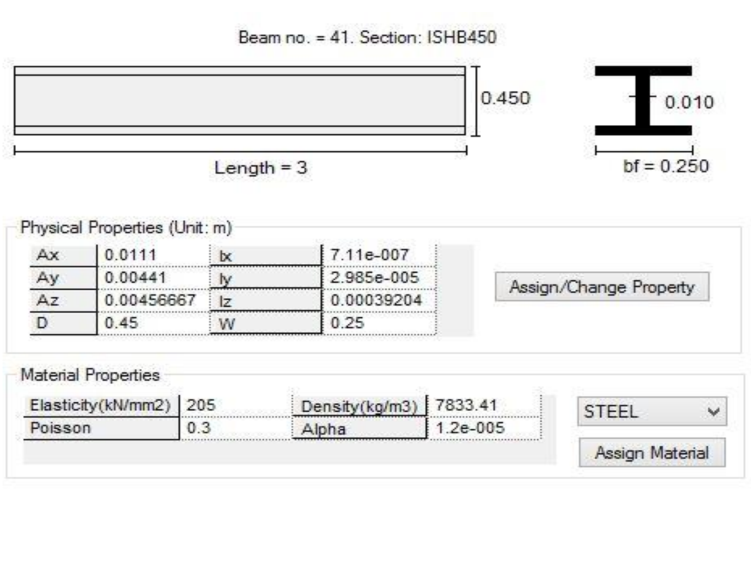


*Fig 12: STEEL BUILDING G+8 MODEL USED FOR STAAD ANALYSIS*




Physical Properties (Unit: m)

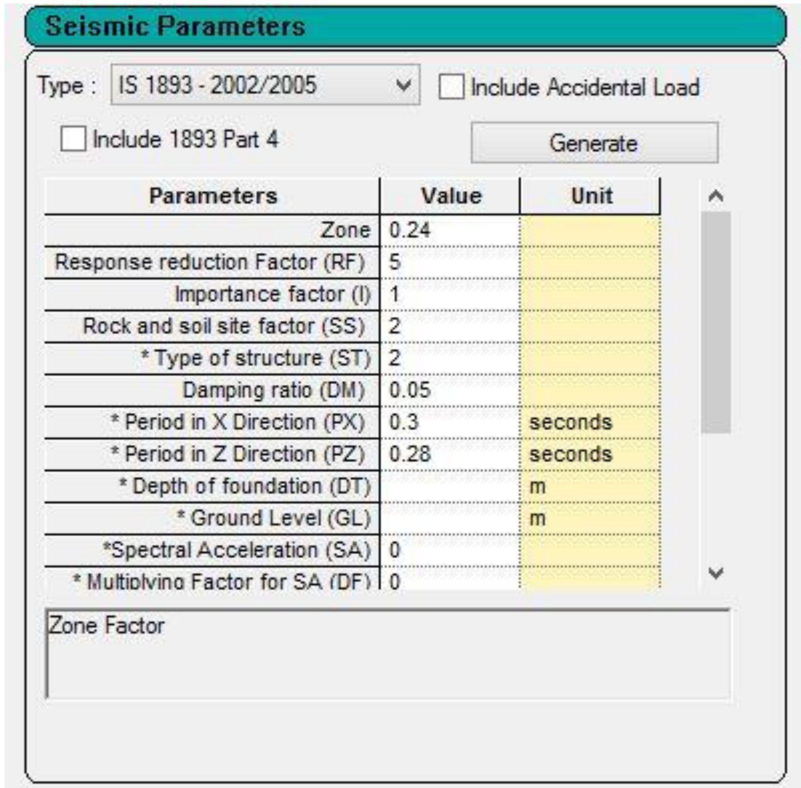
| | | | |
|---|---|---|---|
| Ax | 0.0111 | Ix | 7.11e-007 |
| Ay | 0.00441 | Iy | 2.985e-005 |
| Az | 0.00456667 | Iz | 0.00039204 |
| D | 0.45 | W | 0.25 |

Material Properties

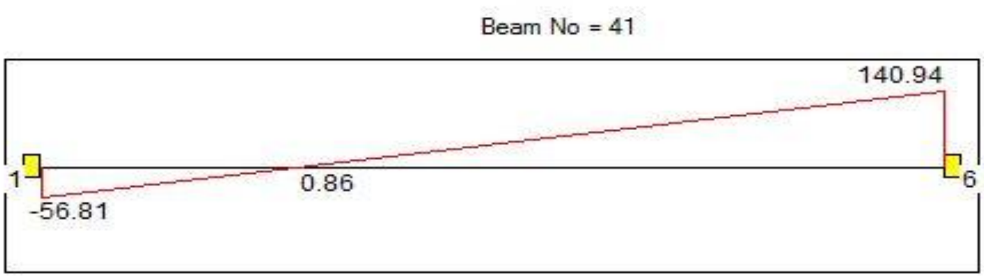
| | | | |
|---|---|---|---|
| Elasticity(kN/mm2) | 205 | Density(kg/m3) | 7833.41 |
| Poisson | 0.3 | Alpha | 1.2e-005 |

*SECTION PROPERTIES*

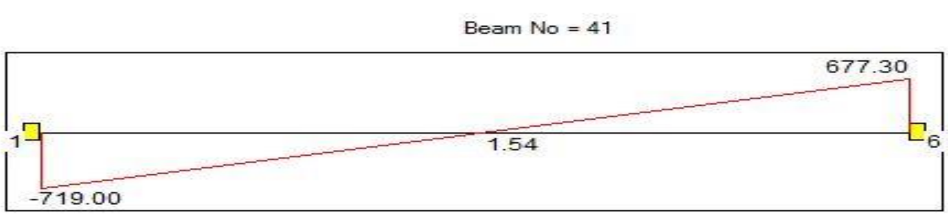
## *SEISMIC DEFINATION*




## CRITICAL VALUES FOR CORNER COLUMN MEMBER




Mz(BENDING MOMENT IN ZZ DIRECTION)




My(BENDING MOMENT IN YY DIRECTION)

# COMREL ANALYSIS

# Numerical Results for beam no.41

---------------------------------------------------------------------------

Iteration No.  1; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.2015E-08; BETA =      0.7516; BETA/||U||=      0.0706

Multipl.=  0.5209E+11; Step-length=    0.0132; State Func.calls:  315

---------------------------------------------------------------------------

Iteration No.  2; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.2002E-08; BETA =     10.6099; BETA/||U||=      0.9961

Multipl.=  0.7731E+10; Step-length=    0.0132; State Func.calls:  329

---------------------------------------------------------------------------

Iteration No.  3; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.1988E-08; BETA =     10.6190; BETA/||U||=      0.9962

Multipl.=  0.7735E+10; Step-length=    0.0132; State Func.calls:  343

---------------------------------------------------------------------------

Iteration No.  4; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.1975E-08; BETA =     10.6280; BETA/||U||=      0.9963

Multipl.=  0.7738E+10; Step-length=    0.0132; State Func.calls:  357

---------------------------------------------------------------------------

Iteration No.  5; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.1962E-08; BETA =     10.6370; BETA/||U||=      0.9964

Multipl.=  0.7741E+10; Step-length=    0.0132; State Func.calls:  371

---------------------------------------------------------------------------

Iteration No.  6; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.2190E-08; BETA =      0.7938; BETA/||U||=      0.0753

Multipl.=  0.5689E+11; Step-length=    0.0132; State Func.calls:  385

---------------------------------------------------------------------------

Iteration No.  7; CPU-seconds(cumulative):     0.203

Scaled St.F(U) =  0.2174E-08; BETA =     10.5058; BETA/||U||=      0.9956

Multipl.=  0.7701E+10; Step-length=    0.0132; State Func.calls:  399

---------------------------------------------------------------------------

Iteration No.  8; CPU-seconds(cumulative):     0.203

Scaled St.F(U) = 0.2158E-08; BETA = 10.5157; BETA/||U||= 0.9957

Multipl.= 0.7704E+10; Step-length= 0.0132; State Func.calls: 413

--------------------------------------------------------------------------

Iteration No. 9; CPU-seconds(cumulative): 0.219

Scaled St.F(U) = 0.2143E-08; BETA = 10.5254; BETA/||U||= 0.9958

Multipl.= 0.7707E+10; Step-length= 0.0132; State Func.calls: 427

--------------------------------------------------------------------------

Iteration No. 10; CPU-seconds(cumulative): 0.219

Scaled St.F(U) = 0.2387E-08; BETA = 0.8524; BETA/||U||= 0.0816

Multipl.= 0.6257E+11; Step-length= 0.0132; State Func.calls: 441

--------------------------------------------------------------------------

Iteration No. 11; CPU-seconds(cumulative): 0.219

Scaled St.F(U) = 0.2368E-08; BETA = 10.3966; BETA/||U||= 0.9949

Multipl.= 0.7673E+10; Step-length= 0.0132; State Func.calls: 455

--------------------------------------------------------------------------

Iteration No. 12; CPU-seconds(cumulative): 0.234

Scaled St.F(U) = 0.2347E-08; BETA = 10.4498; BETA/||U||= 0.9990

Multipl.= 0.7669E+10; Step-length= 0.0132; State Func.calls: 469

--------------------------------------------------------------------------

Iteration No. 13; CPU-seconds(cumulative): 0.234

Scaled St.F(U) = 0.2610E-08; BETA = 0.9435; BETA/||U||= 0.0913

Multipl.= 0.6955E+11; Step-length= 0.0132; State Func.calls: 483

--------------------------------------------------------------------------

Iteration No. 14; CPU-seconds(cumulative): 0.234

Scaled St.F(U) = 0.2587E-08; BETA = 10.2808; BETA/||U||= 0.9938

Multipl.= 0.7645E+10; Step-length= 0.0132; State Func.calls: 497

--------------------------------------------------------------------------

Iteration No. 15; CPU-seconds(cumulative): 0.250

Scaled St.F(U) = 0.2870E-08; BETA = 1.0424; BETA/||U||= 0.1020

Multipl.= 0.7780E+11; Step-length= 0.0132; State Func.calls: 511

--------------------------------------------------------------------------

Iteration No. 16; CPU-seconds(cumulative): 0.250

Scaled St.F(U) = 0.2840E-08; BETA = 10.2214; BETA/||U||= 0.9985

Multipl.= 0.7631E+10; Step-length= 0.0132; State Func.calls: 525

-------------------------------------------------------------------------

Iteration No. 17; CPU-seconds(cumulative): 0.250

Scaled St.F(U) = 0.2810E-08; BETA = 10.2343; BETA/||U||= 0.9985

Multipl.= 0.7632E+10; Step-length= 0.0132; State Func.calls: 539

-------------------------------------------------------------------------

Iteration No. 18; CPU-seconds(cumulative): 0.266

Scaled St.F(U) = 0.3111E-08; BETA = 1.1640; BETA/||U||= 0.1149

Multipl.= 0.8625E+11; Step-length= 0.0132; State Func.calls: 553

-------------------------------------------------------------------------

Iteration No. 19; CPU-seconds(cumulative): 0.266

Scaled St.F(U) = 0.3075E-08; BETA = 10.1258; BETA/||U||= 0.9979

Multipl.= 0.7622E+10; Step-length= 0.0132; State Func.calls: 567

-------------------------------------------------------------------------

Iteration No. 20; CPU-seconds(cumulative): 0.281

Scaled St.F(U) = 0.3040E-08; BETA = 10.1398; BETA/||U||= 0.9979

Multipl.= 0.7623E+10; Step-length= 0.0132; State Func.calls: 581

-------------------------------------------------------------------------

FORM-beta= 4.897 ; SORM-beta= 4.57

FORM-Pf=1.23E-05 ; SORM-Pf= 1.32E-5

| | | | |
|---|---|---|---|
| FORM-beta | 4.897 | SORM-beta | 4.57 |
| FORM-Pf | 1.23E-05 | SORM-Pf | 1.32E-05 |

**TABLE 1: RELIABILITY ANALYSIS FOR BEAM NO.41**

## Limit State Functions

```
FLIM(1){LIMIT STATE EQUATION FOR CORNER COLUMN}=
1-(My/(63.89*N*fy+2409647*fy*fy-0.000635*N*N))^(0.0002*N/fy)-(Mz/(2.75*N*fy+104011
*fy*fy-0.0002*N*N))^2
```

### Variables in FLIM(1)

| | | |
|---|---|---|
| My | R | MOME |
| N | R | AXIAL LOAD |
| fy | R | YIELD STRESS |
| Mz | R | MOMENT IN ZZ DIRCETION |

## Summary Symbolic Variables

| | | |
|---|---|---|
| My | R | MOMENT IN YY DIRECTION |
| N | R | AXIAL LOAD |
| fy | R | YIELD STRESS |
| Mz | R | MOMENT IN ZZ DIRCETION |

## Tabular Form

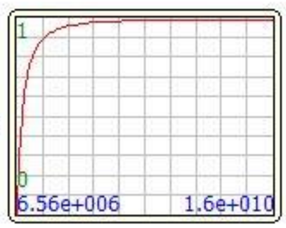
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| R | My | MOMENT IN YY DIRECTION | Lognormal | M | ✓ | $\bar{x}$ c = 7.19e+008 | σ c = 1.4236e+009 |
| R | Mz | MOMENT IN ZZ DIRCETION | Lognormal | M | ✓ | $\bar{x}$ c = 5.681e+007 | σ c = 2.8405e+007 |
| R | N | AXIAL LOAD | Lognormal | M | ✓ | $\bar{x}$ c = 3.537e+006 | σ c = 6.87e+006 |
| R | fy | YIELD STRESS | Normal (Gauss) | M | ✓ | $\bar{x}$ c = 250 | σ c = 21.04 |

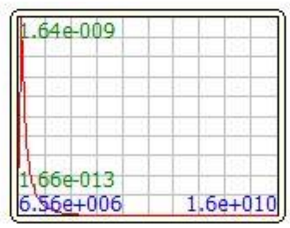
## Graphical Form

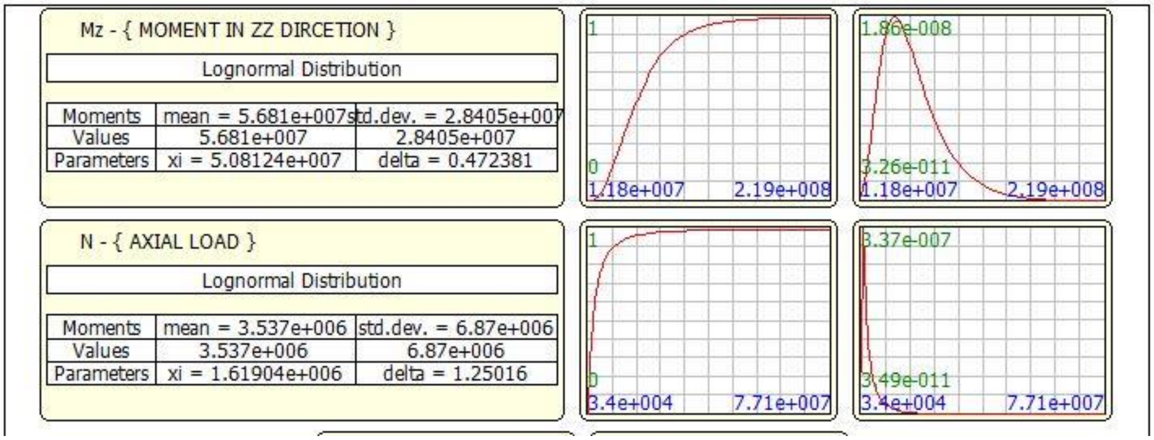
My - { MOMENT IN YY DIRECTION }

Lognormal Distribution

| | | |
|---|---|---|
| Moments | mean = 7.19e+008 | std.dev. = 1.4236e+009 |
| Values | 7.19e+008 | 1.4236e+009 |
| Parameters | xi = 3.24141e+008 | delta = 1.26229 |





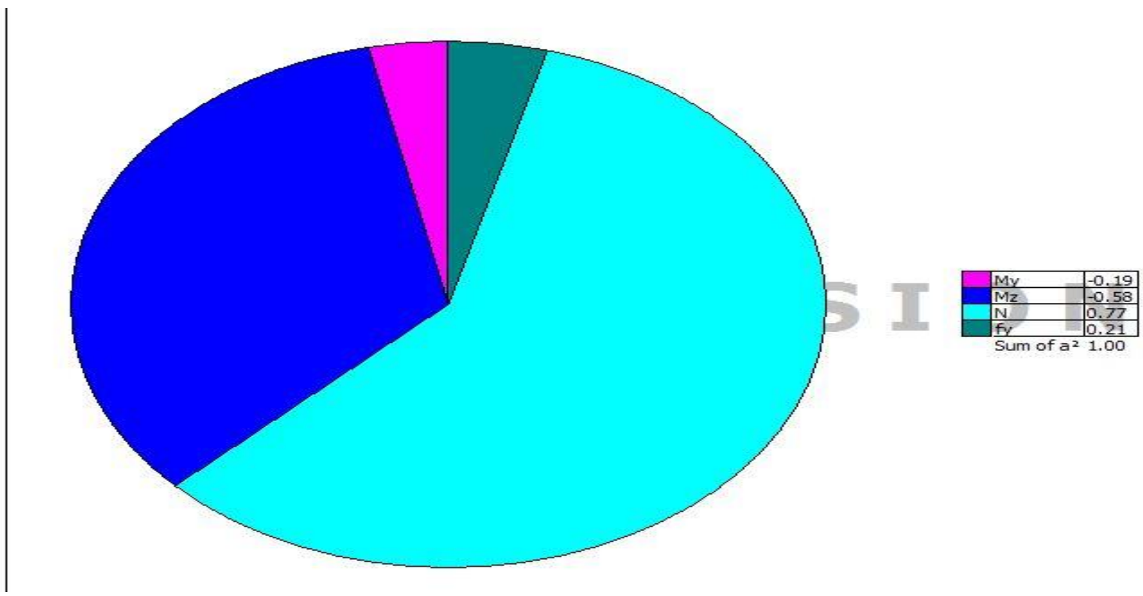
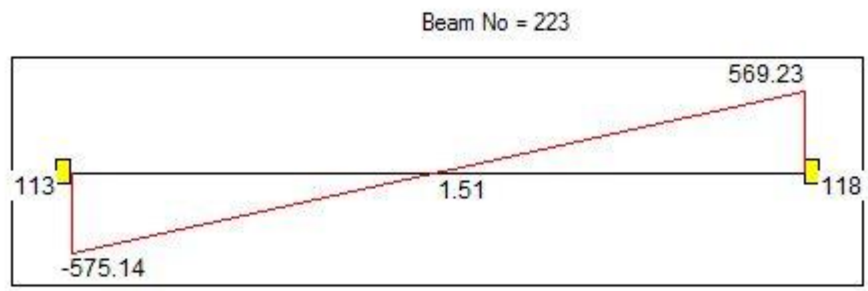
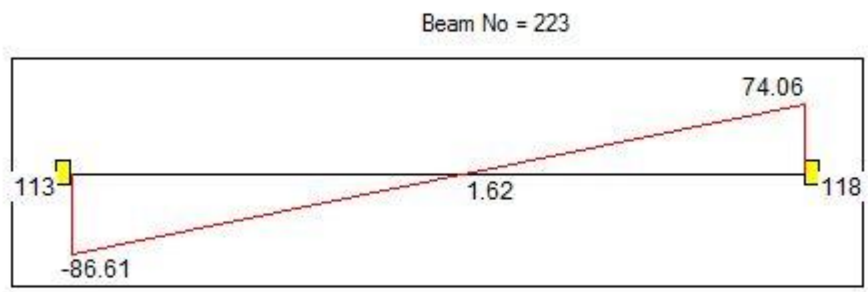




**Fig.13: REPRESENTATIVE ALPHAS FOR THE VARIABLES FOR BEAM NO.41**




**Numerical Results for beam no.223**

--------------------------------------------------------------------------------

Comment : LIMIT STATE EQUATION FOR CENTRAL COLUMN

Transformation type : Rosenblatt

Optimization algorithm: RFLS

--------------------------------------------------------------------------------

--------------------------------------------------------------------------------

Iteration No. 1; CPU-seconds(cumulative): 0.000

Scaled St.F(U) = 0.1091 ; BETA = 0.0000; BETA/||U||= 0.0000

Multipl.= 10.92 ; Step-length= 1.0000; State Func.calls: 6

--------------------------------------------------------------------------------

Iteration No. 2; CPU-seconds(cumulative): 0.000

Scaled St.F(U) = 0.7783E-01; BETA = 2.3370; BETA/||U||= 0.8939

Multipl.= 47.94 ; Step-length= 0.3354; State Func.calls: 12

--------------------------------------------------------------------------------

Iteration No.  3; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.5754E-01; BETA =      2.6142; BETA/||U||=     0.9144

Multipl.=   71.73    ; Step-length=    0.3004; State Func.calls:   18

------------------------------------------------------------------------

Iteration No.  4; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.4369E-01; BETA =      2.8588; BETA/||U||=     0.9282

Multipl.=   102.7    ; Step-length=    0.2743; State Func.calls:   24

------------------------------------------------------------------------

Iteration No.  5; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.3386E-01; BETA =      3.0798; BETA/||U||=     0.9381

Multipl.=   142.1    ; Step-length=    0.2541; State Func.calls:   30

------------------------------------------------------------------------

Iteration No.  6; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.2667E-01; BETA =      3.2831; BETA/||U||=     0.9455

Multipl.=   191.7    ; Step-length=    0.2380; State Func.calls:   36

------------------------------------------------------------------------

Iteration No.  7; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.2129E-01; BETA =      3.4724; BETA/||U||=     0.9512

Multipl.=   253.2    ; Step-length=    0.2249; State Func.calls:   42

------------------------------------------------------------------------

Iteration No.  8; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.1718E-01; BETA =      3.6505; BETA/||U||=     0.9558

Multipl.=   328.9    ; Step-length=    0.2140; State Func.calls:   48

------------------------------------------------------------------------

Iteration No.  9; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.1400E-01; BETA =      3.8192; BETA/||U||=     0.9596

Multipl.=   421.1    ; Step-length=    0.2047; State Func.calls:   54

------------------------------------------------------------------------

Iteration No. 10; CPU-seconds(cumulative):     0.031

Scaled St.F(U) =  0.1149E-01; BETA =      3.9800; BETA/||U||=     0.9627

Multipl.=   532.7    ; Step-length=    0.1967; State Func.calls:   60

------------------------------------------------------------------------

Iteration No. 11; CPU-seconds(cumulative):     0.031

Scaled St.F(U) =  0.9503E-02; BETA =      4.1339; BETA/||U||=     0.9654

Multipl.=   666.8    ; Step-length=    0.1898; State Func.calls:   66

----------------------------------------------------------------------------

Iteration No. 12; CPU-seconds(cumulative):     0.047

Scaled St.F(U) =  0.7904E-02; BETA =      4.2819; BETA/||U||=      0.9677

Multipl.=   826.9    ; Step-length=    0.1838; State Func.calls:   72

----------------------------------------------------------------------------

Iteration No. 13; CPU-seconds(cumulative):     0.047

Scaled St.F(U) =  0.6609E-02; BETA =      4.4245; BETA/||U||=      0.9697

Multipl.=   1017.    ; Step-length=    0.1785; State Func.calls:   78

----------------------------------------------------------------------------

Iteration No. 14; CPU-seconds(cumulative):     0.047

Scaled St.F(U) =  0.5552E-02; BETA =      4.5623; BETA/||U||=      0.9715

Multipl.=   1242.    ; Step-length=    0.1738; State Func.calls:   84

----------------------------------------------------------------------------

Iteration No. 15; CPU-seconds(cumulative):     0.062

Scaled St.F(U) =  0.4683E-02; BETA =      4.6959; BETA/||U||=      0.9730

Multipl.=   1505.    ; Step-length=    0.1697; State Func.calls:   90

----------------------------------------------------------------------------

Iteration No. 16; CPU-seconds(cumulative):     0.078

Scaled St.F(U) =  0.3964E-02; BETA =      4.8254; BETA/||U||=      0.9744

Multipl.=   1814.    ; Step-length=    0.1661; State Func.calls:   96

----------------------------------------------------------------------------

Iteration No. 17; CPU-seconds(cumulative):     0.078

Scaled St.F(U) =  0.3365E-02; BETA =      4.9513; BETA/||U||=      0.9756

Multipl.=   2173.    ; Step-length=    0.1632; State Func.calls:  102

----------------------------------------------------------------------------

Iteration No. 18; CPU-seconds(cumulative):     0.078

Scaled St.F(U) =  0.2862E-02; BETA =      5.0740; BETA/||U||=      0.9767

Multipl.=   2590.    ; Step-length=    0.1609; State Func.calls:  108

----------------------------------------------------------------------------

Iteration No. 19; CPU-seconds(cumulative):     0.078

Scaled St.F(U) =  0.2438E-02; BETA =      5.1936; BETA/||U||=      0.9776

Multipl.=   3071.    ; Step-length=    0.1594; State Func.calls:  114

--------------------------------------------------------------------------

Iteration No. 20; CPU-seconds(cumulative): 0.094

Scaled St.F(U) = 0.2076E-02; BETA = 5.3105; BETA/||U||= 0.9783

Multipl.= 3627. ; Step-length= 0.1591; State Func.calls: 120

--------------------------------------------------------------------------

Iteration No. 21; CPU-seconds(cumulative): 0.094

Scaled St.F(U) = 0.1765E-02; BETA = 5.4254; BETA/||U||= 0.9787

Multipl.= 4267. ; Step-length= 0.1606; State Func.calls: 126

--------------------------------------------------------------------------

Iteration No. 22; CPU-seconds(cumulative): 0.094

Scaled St.F(U) = 0.1493E-02; BETA = 5.5387; BETA/||U||= 0.9788

Multipl.= 5006. ; Step-length= 0.1649; State Func.calls: 132

--------------------------------------------------------------------------

Iteration No. 23; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.1250E-02; BETA = 5.6517; BETA/||U||= 0.9783

Multipl.= 5864. ; Step-length= 0.1748; State Func.calls: 138

--------------------------------------------------------------------------

Iteration No. 24; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.1020E-02; BETA = 5.7663; BETA/||U||= 0.9766

Multipl.= 6879. ; Step-length= 0.1971; State Func.calls: 144

--------------------------------------------------------------------------

Iteration No. 25; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.7729E-03; BETA = 5.8869; BETA/||U||= 0.9712

Multipl.= 8125. ; Step-length= 0.2597; State Func.calls: 150

--------------------------------------------------------------------------

Iteration No. 26; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.3189E-04; BETA = 6.0245; BETA/||U||= 0.9129

Multipl.= 9818. ; Step-length= 1.0000; State Func.calls: 155

--------------------------------------------------------------------------

Iteration No. 27; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = -0.7439E-03; BETA = 5.9512; BETA/||U||= 0.9944

Multipl.= 0.1269E+05; Step-length= 1.0000; State Func.calls: 160

--------------------------------------------------------------------------

Iteration No. 28; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = -0.4532E-03; BETA = 5.9542; BETA/||U||= 1.0022

Multipl.= 1337. ; Step-length= 0.3223; State Func.calls: 166

---------------------------------------------------------------------------

Iteration No. 29; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = -0.2939E-03; BETA = 5.9368; BETA/||U||= 1.0021

Multipl.= 1139. ; Step-length= 0.3299; State Func.calls: 172

---------------------------------------------------------------------------

Iteration No. 30; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = -0.2068E-03; BETA = 5.9237; BETA/||U||= 1.0013

Multipl.= 1071. ; Step-length= 0.2913; State Func.calls: 178

---------------------------------------------------------------------------

Iteration No. 31; CPU-seconds(cumulative): 0.125

Scaled St.F(U) = -0.1090E-03; BETA = 5.9161; BETA/||U||= 1.0015

Multipl.= 1052. ; Step-length= 0.4709; State Func.calls: 184

---------------------------------------------------------------------------

Iteration No. 32; CPU-seconds(cumulative): 0.125

Scaled St.F(U) = -0.2919E-05; BETA = 5.9073; BETA/||U||= 1.0016

Multipl.= 1046. ; Step-length= 1.0000; State Func.calls: 189

---------------------------------------------------------------------------

Iteration No. 33; CPU-seconds(cumulative): 0.125

Scaled St.F(U) = -0.1292E-06; BETA = 5.8975; BETA/||U||= 1.0000

Multipl.= 1073. ; Step-length= 1.0000; State Func.calls: 194

---------------------------------------------------------------------------

Iteration No. 34; CPU-seconds(cumulative): 0.125

Scaled St.F(U) = -0.5771E-09; BETA = 5.8972; BETA/||U||= 1.0000

Multipl.= 1111. ; Step-length= 1.0000; State Func.calls: 199

---------------------------------------------------------------------------

Iteration No. 35; CPU-seconds(cumulative): 0.141

Scaled St.F(U) = -0.4832E-11; BETA = 5.8972; BETA/||U||= 1.0000

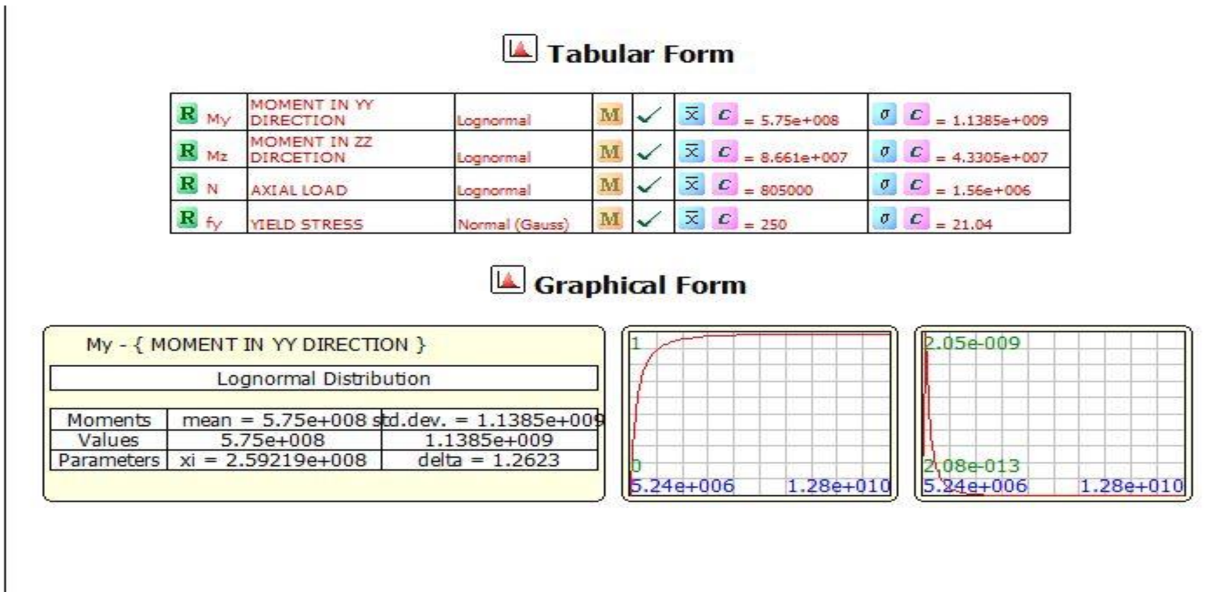
Multipl.= 1113. ; Step-length= 1.0000; State Func.calls: 204

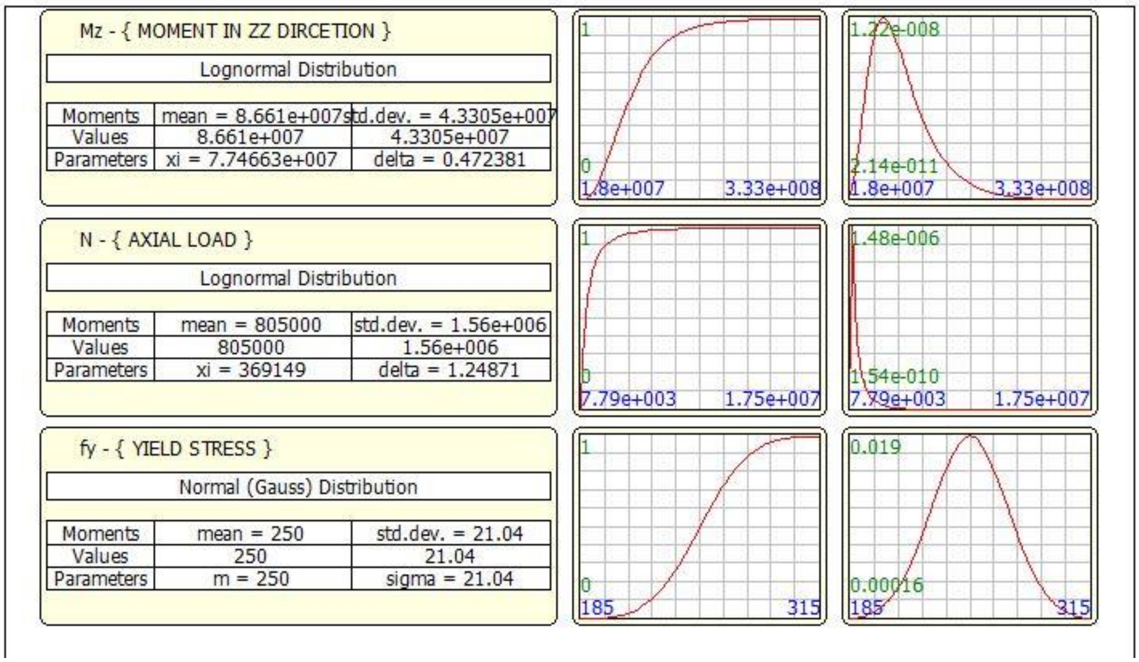
FORM-beta= 5.897; SORM-beta= 5.27 ;beta(Sampling)= -- (IER= 0)

FORM-Pf= 1.85E-09; SORM-Pf=1.24E-09;Pf(Sampling)= --

**TABLE 2: RELIABILITY ANALYSIS FOR BEAM NO.223**

| | | | |
|---|---|---|---|
| FORM-beta | 5.897 | SORM-beta | 5.27 |
| FORM-Pf | 1.85E-09 | SORM-Pf | 1.24E-09 |





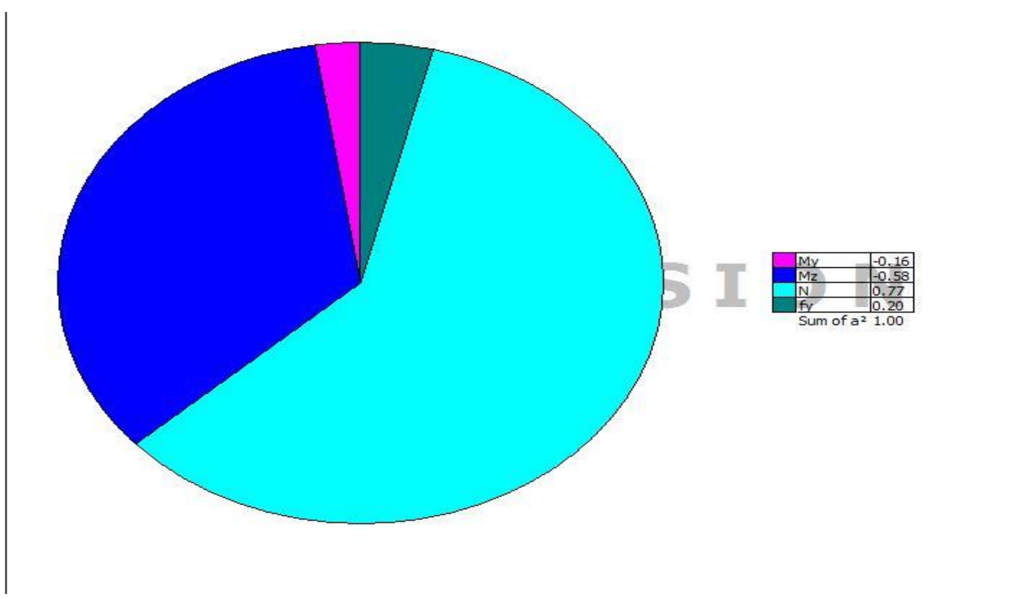
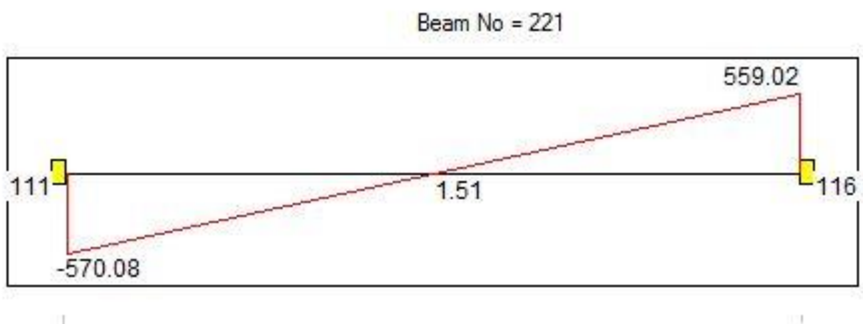
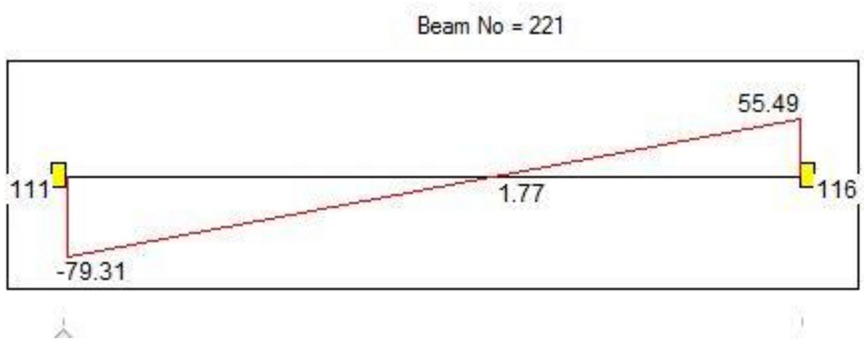




**Fig 14: REPRESENTATIVE ALPHAS FOR THE VARIABLES FOR BEAM NO.223**




**Numerical Results for beam no. 221**

Comment : LIMIT STATE EQUATION FOR CORNER CENTRAL COLUMN

Transformation type : Rosenblatt

Optimization algorithm: RFLS

**------------------------------------------------------------------------------**

Iteration No. 1; CPU-seconds(cumulative): 0.000

Scaled St.F(U) = 0.3197E-01; BETA = 0.0000; BETA/||U||= 0.0000

Multipl.= 24.28 ; Step-length= 1.0000; State Func.calls: 6

------------------------------------------------------------------------------

Iteration No. 2; CPU-seconds(cumulative): 0.000

Scaled St.F(U) = 0.2537E-01; BETA = 3.4838; BETA/||U||= 0.9498

Multipl.= 213.4 ; Step-length= 0.2305; State Func.calls: 12

------------------------------------------------------------------------------

Iteration No.  3; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.2039E-01; BETA =      3.6673; BETA/||U||=      0.9549

Multipl.=   278.9    ; Step-length=    0.2181; State Func.calls:   18

---------------------------------------------------------------------------

Iteration No.  4; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.1656E-01; BETA =      3.8402; BETA/||U||=      0.9590

Multipl.=   358.8    ; Step-length=    0.2077; State Func.calls:   24

---------------------------------------------------------------------------

Iteration No.  5; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.1357E-01; BETA =      4.0042; BETA/||U||=      0.9623

Multipl.=   455.6    ; Step-length=    0.1990; State Func.calls:   30

---------------------------------------------------------------------------

Iteration No.  6; CPU-seconds(cumulative):     0.000

Scaled St.F(U) =  0.1120E-01; BETA =      4.1608; BETA/||U||=      0.9651

Multipl.=   572.1    ; Step-length=    0.1914; State Func.calls:   36

---------------------------------------------------------------------------

Iteration No.  7; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.9308E-02; BETA =      4.3110; BETA/||U||=      0.9675

Multipl.=   711.4    ; Step-length=    0.1849; State Func.calls:   42

---------------------------------------------------------------------------

Iteration No.  8; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.7778E-02; BETA =      4.4555; BETA/||U||=      0.9696

Multipl.=   877.0    ; Step-length=    0.1791; State Func.calls:   48

---------------------------------------------------------------------------

Iteration No.  9; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.6533E-02; BETA =      4.5951; BETA/||U||=      0.9714

Multipl.=   1073.    ; Step-length=    0.1741; State Func.calls:   54

---------------------------------------------------------------------------

Iteration No. 10; CPU-seconds(cumulative):     0.016

Scaled St.F(U) =  0.5512E-02; BETA =      4.7302; BETA/||U||=      0.9730

Multipl.=   1304.    ; Step-length=    0.1695; State Func.calls:   60

---------------------------------------------------------------------------

Iteration No. 11; CPU-seconds(cumulative): 0.016

Scaled St.F(U) = 0.4670E-02; BETA = 4.8612; BETA/||U||= 0.9744

Multipl.= 1574. ; Step-length= 0.1655; State Func.calls: 66

---------------------------------------------------------------------------

Iteration No. 12; CPU-seconds(cumulative): 0.031

Scaled St.F(U) = 0.3969E-02; BETA = 4.9885; BETA/||U||= 0.9757

Multipl.= 1890. ; Step-length= 0.1620; State Func.calls: 72

---------------------------------------------------------------------------

Iteration No. 13; CPU-seconds(cumulative): 0.047

Scaled St.F(U) = 0.3385E-02; BETA = 5.1124; BETA/||U||= 0.9768

Multipl.= 2257. ; Step-length= 0.1589; State Func.calls: 78

---------------------------------------------------------------------------

Iteration No. 14; CPU-seconds(cumulative): 0.047

Scaled St.F(U) = 0.2893E-02; BETA = 5.2332; BETA/||U||= 0.9778

Multipl.= 2681. ; Step-length= 0.1562; State Func.calls: 84

---------------------------------------------------------------------------

Iteration No. 15; CPU-seconds(cumulative): 0.062

Scaled St.F(U) = 0.2478E-02; BETA = 5.3510; BETA/||U||= 0.9787

Multipl.= 3172. ; Step-length= 0.1541; State Func.calls: 90

---------------------------------------------------------------------------

Iteration No. 16; CPU-seconds(cumulative): 0.062

Scaled St.F(U) = 0.2125E-02; BETA = 5.4663; BETA/||U||= 0.9794

Multipl.= 3736. ; Step-length= 0.1527; State Func.calls: 96

---------------------------------------------------------------------------

Iteration No. 17; CPU-seconds(cumulative): 0.062

Scaled St.F(U) = 0.1824E-02; BETA = 5.5791; BETA/||U||= 0.9801

Multipl.= 4384. ; Step-length= 0.1521; State Func.calls: 102

---------------------------------------------------------------------------

Iteration No. 18; CPU-seconds(cumulative): 0.062

Scaled St.F(U) = 0.1563E-02; BETA = 5.6900; BETA/||U||= 0.9805

Multipl.= 5127. ; Step-length= 0.1527; State Func.calls: 108

---------------------------------------------------------------------------

Iteration No. 19; CPU-seconds(cumulative): 0.078

Scaled St.F(U) = 0.1336E-02; BETA = 5.7994; BETA/||U||= 0.9807

Multipl.= 5980. ; Step-length= 0.1553; State Func.calls: 114

---------------------------------------------------------------------------

Iteration No. 20; CPU-seconds(cumulative): 0.078

Scaled St.F(U) = 0.1134E-02; BETA = 5.9081; BETA/||U||= 0.9806

Multipl.= 6964. ; Step-length= 0.1613; State Func.calls: 120

---------------------------------------------------------------------------

Iteration No. 21; CPU-seconds(cumulative): 0.094

Scaled St.F(U) = 0.9497E-03; BETA = 6.0174; BETA/||U||= 0.9797

Multipl.= 8110. ; Step-length= 0.1739; State Func.calls: 126

---------------------------------------------------------------------------

Iteration No. 22; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.7695E-03; BETA = 6.1296; BETA/||U||= 0.9773

Multipl.= 9477. ; Step-length= 0.2029; State Func.calls: 132

---------------------------------------------------------------------------

Iteration No. 23; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.5586E-03; BETA = 6.2504; BETA/||U||= 0.9698

Multipl.= 0.1119E+05; Step-length= 0.2940; State Func.calls: 138

---------------------------------------------------------------------------

Iteration No. 24; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = -0.4994E-04; BETA = 6.3950; BETA/||U||= 0.9208

Multipl.= 0.1368E+05; Step-length= 1.0000; State Func.calls: 143

---------------------------------------------------------------------------

Iteration No. 25; CPU-seconds(cumulative): 0.109

Scaled St.F(U) = 0.6012E-05; BETA = 6.0935; BETA/||U||= 0.9346

Multipl.= 0.1470E+05; Step-length= 0.2901; State Func.calls: 149

---------------------------------------------------------------------------

Iteration No. 26; CPU-seconds(cumulative): 0.125

Scaled St.F(U) = -0.9479E-04; BETA = 6.1850; BETA/||U||= 0.9995

Multipl.= 6843. ; Step-length= 1.0000; State Func.calls: 154

---------------------------------------------------------------------------

Iteration No. 27; CPU-seconds(cumulative): 0.141

Scaled St.F(U) = 0.7100E-05; BETA = 6.1872; BETA/||U||= 1.0016

Multipl.= 1324. ; Step-length= 1.0000; State Func.calls: 159

---------------------------------------------------------------------------

Iteration No. 28; CPU-seconds(cumulative): 0.141

Scaled St.F(U) = 0.2443E-06; BETA = 6.1768; BETA/||U||= 0.9999

Multipl.= 1220. ; Step-length= 1.0000; State Func.calls: 164

---------------------------------------------------------------------------

Iteration No. 29; CPU-seconds(cumulative): 0.141

Scaled St.F(U) = -0.1179E-08; BETA = 6.1775; BETA/||U||= 1.0000

Multipl.= 1270. ; Step-length= 1.0000; State Func.calls: 169

---------------------------------------------------------------------------

Iteration No. 30; CPU-seconds(cumulative): 0.156

Scaled St.F(U) = -0.3873E-10; BETA = 6.1776; BETA/||U||= 1.0000

Multipl.= 1267. ; Step-length= 1.0000; State Func.calls: 174

FORM-beta= 5.178; SORM-beta= 4.98

FORM-Pf= 3.27E-7; SORM-Pf= 3.07E-7

Reliability analysis is finished

**TABLE 3: RELIABILITY ANALYSIS FOR BEAM NO.221**

| | | | |
|---|---|---|---|
| FORM-beta | 5.178 | SORM-beta | 4.98 |
| FORM-Pf | 3.27E-7 | SORM-Pf | 3.07E-7 |

## Tabular Form

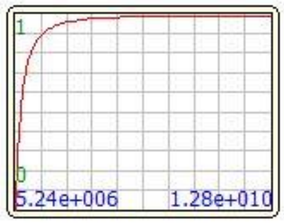
| | | | | | | |
|---|---|---|---|---|---|---|
| R My | MOMENT IN YY DIRECTION | Lognormal | M | ✓ | $\bar{x}$ = 5.75e+008 | σ = 1.1385e+009 |
| R Mz | MOMENT IN ZZ DIRCETION | Lognormal | M | ✓ | $\bar{x}$ = 7.931e+007 | σ = 3.96e+007 |
| R N | AXIAL LOAD | Lognormal | M | ✓ | $\bar{x}$ = 1.058e+006 | σ = 2.05e+006 |
| R fy | YIELD STRESS | Normal (Gauss) | M | ✓ | $\bar{x}$ = 250 | σ = 21.04 |

## Graphical Form

My - { MOMENT IN YY DIRECTION }

Lognormal Distribution

| | | |
|---|---|---|
| Moments | mean = 5.75e+008 | std.dev. = 1.1385e+009 |
| Values | 5.75e+008 | 1.1385e+009 |
| Parameters | xi = 2.59219e+008 | delta = 1.2623 |

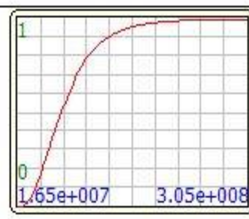


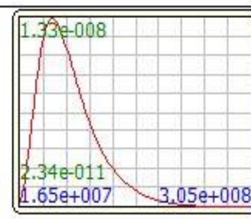


Mz - { MOMENT IN ZZ DIRCETION }

Lognormal Distribution

| | | |
|---|---|---|
| Moments | mean = 7.931e+007 | std.dev. = 3.96e+007 |
| Values | 7.931e+007 | 3.96e+007 |
| Parameters | xi = 7.09567e+007 | delta = 0.471793 |

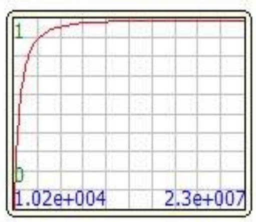



N - { AXIAL LOAD }

Lognormal Distribution

| | | |
|---|---|---|
| Moments | mean = 1.058e+006 | std.dev. = 2.05e+006 |
| Values | 1.058e+006 | 2.05e+006 |
| Parameters | xi = 485221 | delta = 1.24862 |

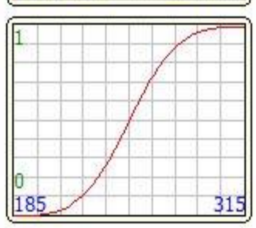


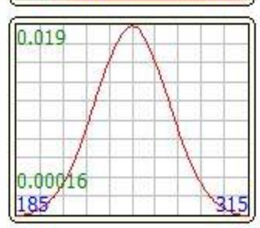


fy - { YIELD STRESS }

Normal (Gauss) Distribution

| | | |
|---|---|---|
| Moments | mean = 250 | std.dev. = 21.04 |
| Values | 250 | 21.04 |
| Parameters | m = 250 | sigma = 21.04 |



# CONCLUSION

The objective of the project to determine the reliability of the corner column, middle corner column and central column for a G+8 building was successfully conducted. The important conclusive points are discussed below-:

1. There is an inclusion of approximate methods (first order reliability methods and second order reliability methods i.e. FORM AND SORM methods) in the project, which have an advantage of being simple in nature and their computation takes lesser time.
2. Response surface methods have been introduced that includes the basic theory and there is a simplification for complex systems through repetitive solution methods.
3. The reliability index method proposed by Hasofer and Lind accounts for the drawbacks of MVFOSM.
4. The method has the potential to greatly reduce the risk factor involved in the designing leading to the larger life expectancy of the structure.
5. The methods used are capable of producing the complete sensitive analysis that are capable of accounting any random variation in the parametric analysis.
6. The local estimate of reliability through FORM gets verified by SORM at a single point of design which further by method of simulation is used to determine the reliability globally at multiple points of design.
7. The method proposed is one of the advanced method so as to determine the probability of failure of a structure or building components.
8. The method proposed by Hasofer and Lind accounts for the drawbacks of MVFOSM.

# STAAD PRO ANALYSIS

## TABLE 4: STAAD ANALYSIS FOR BEAM NO.41

| MEMBER | LOAD | JT | AXIAL | SHEAR-Y | | SHEAR-Z | TORSION | MOM-Y | MOM-Z |
|---|---|---|---|---|---|---|---|---|---|
| 41 | 1 | 1 | -246.87 | 28.35 | | -0.93 | 0 | 0.92 | 55.64 |
| | | 6 | 246.87 | -28.35 | | 0.93 | 0 | 1.86 | 29.42 |
| | 2 | 1 | -324 | 4.97 | | -34.64 | 0 | 53.7 | 4.27 |
| | | 6 | 324 | -4.97 | | 34.64 | 0 | 50.23 | 10.64 |
| | 3 | 1 | 1016.78 | -15.97 | | 109.7 | 0 | -169.36 | -13.77 |
| | | 6 | -1014.22 | 15.97 | | -109.7 | 0 | -159.74 | -34.15 |
| | 4 | 1 | 1064.16 | -22.8 | | 164.08 | 0 | -253.58 | -19.64 |
| | | 6 | -1064.16 | 22.8 | | -164.08 | 0 | -238.67 | -48.75 |
| | 5 | ***1*** | ***3537.6*** | ***-65.92*** | | ***465.43*** | ***0*** | ***-719*** | ***-56.81*** |
| | | ***6*** | ***-3533.25*** | ***65.92*** | | ***-465.43*** | ***0*** | ***-677.3*** | ***-140.94*** |
| | 6 | 1 | 1308.84 | 21.04 | | 184.91 | 0 | -286.34 | 71.17 |
| | | 6 | -1304.49 | -21.04 | | -184.91 | 0 | -268.39 | -8.06 |
| | 7 | 1 | 1177.72 | -18.71 | | 127.6 | 0 | -196.62 | -16.16 |
| | | 6 | -1173.37 | 18.71 | | -127.6 | 0 | -186.16 | -39.98 |
| | 8 | 1 | 2148.21 | -75.35 | | 188.07 | 0 | -289.48 | -117.99 |
| | | 6 | -2143.86 | 75.35 | | -188.07 | 0 | -274.73 | -108.07 |
| | 9 | 1 | 2279.33 | -35.6 | | 245.39 | 0 | -379.2 | -30.66 |
| | | 6 | -2274.99 | 35.6 | | -245.39 | 0 | -356.96 | -76.15 |
| | 10 | 1 | 2384.29 | -13.55 | | 354.71 | 0 | -548.62 | 28.89 |
| | | 6 | -2380.96 | 13.55 | | -354.71 | 0 | -515.51 | -69.54 |
| | 11 | 1 | 2284.02 | -43.95 | | 310.88 | 0 | -480.01 | -37.89 |
| | | 6 | -2280.69 | 43.95 | | -310.88 | 0 | -452.63 | -93.95 |
| | 12 | 1 | 3026.16 | -87.26 | | 357.13 | 0 | -551.02 | -115.77 |
| | | 6 | -3022.83 | 87.26 | | -357.13 | 0 | -520.36 | -146.02 |
| | 13 | 1 | 3126.43 | -56.86 | | 400.96 | 0 | -619.63 | -48.99 |
| | | 6 | -3123.11 | 56.86 | | -400.96 | 0 | -583.24 | -121.61 |

MOST CRITICAL LOAD → 5

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 14 | 1 | 1728.53 | -27.16 | | 186.49 | 0 | -287.91 | -23.41 |
| | | 6 | -1724.18 | 27.16 | | -186.49 | 0 | -271.56 | -58.06 |
| | 15 | 1 | 2705.23 | -50.41 | | 355.92 | 0 | -549.82 | -43.44 |
| | | 6 | -2701.9 | 50.41 | | -355.92 | 0 | -517.94 | -107.78 |

## TABLE 5: STAAD ANALYSIS FOR BEAM NO.223

| MEMBER | LOAD | JOINT | AXIAL | Fy | Fz | Tz | My | Mz |
|---|---|---|---|---|---|---|---|---|
| **223** | **1** | **113** | **0** | **41.2** | **0** | **0** | **0** | **66.62** |
| | | 118 | 0 | -41.2 | 0 | 0 | 0 | 56.97 |
| | 2 | 113 | 0 | 0 | -37.45 | 0 | 56.47 | 0 |
| | | 118 | 0 | 0 | 37.45 | 0 | 55.86 | 0 |
| | 3 | 113 | 619.53 | 0 | 117.37 | 0 | -176.97 | 0 |
| | | 118 | -616.97 | 0 | -117.37 | 0 | -175.15 | 0 |
| | 4 | 113 | 0 | 0 | 176.06 | 0 | -265.45 | 0 |
| | | 118 | 0 | 0 | -176.06 | 0 | -262.72 | 0 |
| | 5 | 113 | 1053.2 | 0 | 498.83 | 0 | -752.11 | 0 |
| | | 118 | -1048.85 | 0 | -498.83 | 0 | -744.38 | 0 |
| | 6 | 113 | 1053.2 | 70.04 | 199.53 | 0 | -300.84 | 113.26 |
| | | 118 | -1048.85 | -70.04 | -199.53 | 0 | -297.75 | 96.85 |
| | 7 | 113 | 1053.2 | 0 | 135.87 | 0 | -204.84 | 0 |
| | | 118 | -1048.85 | 0 | -135.87 | 0 | -202.78 | 0 |
| | 8 | 113 | 1053.2 | -70.04 | 199.53 | 0 | -300.84 | -113.26 |
| | | 118 | -1048.85 | 70.04 | -199.53 | 0 | -297.75 | -96.85 |
| | 9 | 113 | 1053.2 | 0 | 263.19 | 0 | -396.85 | 0 |
| | | 118 | -1048.85 | 0 | -263.19 | 0 | -392.72 | 0 |
| MOST CRICAL LOAD | 10 | 113 | 805.39 | 53.56 | 381.46 | 0 | -575.14 | 86.61 |
| | | 118 | -802.06 | -53.56 | -381.46 | 0 | -569.23 | 74.06 |
| | 11 | 113 | 805.39 | 0 | 332.78 | 0 | -501.72 | 0 |
| | | 118 | -802.06 | 0 | -332.78 | 0 | -496.61 | 0 |
| | 12 | 113 | 805.39 | -53.56 | 381.46 | 0 | -575.14 | -86.61 |
| | | 118 | -802.06 | 53.56 | -381.46 | 0 | -569.23 | -74.06 |
| | 13 | 113 | 805.39 | 0 | 430.14 | 0 | -648.56 | 0 |
| | | 118 | -802.06 | 0 | -430.14 | 0 | -641.86 | 0 |
| | 14 | 113 | 1053.2 | 0 | 199.53 | 0 | -300.84 | 0 |
| | | 118 | -1048.85 | 0 | -199.53 | 0 | -297.75 | 0 |
| | 15 | 113 | 805.39 | 0 | 381.46 | 0 | -575.14 | 0 |
| | | 118 | -802.06 | 0 | -381.46 | 0 | -569.23 | 0 |

# TABLE 6: STAAD ANALYSIS FOR BEAM NO.221

| MEMBER | LOAD | JOINT | AXIAL- | Fy | FZ | Tz | My | Mz |
|---|---|---|---|---|---|---|---|---|
| **221** | **1** | **111** | **321.06** | **33.35** | **0** | **0** | **0** | **59.97** |
| | | 116 | 321.06 | -33.35 | 0 | 0 | 0 | 40.08 |
| | 2 | 111 | 0 | 0 | -36.93 | 0 | 55.96 | 0 |
| | | 116 | 0 | 0 | 36.93 | 0 | 54.82 | 0 |
| | 3 | 111 | 492.93 | -1.21 | 115.81 | 0 | -175.41 | -1.04 |
| | | 116 | -490.37 | 1.21 | -115.81 | 0 | -172.01 | -2.6 |
| | 4 | 111 | 0 | 0 | 173.71 | 0 | -263.11 | 0 |
| | | 116 | 0 | 0 | -173.71 | 0 | -258.01 | 0 |
| | 5 | 111 | 837.98 | -2.06 | 492.17 | 0 | -745.49 | -1.77 |
| | | 116 | -833.63 | 2.06 | -492.17 | 0 | -731.03 | -4.42 |
| | 6 | 111 | 292.17 | 54.63 | 196.87 | 0 | -298.2 | 100.17 |
| | | 116 | -287.82 | -54.63 | -196.87 | 0 | -292.41 | 63.72 |
| | 7 | 111 | 837.98 | -2.06 | 134.09 | 0 | -203.06 | -1.77 |
| | | 116 | -833.63 | 2.06 | -134.09 | 0 | -199.21 | -4.42 |
| | 8 | 111 | 1383.79 | -58.76 | 196.87 | 0 | -298.2 | -103.72 |
| | | 116 | -1379.44 | 58.76 | -196.87 | 0 | -292.41 | -72.56 |
| | 9 | 111 | 837.98 | -2.06 | 259.65 | 0 | -393.33 | -1.77 |
| | | 116 | -833.63 | 2.06 | -259.65 | 0 | -385.61 | -4.42 |
| | 10 | 111 | 223.43 | 41.78 | 376.37 | 0 | -570.08 | 76.6 |
| | | 116 | -220.1 | -41.78 | -376.37 | 0 | -559.02 | 48.72 |
| | 11 | 111 | 640.81 | -1.58 | 328.36 | 0 | -497.33 | -1.35 |
| | | 116 | -637.48 | 1.58 | -328.36 | 0 | -487.75 | -3.38 |
| | 12 | 111 | 1058.19 | -44.93 | 376.37 | 0 | -570.08 | -79.31 |
| | | 116 | -1054.87 | 44.93 | -376.37 | 0 | -559.02 | -55.49 |
| | 13 | 111 | 640.81 | -1.58 | 424.37 | 0 | -642.83 | -1.35 |
| | | 116 | -637.48 | 1.58 | -424.37 | 0 | -630.29 | -3.38 |
| | 14 | 111 | 837.98 | -2.06 | 196.87 | 0 | -298.2 | -1.77 |
| | | 116 | -833.63 | 2.06 | -196.87 | 0 | -292.41 | -4.42 |
| | 15 | 111 | 640.81 | -1.58 | 376.37 | 0 | -570.08 | -1.35 |
| | | 116 | -637.48 | 1.58 | -376.37 | 0 | -559.02 | -3.38 |

MOST CRICAL LOAD → 12

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