Reliability Based Approach To Study The Critical Failure Path Of Truss Structures

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STRUCTURAL REPAIR AND RETROFIT ENGINEERING

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CERTIFICATE OF RECOMMENDATIONS

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This is to certify that the thesis entitled "**Reliability Based Approach to Study the Critical Failure Path of Truss Structures."** has been prepared by **Chandan Karmakar** (Class Roll No:-**001610602010**, Examination Roll No: - **M6CNE19010**, Reg. No:-**76523 of 2000-2001**) for partial fulfillment of the requirement for the award of **Master Degree in Construction Engineering (MCE)** with specialization in **Structural Repair & Retrofit Engineering**, is a record of research work carried out under my Guidance and Supervision. I hereby approve this thesis for submission and presentation.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approval the undersigned do not endorse or approve any settlement made, opinion expressed or conclusion drawn therein but approved the thesis only for the purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

It is hereby declared that the thesis entitled "**Reliability Based Approach to Study the Critical Failure Path of Truss Structures."** Contains literature survey and original research work done by the undersigned candidate and have been submitted for partial fulfillment of the continuous assessment of the course of **Master of Construction Engineering** with specialization in " **Structural Repair and Retrofit Engineering**" under Jadavpur University.

All information in the document have been obtained and presented in accordance with academic rules and ethical conduct.

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ABSTRACT

Structural design parameters are random in nature to various extents. Deterministic method not able to address the randomness of these parameters related to material property (yield stress, modulus of elasticity etc), geometrical property (element's c/s area, moment of inertia section modulus etc) and loads. Subsequently Limit State Method considered the probabilistic approach considering the randomness of these design parameters. However, the effect of these parameters is not able to address the safety of the structure in a component level.

Reliability based approach may address the safety of the element in a much better quantative manner. Even in case of indeterminate truss the sequence of elemental failure i.e critical failure path seems to be significantly important from safety aspect and timely intervention for retrofit. Many times unnecessary expenditure is incurred for overall retrofit. Reliability estimation and subsequent detection of critical element provides direction towards better retrofit.

Therefore the objective of study is to reliability estimation of the structural elements of the truss. Reliability estimation of truss has been made in terms of evaluation of reliability indices both at the component level as well as at the system level. Evaluation of critical failure path of the truss is also attempted based on reliability approach. A generalised code in MATLAB platform for linear elastic analysis with incremental loads and subsequent estimation of reliability indices of truss element at component level and system level is developed. Based on this reliability approach the focus is to detect the truss element which is more vulnerable against failure. Reliability estimation with variation of cross sectional area of one critical element is also studied. Detection of subsequent critical elements based on abruptly declined reliability indices is also studied. A nominal 20% of initial value of "E" is designated to indicate the failure element.

A target reliability index is considered for the initial design parameter by trial and error estimation.

One statically determinate truss and one indeterminate truss are considered for reliability estimation at component level as well as system level. Determination of critical failure path for another indeterminate truss is also considered based on reliability analysis.

It is noted that reliability index gradually reduces with the failure of different critical elements. However, more study is required to sustain a generalised critical failure path.

Keywords: Randomness, Reliability Index, critical failure path.

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Abbreviations:

CDF: Cumulative Distribution Function

FEM: Finite Element Methods

FOSM: First Order Second Moment

LSF: Limit State Function

PDF: Probability Density Function

RI: Reliability Index

DL: Dead Load

LL: Live Load

WL: Wind Load.

COV: Coefficient of Variance

Nomenclature

= Reliability Index

P_f = Probability of Failure

A_i = Cross Sectional area of the ith truss element.

a_{ij} = Coefficient of influence on member end forces of the ith truss elements against nodal force acting at jth node.

a_{ij}^{p} = Coefficient of influence on member end forces of the ith truss elements due to failure of element p.

C=Covariance Matrix

R_i = Resistance of the ith element

S_i = Load Effect of the ith element

G/M= Performance Function.

X_i = ith variable.

«$_R$ = Mean of Resistance

±$_R$ = Standard Deviation of resistance.

«$_{S_j}$ = Mean of nodal load acting at jth node.

F_{X_i} = Cumulative distribution function of random variable X_i

¤$_n$ = Multivariate Normal Distribution Function

¨$_X$ = Cumulative Distribution function of random variable X

°$_{XY}$ = Correlation coefficient between variables X and Y.

Z_i = Transformation/ Reduced form of variable X_i .

{G}= Vector of partial derivative of LSF w.r.t reduced variates.

$\{\sim\}$ =Vector of sensitivity factors.

Z^* = Vector of reduced variates.

$_s$ = System Reliability.

D=Design Vector.

E_i =Modulus of elasticity of the ith member.

$f_y =$ Yield Stress.

¡ = Stress Reduction Factor for compression member.

$\{k_i\}$ =Elemental Stiffness Matrix of ith element.

L_j =External load applied to the structure (j = 1,2, ... , 3l)

$\bar{\bar{K}}_i$ =Global Stiffness Matrix.

$\bar{T}_i$ =Transformation Matrix.

$\bar{d}_i$ =Displacement vector of the ith member w.r.t global coordinate system.

$\bar{X}_i$ =Nodal force vector of the ith member w.r.t global coordinate system.

n=Number of members

l=Number of nodes

l_i =Length of the ith member

$\bar{x}_i$ = Nodal force vector of the ith member in local coordinate system.

$\bar{¢}_i$ =Displacement of ith member in local coordinate system.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The main objective of structural engineering is to design a safe structure and that has to perform well within its design life. While designing any structural element that has to satisfy certain criteria under applied load otherwise structural component will be considered as in failure state. The response of the structure i.e member end forces, displacements are the function of applied load, structural strength and stiffness. In structural design, the supply can be expressed in terms of resistance, capacity or strength of the member and demand can be expressed in terms of applied load, load combination and their effect. In case of truss type structure the basic resistance parameters of an element are the permissible axial capacity in tension or compression whereas demand of an element may be expressed as the member internal force in tension or compression. From nodal deflection point of view, the capacity may be expressed as the maximum allowable deflection and demand may be defined as the deformation of the node due to load effect.

The aim of structural engineer is to design the structure in most economical and optimal way so that the structure should satisfy all performance requirements within its design life. But analysis and design based on deterministic approach fails to address the randomness of the design parameters. Since most of the design parameters involved in the design are probabilistic in nature. The uncertainties includes randomness of load, material properties (e.g Young Modulus, Yield stress, permissible buckling stress etc), geometrical properties(c/s area, length , moment of inertia, section modulus etc), uncertainties of theoretical models due to the simplification of actual condition, etc. In case of limit state method of structural design, partial safety factors are applied in load and resistance parameters i.e some probabilistic approach is applied only in load and resistance parameters. Therefore it is important to perform full reliability analysis of structure both in component level as well as system level to take into account the uncertainties involved in structural analysis and design. Truss type structure will be selected due to simplicity in analysis and widely used in the industry

In case of truss type structures the basic random variables are the nodal loads which may be dead load, live load, wind load and various combination of loads i.e (DL+LL), (DL+WL) and load effect i.e internal force/ stress (tensile or compressive according to type of loading condition) of the truss member. Geometrical property of the truss element i.e cross sectional area, length, sectional modulus, moment of inertia, Mechanical property i.e Young Modulus “E”, Yield stress, tensile capacity, compression capacity , load vs. deformation characteristics are also considered as the random variable. Structural support restrained may also be considered as random variable.

There are many modes of failure in structural system since the structural elements may experience various types of failure depending of structural configuration; loading condition etc.it is not easy to find out the failure of structure composed of many elements. The failure mode of truss element for ultimate limit states of collapse are axial tension or compression failure.i.e only two failure modes has to be considered against ultimate limit states. In case of truss type structure, the loads (random variable) are applied at the nodes and as a load effect; internal stresses which are also a random variable (compressive or tensile according to various types of load and their combination) are developed in the truss elements.

1.2 OBJECTIVE OF THE PRESENT WORK:

The objective of this thesis is to reliability estimation of the truss structures in terms of evaluation of reliability indices both at the component level as well as at the system level. Using reliability based approach; evaluation of critical failure path of the truss structure is also the objective of thesis work. Development of a generalised code in MATLAB platform for linear elastic analysis with incremental loads and subsequent estimation of reliability indices of truss element at component level and system level is also the objective of thesis work.

1.3 SCOPE OF WORK:

The thesis focused on complete structural reliability analysis of statically determinate and statically indeterminate truss structure. First order second moment (FORM) is used to determine the component reliability of all truss structural elements. By estimation of the reliability index at the elemental level, the probable critical failure path may be possible to determine by making proper algorithm.

Following methodology will be considered for reliability analysis of truss.

1. Development of Numerical Model of selected Truss structure.

2. Consideration of Probability Density Function (PDF) of capacity and demand related parameters. (Here all random variables are considered as normally distributed)
3. Calculation for of internal forces of elements due for various types of loading based on finite element method with incremental loading and subsequent development of their statistical model.
4. Development of Limit state functions for the truss elements.
5. Estimation of the safety margin & determination of reliability index for each element.
6. Estimation of the system reliability based on the critical load path.

This study is limited to truss structures where all the connections are assumed to be hinged. This means the members of the truss act as bar elements which can only carry axial loads either in tension or compression. Truss structures were selected for the following reasons:

1. Truss structures are simpler in terms of analysis, and in case of ultimate limit states of collapse only compression and tension failure modes of each truss element are to be considered.
2. Truss type structure is widely used in construction of bridges, towers etc. Therefore reliability-based assessment of these structures is essential to judge their safety. The reliability-based analysis of truss structure is also utilised for optimization of the structural element.

The aims of the thesis can be outlined as stated below:

1. Development of generalised code in MATLAB platform for linear elastic analysis with incremental loads.
2. Component level reliability analysis of statically determinate and indeterminate truss structures addressing all dominant limit state functions. Methods like FORM are used in that case.
3. System level reliability analysis (upto level 1) of statically determinate and indeterminate truss structures by -unzipping method.
4. Detection of critical failure path of the truss structure based on reliability approach.
5. Observations of changes of reliability indices of the truss elements due randomness of cross sectional area of critical truss element and reduction of the modulus of elasticity values of the critical failure element to 20% of initial value of “E” which is designated to indicate the failure element.

Chapter 2

LITERATURE REVIEW

2.0 GENERAL:

Reliability based analysis and design of structure is essential for properly handle the uncertainties presents in the consideration of loads, material strength, geometrical properties of structural elements and other matters. Therefore reliability based structural design is increasing interest among the structural engineers. In this chapter review of relevant literature on reliability based analysis of truss structures have been presented.

Y.Murotsu, H.Okada, K.Niwa, S.Miwa (1980) [1] Proposed method of systematically generating the failure criteria of truss structure using Matrix Method. They proposed failure criteria of both statically determinate and indeterminate truss. The failure criterion for statically determinate truss is very simple and probability of failure can easily determine. For statically indeterminate truss there are many possible modes or path to complete failure of structure. The failure probability is estimated by evaluating lower and upper bounds. The lower bounds is evaluated by selecting the dominant modes of failure and calculating their failure probabilities and upper bound is evaluated by assuming that the redundant truss behaves itself like a statically determinate truss. In determinate structures there are fairly narrow except when the failure probabilities are presumed to be very low which will be good estimation of the failure probabilities. They also proposed formation of limit state equation for different modes of failure.

In the conclusion they stated that, they proposed systematic method for generation of failure criteria of the statically determinate truss or statically indeterminate truss for any type of truss configuration and loading condition using matrix method of structural analysis. The failure probability of statically determinate truss can be very accurately evaluated. They also proposed to evaluate the failure probability of statically indeterminate truss by calculating lower and upper bound. They also proposed that the failure probability is greatly influenced by inclusion of buckling failure of the compression member.

R.Nakib (1991) [2] Performed analytical investigation into both in deterministic and reliability based optimization of bridge. In reliability based optimization approach to design of truss bridges, the uncertainties related to strength and loads are considered and analytically optimization of truss structure is done with the concept that minimum weight with structural reliability constraint and minimum probability of failure with structural weight constraints. He concluded that component material behavior can have a major impact on the optimum weight of deterministic truss bridges.

A Karamchandani, X.A Cornell [1992][3] Performed reliability analysis of truss structures with multi state elements. They studied failure path approach to identify important sequence of elemental failure leading to collapse of structure and estimation of probability of failure. In this paper, failure-path approaches are extended from the two-state element representation (in which an element is either safe or failed) to a multistate representation in which the element has piecewise linear force-deformation characteristics.

Hong Li. Ricarddo, O. Foschi[1998] [4] Proposed to determine design variables using inverse reliability approach. By fixing the target reliability index, they proposed a method to determine the design variables using inverse reliability method. They proposed both of single and multiple design parameter problems. They studied this methodology with examples.

C.K Prasad VermaThampan and C.S Krishnamoorty(2001) [5] **P**erformed system reliability based configuration optimization of trusses. In their study the reliability based configuration optimization of trusses with respect to member sizes and con-figuration has been carried out using GA-based methodologies. The proposed methodology is efficient and capable of performing reliability-based configuration optimization of practical structures by including constraints pertaining to total or partial collapse and functional requirements.

F. Necati Catbas, Melih Susoy, Dan M. Frangopol[2008][6] Performed reliability estimation of the main truss components as well as estimation of system reliability of the whole structural system of long span bridges. They assessed safety levels of the truss bridges by using probabilistic approach in terms of component and system reliability indices.

Dan M. Frangopol, Alfred Strauss, Sunyong Kim[2008][7] Proposed reliability assessment of bridges based on monitoring. They proposed reliability estimation of the structural component and structural system based on field monitoring data for detecting proper maintenance, repair, rehabilitation strategies or replacement of the structure.as per evaluated data of reliability analysis. They provide n approach for the efficient inclusion of monitoring data in the structural reliability assessment process and to demonstrate the use of monitored data for the development of prediction models.

J.Renuka Kumari, K.V.Valsarajan [2016][8] Performed reliability based design and optimization of trusses by Genetic Algorithms. Optimization is done with a concept that by minimizing the structural weight and satisfying the reliability index requirement for every failure mode. They concluded that reliability based design and optimization is very effective in obtaining optimal solution for frame structure.

Yogish C.B, V. Devaraj[2017][9] Computed, the reliability index for Pratt truss with post-tension member of different profiles (straight, one drape and two drape) by method of Advanced FOSM (Hasofer-Lind method), post-tensioning of truss as a technique of strengthening and rehabilitation of structurally and functionally deficit bridges. Pratt truss with post-tension member of different profiles are analyzed to compute reliability index, Load and resistance factors using MATLAB function program by Hasofer-Lind method. They concluded that the introduction of post tensioned cable in a pratt truss, the member forces and joint displacement reduced significantly.by estimating the reliability of the element and compared with the accepted target reliability for the failure mode and if computed reliabilities is lower than the target reliability then the structure is less safe otherwise structure is safe.

K. Biabani Hamedani and V.R. Kalatjari[2018][10] Performed structural system reliability-based optimization of truss structures using genetic algorithm. They developed a logical framework for system reliability analysis of truss structure and simultaneous size and geometry optimization of truss structure subjected to structural reliability constraint. The objective of optimization is is to minimize the total weight of truss against the various constraint i.e randomness of various design parameters.

2.1 CRITICAL OBSERVATIONS:

- Systematic method of failure criteria of truss structure has been defined by various papers.
- Formulation of limit state function for different failure modes of truss element has also been proposed. Consideration of mostly dominant failure modes also suggested by various papers.
- Failure probability of truss structure has been estimated by calculating its lower and upper bound. Failure probability of truss structure is greatly influenced by buckling failure of compression member.
- System reliability based optimization of has been proposed by various papers using genetic algorithm.
- Deterministic and reliability based optimization has been proposed by various papers.
- Determination of design variables using inverse reliability approach is proposed by few papers.
- Some paper proposed reliability analysis of component and system based on monitoring as well as observed field data.

Chapter 3

STRUCTURAL RELIABILITY THEORY

3.1 INTRODUCTION:

Factors involved in the design of any structure are not deterministic in nature that means of the design parameters are random variables i.e these variables are following certain probability distribution function, here in all cases all random variables are considered as normally distributed. Structural reliability theory is used to assess whether the element in the structure is safe or unsafe considering all the uncertainties and randomness associated with that element. Using the concepts of reliability theory, the reliability index value corresponding to a probability of failure that provides an estimate of the safety of an element.

While planning and design of any structure, the primary objective or basic criteria is that the element wise supply or resistance of the structure should be greater than the demand. In structural design, the supply can be expressed in terms of resistance, capacity or strength of the member and demand can be expressed in terms of applied load, load combination and their effect. The reliability of the structure can be defined as its ability to fulfil design purpose for stipulated period of time i.e design period. Most of the structures have several numbers of possible failure modes. While determining the reliability of structure all possible dominant failure modes have taken into consideration. In structural reliability analysis, the first step is to estimate structural reliability with respect to mostly dominant failure modes or in other words probability of failure of structural elements or structure for various failure modes. And the next step is to estimate the overall reliability of structure from system point of view .

The reliability of a structure is denoted and is defined as

$$= (1 - P_f)$$

Where P_f is the probability that the structure will fail during its design life.

Here level 2 method of reliability analysis will be taken for the structures .In level 2 method of reliability analysis an approximation of probability of failure of the structure is obtained by idealization of failure surface and by simplifying the probabilistic data of the relevant uncertainty variables. More advance method is the level 3 method is the probabilistic method of analysis based on knowledge of joint distribution function of all relevant uncertainty variables. Level 3 method of structural reliability analysis provides exact probability of failure of structure. In the level 2 method the non- linear failure surface is approximated by a tangent hyperplane at the point of the failure sur- face closest to the origin, when the surface has been mapped into a standard normal space. Further, each uncertainty variable is characterized by two parameters (usually the expected value and the variance) and the correlation between any pair of variables is characterized by a single measure, namely the covariance.

3.2 Definition of Failure:

While defining the reliability of any structural element, types of failure/ modes of failure of structural element is to be considered. Different types of failure mode of the element can be considered in reliability analysis. Each type of failure types can be assessed separately and as a result we obtained separate probabilities of failure or reliability indices of the element.

For different failure mode of the element, there will be specific limit state function or performance function (safety margin) which provides specific reliability index corresponding to a particular failure mode. In structural reliability analysis three types of performance functions/ limit state function is considered in evaluating component level reliability index.

These performance functions are given below.

1. Performance functions based on ultimate limit state

   In case of ultimate limit state, the performance function is evaluated for different mode of failure which is fall under ultimate limit states. In case of truss element the performance function for ultimate limit state is the difference between tensile capacity and tensile axial force[mode of failure tension] while the element is subjected to tensile force and another limit state is the difference between compression capacity and axial of force of element which are in compression[when mode of failure compression]. In case of beam element, the number of failure element is higher e,g failure mode against moment/shear at end supports , at any span against moment, and whole structure will contain huge numbers of failure mode. Therefore while performing reliability analysis of any structure mostly dominant failure modes have to taken into consideration.

2. Performance functions based on serviceability limit state

Serviceability limit states may also be adopted in structural reliability analysis. The deflection of a certain element may not exceed permissible limit or the number of cracks developed in a concrete element may not exceed a certain amount.

3. Performance functions based on fatigue failure

Fatigue limit state refers reduction of strength due to repetitive/cyclic loading. Due to the cycles of loading and repetition of the applied loads an accumulation of damage and deterioration can take place which may result collapse of the element. Fatigue can become a serious issue especially on railway bridges. Fatigue limit state is not considered in this research.

3.3 Probability of failure and reliability index

3.3.1 General concept of probability of failure:

The probability of failure of an element is the probability of that the structural element will fail. It may possible to find the probability of failure of an element (or even probability of failure of the whole structure as a system) by stochastically evaluating the performance function of that element relating to the considered different failure modes.

The variables involved in the performance function or limit state are random variables. It means they follow a specific probability density function. The random variables are denoted by capital letters (X) and their realization or sample values are shown with lower-case letters (x). Mostly, the performance function has the following form when the ultimate limit state is considered.

$$G = R - S$$

In the above equation R is considered as resistance (Supply) variable of the element and S is considered as load effect (Demand) which is also a random variable of that element.

Both R and E are in terms of random variables and consequently G(safety margin) is also in terms of those random variables. It can be written in the form shown below. If the random variables are $X_1, X_2, X_3, X_4.......X_n$, then,

$$G(X_1, X_2, X_3, X_4......., X_n) = \mathrm{R}(X_1, X_2, X_3, X_4......., X_n) - S(X_1, X_2, X_3, X_4......., X_n)$$

When the performance function is defined the failure probability can be defined as the probability that $G \leq 0$. It is shown as $P_f = P(G \leq 0)$ .If the probability distributions of resistance (R) and load effect (S) are known, then they can be depicted as shown in the following Figure.

In case of truss, the failure mode may be tensile failure, compression failure. The ultimate limit state of any truss element may be expressed when resistance (tensile or compressive) is equal to the demand of the structure i.e the load effect.

For example let R represent the resistance (Tensile Capacity) and S represent the load effect (internal tensile force of the element)

Then, the limit State Function or Performance Function for that mode of failure is

G(R, S) =R-S

When g=0 it represents the boundary between the desirable and undesirable performance against that mode of failure.

If $g \geq 0$, then the structure is safe

And g<0 , the structure is not safe (undesirable performance)

The probability of failure P_f is equal to the probability of undesirable performance will occur.

Mathematically probability of failure may be expressed as

$P_f = P(R - S < 0) = P(g < 0)$

The structure is safe, if load effect is less than resistance and failure occurs when load effect is more than the resistance of structure.

In case of truss type structure, there are several ultimate limit states according to various types of load and their load combination.

The failure of structure can be expressed using various parameters $X_1, X_2, X_3, ...\mathrm{X}_n$ which are load & resistance parameter such as Dead Load, Live Load, wind load, length, depth, compressive strength, tensile strength, etc.

For example X_1 represent the difference axial tensile capacity and tensile internal force of the truss element. X_2 Represent the difference axial compressive capacity and compressive internal force of the truss element and so on.

Boundary conditions:

$g(X_1, X_2, X_3, ...X_n) > 0$ for safe structure

$g(X_1, X_2, X_3, ...X_n) = 0$ Boundary between safe and unsafe

$g(X_1, X_2, X_3, ...X_n) < 0$ for failure of structure.

Due to presence of uncertainty both in load and resistance parameters it is not always satisfy the design requirement of the structure. in simple case considering two variables relating to demand of the structure e.g load on the structure "S" and other is the capacity of the structure "R". the randomness of R and S can be represented by their mean $«_s, «_R$ and standard deviation $\pm_s and \pm_R$ and corresponding their probability density function $f_S(s)$ and f_R(r) respectively.

Considering normal distribution of both resistance $N(«_R, \pm_R)$ and load $N(«_S, \pm_S)$ and if we plot probability density function vs resistance and demand in a single plot then zone of failure can be detected. Another random variable Z=R-S can be introduced.

The distribution of variable G can be plot using normal distribution $N(«_R - «_S, \sqrt{\pm_R^2 + \pm_S^2})$)

Then probability of failure can be defined $P_f = P(G < 0)$

And reliability index is given by= $= («_R - «_S) / \sqrt{(\pm_R^2 + \pm_S^2)}$

But the structure is subjected to various types of load and their combination and according to that various types of failure may possible.

For combined load case, the reliability index for particular type of failure can be determined by: (The primary loads are statistically independent to each other)

$$«_R = («_{S_1} + «_{S_2} + «_{S_3} + ... + «_{S_n}) + \sqrt{\pm_R^2 + (\pm_{S_1}^2 + \pm_{S_2}^2 + \pm_{S_3}^2 + ...\pm_{S_n}^2)}$$

Where is the reliability index, $«_{S_1}, «_{S_2}, «_{S_3}, ...«_{S_n}$ are the mean of different primary load cases and $\pm_{S_1}, \pm_{S_2}, \pm_{S_3}, ...\pm_{S_n}$ are the SD of loads and $\pm_R$ SD of resistance parameter.

Assumptions for reliability analysis of truss:

1. All the loads applied on the truss structure are assumed to be static and the response of the structure is obtained by performing a static linear finite element analysis, thus the dynamics are ignored.
2. Resistances of the elements can be considered as random variables.

3. Geometrical parameters C/S area will be taken as random variable. Length of the element will not take as random variable.
4. Variation of nodal Loads at the nodes will be fixed type.

3.3.2 Normal Random Variables

One of the common distributions that can be used for a random variable is a normal distribution. Normal distribution is the most important type of probability distribution in structural reliability. Its probability density function follows the form:

$$f_X(x) = \frac{1}{\pm_X \sqrt{2®}} \exp\left[\frac{1}{2}.\left(\frac{x - «_x}{\pm_x}\right)^2\right], -\infty < x < +\infty$$

3.4 The Fundamental Case:

The reliability of a structure or a structural element is determined by considering only two independent random variables related to load effect variable S and a resistance variable R and limit state function is given by $(r - s) = 0$ and element will fail when $(r - s) < 0$. This case is called the fundamental case and given in the following figure. The probability of failure P_f can easily be calculated in the following way. The probability of the event that the load effect S lies in the interval [x - dx/2; x + dx/2] is equal to $f_s(x)dx$. Failure occurs when the resistance R is lower than x, and the probability of this event is $F_R(x)$ considering independence of the variable S and R and assuming that the load is in the interval shown, the probability of failure is $F_R(x) f_s(x)dx$. Therefore, the total probability of failure is $P_f = \int_{-\infty}^{+\infty} F_R(x) f_s(x)dx$.

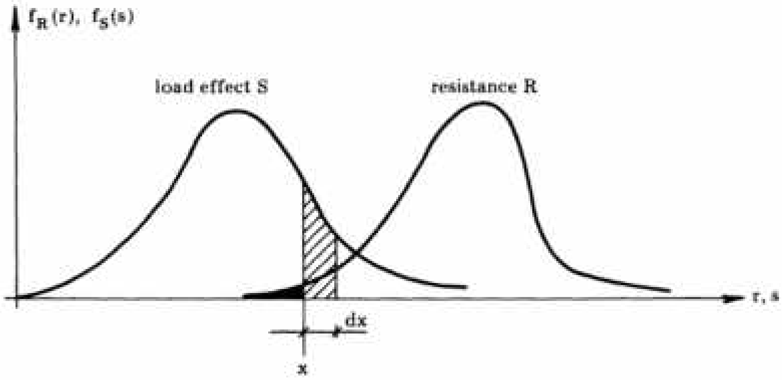


Fig:3.1 The Fundamental case of Reliability

3.4.1 The fundamental case of reliability

If R and S are independent and normally distributed $N(«_R, ±_R)$ and $N(«_S, ±_S)$ then the probability of failure can be exactly calculated. Let M = R - S. Then M is normally distributed, with $«_M = («_R - «_S)$ and $±_M^2 = (±_R^2 + ±_S^2)$

$$P_f = P(R - S \leq 0) = P(M \leq 0) = ¤(\frac{0 - «_M}{±_M}) = ¤(\frac{«_S - «_R}{\sqrt{±_S{}^2 + ±_R{}^2}})$$

Where ¤ is the standard normal distribution function.

For the fundamental case the reliability index is defined by: $= \frac{«_M}{±_M}$ (for un-correlated random variables)

Where M= R-S is called the safety margin, $«_M$ and $±_M$ the mean value and standard deviation of M.

$$P_f = ¤(- \quad) \Leftrightarrow \quad = -¤^{-1}(P_f)$$

Reliability index for correlated random variable R and S is given by in the same form but standard deviation of M is given by $±_M^2 = ±_R^2 + ±_S^2 - 2°±_R±_S$

where ° is the correlation coefficient. The correlation coefficient ° p is defined by

$$° = \frac{COV(R,S)}{±_R±_S}$$

Where $COV(R,S)$ is the covariance of R and S.

3.5 Methods of Structural Reliability Analysis

First order reliability methods are one of the common and effective ways of reliability analysis. These methods were developed based on the so-called “second moment" methods that were mainly developed by Cornell.

3.5.1 First-Order Second Moment Method (FOSM)

If the limit state function $M = f(X_1, X_2, X_3, ...X_n)$ is linear that is expressed in the following form:

$$M = a_0 + a_1.X_1 + a_2.X_2 + a_3.X_3 + ...+ a_n.X_n$$

Where $a_0, a_1, a_2, a_3...........a_n$ are constants and $X_0, \mathrm{X}_1, \mathrm{X}_2, \mathrm{X}_3 ....\mathrm{X}_n$ are the normally distributed uncorrelated basic random variable.

The fundamental case with safety margin M=R-S is the special case of linear safety margin where $a_0 = 0, a_1 = 1 \& a_2 = -1$

The reliability index will be given by: $= \frac{«_M}{\pm_M}$

Where $«_M = a_0 + a_1.«_1 + a_2.«_2 + a_3.«_3 + ...+ a_n.«_n = a_0 + \sum_{i=1}^{n} a_i.«_i$

And $\pm_M^2 = (a_1.\pm_1)^2 + (a_2.\pm_2)^2 + (a_3.\pm_3)^2 + ...+ (a_n.\pm_n)^2 = \sum_{i=1}^{n} (a_i.\pm_i)^2$

Or $\pm_M = \sqrt{\sum_{i=1}^{n} (a_i.\pm_i)^2}$

When the normally distributed basic variables are correlated, then $«_M$ will remain unchanged but $\pm_M$ will be changed in the following form:

$$\pm_M^2 = (a_1.\pm_1)^2 + (a_2.\pm_2)^2 + (a_3.\pm_3)^2 + ...+ (a_n.\pm_n)^2 + \sum_{i=1}^{n} . \sum_{j=1, j \neq i}^{n} °_{X_i X_j} a_i a_j \pm_{X_i} \pm_{X_j}$$

Where $°_{X_i X_j} = \frac{COV[X_i, X_j]}{\pm_{X_i} \pm_{X_j}}$ is the coefficient of correlation between two random variables $[X_i, X_j]$.

The above stated equations can be expressed in more convenient way using vector and matrix notation.

$$\overline{X} = (X_1, X_2, X_3, ...X_n)$$
$$\overline{a} = (\mathrm{a}_1, \mathrm{a}_2, \mathrm{a}_3, ...\mathrm{a}_n)$$
$$\mu_{\overline{X}} = (\mu_{X_1}, \mu_{X_2}, \mu_{X_3}, ...\mu_{X_n})$$
$$\overline{\overline{C}} = \begin{pmatrix} \mathrm{Var}(X_1) & COV[\mathrm{X}_1, \mathrm{X}_2]\ldots & COV[\mathrm{X}_1, \mathrm{X}_n] \\ COV[\mathrm{X}_2, \mathrm{X}_1] & \mathrm{Var}(X_2) & COV[\mathrm{X}_2, \mathrm{X}_n] \\ \vdots & \vdots & \vdots \\ COV[\mathrm{X}_n, \mathrm{X}_1] & \cdots & \mathrm{Var}(X_n) \end{pmatrix}$$

Then Limit State function M will be given by:

$$M = a_0 + \overline{a}^T.\overline{X}$$
$$\mu_M = a_0 + \overline{a}^T.\mu_{\overline{X}}$$
$$\sigma_M^2 = \overline{a}^T.\overline{\overline{C}}.\overline{a}$$

The probability of failure $P_f = P(M \le 0) = \Phi(\frac{0-\mu_M}{\sigma_M}) = \Phi(-\ )$

If the limit state function is non-linear, then the limit state function needs to be linearized. One method for linearization of limit state function is Taylor series expansion. If the Taylor Series is only expanded up to the derivative of order one, then it will lead to a linear function.

Let the safety margin M be non-linear and given by:

$$M = f(\overline{X}) = f(X_1, X_2, X_3, ...X_n)$$

Then by expanding M in a Taylor series about linearization point $\overline{x}_0 = (x_1^0, x_2^0, x_3^0, ...x_n^0)$ and accepting only linear term we get:

$$M = f(\overline{X}) \cong \mathrm{f}(\overline{\mathrm{x}}_0) + \sum_{i=1}^{n} \frac{\partial f}{\partial x_i}(X_i - x_i^0)$$

Where the derivative $\frac{\partial f}{\partial x_i}$ i= 1 to n are evaluated at linearization point $\overline{x}_0$.

Approximate value of μ_M and σ_M can be calculated using following equation:

$$\mu_M \cong \mathrm{f}(\overline{\mathrm{x}}^0) + \sum_{i=1}^{n} \frac{\partial f}{\partial x_i}(\mu_{X_i} - x_i^0)$$

And $\pm_M \cong \sum_{i=}^{n} . \sum_{j=1}^{n} \frac{¢ f}{¢ x_i} . \frac{¢ f}{¢ x_j} COV[X_i, X_j]$

The value obtained for a non-linear safety margin will depend on the choice of linearization point. The better way is to obtain most convenient value is to use mean point $(«_{X_1}, «_{X_2}, «_{X_3}, ... «_{X_n})$ as a linearization point. This is a very rough method of Reliability Index calculation due to existence of invariance problem.

3.5.2 The Hasofer and Lind Reliability Index:

The Hasofer-Lind method is a method that was introduced in 1974. This method was proposed to solve the problem of invariance observed during reliability index calculation.

Consider the fundamental case with independent basic variables R and S and the safety margin M = R - S. Let mean value of resistance variable R is $«_R$ and mean value of load variable is $«_S$ and the standard deviations are $\pm_R$ and $\pm_S$ respectively. Now transform the normally distributed random variable R and S into standard normal random variable whose means are zero and unit standard deviation.

$$R' = \frac{R - «_R}{\pm_R}; S' = \frac{S - «_S}{\pm_S}$$

The failure surface f(r, s) = r - s = 0 will by the transformation be transformed into a straight line in the normalized (r', s') coordinate system. The failure surface in the (r', s') coordinate system is given by:

$$\pm_R . r' - \pm_S . s' + («_R - «_S) = 0$$

The shortest distance from the origin to this linear failure surface is equal to:

$$\frac{\pm_R .0 - \pm_S .0 + («_R - «_S)}{\sqrt{\pm_R^2 + \pm_S^2}} = \frac{(«_R - «_S)}{\sqrt{\pm_R^2 + \pm_S^2}} =$$

Therefore, an alternative geometrical definition of the reliability index is the shortest distance from the origin to the linear failure surface. This geometrical interpretation is here shown for a linear safety margin with only two basic variables but can easily be extended to a linear safety margin with n basic variables.

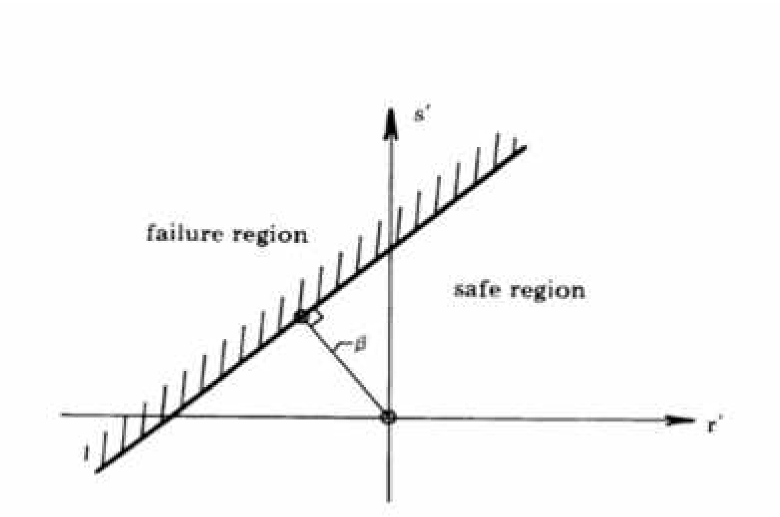


Fig:3.2 Transformation of failure surface to standard normal failure space

3.5.2.1 Hasofer-Lind Reliability index for n-dimensional failure space for n-nos basic random variable:

It is possible to determine Reliability Index   from non-linear equation of safety margin which is a function of n numbers random variable.

Let the basic variables be $\overline{X} = (X_1, X_2, X_3, ...X_n)$ and the (non-linear) failure function

$f' : \mu \cap R$, where µ is the n-dimensional basic variable space. Further, for the sake of simplicity assume that the basic variables are uncorrelated, i.e. the covariance matrix is diagonal

$$\overline{\overline{C}} = \begin{pmatrix} \pm^2_{X_1} & 0\ldots & 0 \\ 0 & \pm^2_{X_2} & 0 \\ \vdots & \vdots & \vdots \\ 0 & \cdots & \pm^2_{X_n} \end{pmatrix}$$

where $\pm_{X_i}$ is the standard deviation of basic random variable X_i

Let $«_{X_i}$ is the mean value of basic random variable X_i

Let $\overline{Z} = (Z_1, Z_2, Z_3, ... Z_n)$ is the transformation of basic normal variables $\overline{X} = (X_1, X_2, X_3, ... X_n)$

$$Z_i = \frac{X_i - «_{X_i}}{±_{X_i}}, i = 1, 2, 3......n$$

The random variables are normalized in the sense that $«_{X_i} = 0$ and $±_{X_i} = 1$.

The failure surface given by $f'(\overline{X}) = 0$ in x-coordinate system is by linear transformation can be mapped into failure surface $f'(\overline{Z}) = 0$ in the reduced coordinate (z-coordinate) system. By transformation the mean values $«_{\overline{X}} = («_{X_1}, «_{X_2}, «_{X_3}, ... «_{X_n})$ is mapped into origin. Therefore origin-O in the normalized z-coordinate system will usually be within the safe region. Further, the z-coordinate system has an important characteristic, namely a rotational symmetry with respect to the standard deviation.

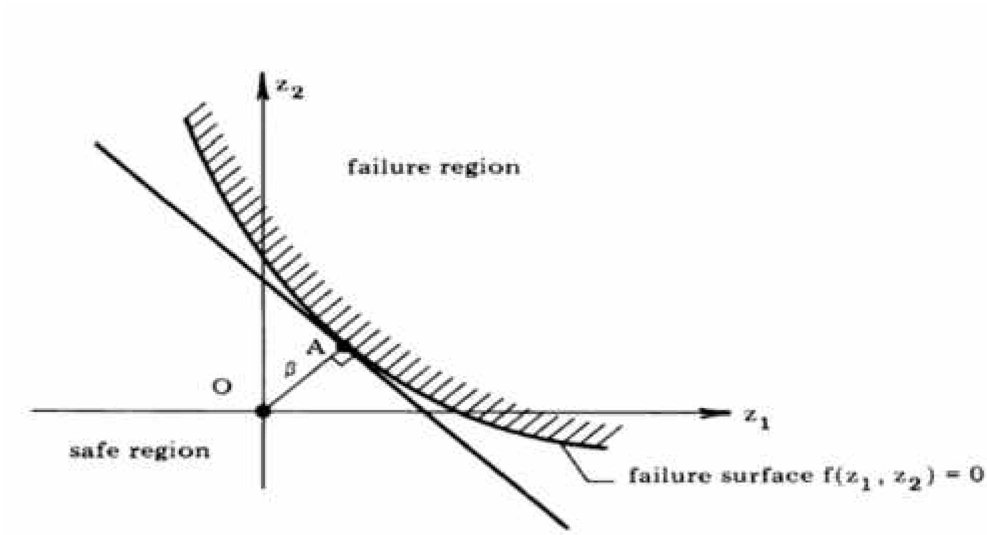


Fig: 3.3 Transformation of nonlinear failure surface into standard normal failure space

Non-linear failure surface is due to non-linear relation between Z_1 & Z_2

The Hasofer and Lind reliability index is defined as the smallest distance from the origin to the failure surface in the normalized z-coordinate system. This is shown for a two- dimensional example in the above figure, where the reliability index is equal to the distance OA. The point A is called the design point. Clearly, by this definition the reliability index for a non-linear failure surface is equal to the reliability index for the linear tangent hyperplane in the design point A. The linearization point must be the design point. By relating the definition of the reliability index   to the failure surface and not to a failure function, a reliability measure is obtained which is failure function invariant since all equivalent failure functions result in the same failure surface in the x-coordinate system and therefore, also in the z-coordinate system.

Calculation of the reliability index with a non-linear failure surface will be done by an iterative method.

The minimum distance from the origin to the limit state surface (   ) can be calculated as below:

If (x'^*) is considered as a vector including the coordinates of the design point in the transformed (reduced) coordinate system:

$$= \sqrt{(z'^*)^T.(z'^*)}$$

In the case of a nonlinear performance function, the problem becomes an optimization problem. The objective of optimization is to minimize the distance from the origin in the transformed coordinated system to the limit state surface to obtain the so-called design point by minimizing above equation ($= \sqrt{(z'^*)^T.(z'^*)}$)

To solve this optimization problem the concept of Langrange Multipliers can be used. It will lead to the following expression to calculate the value of   :

$$= \frac{\sum_{i=1}^{n} (z'^*).(\frac{¢ g}{¢ Z_i'})^*}{\sqrt{\sum_{i=1}^{n} (\frac{¢ g}{¢ Z'})^{2*}}}$$

The expression $(\frac{¢ g}{¢ z_i})^*$ is the partial derivative evaluated at the design point, where the coordinates are $(z_1'^*, z_2'^*, z_3'^*, \ldots\ldots\ldots z_n'^*)$. In other terms, it can be said that the design

point can be obtained from:

$$z_i'^* = -\sim_i .$$

And $\sim_i$ can be defined as the directional cosines along the U_i coordinate axes.

$\sim_i$ can be calculated as below:

$$\sim_i = \frac{(\frac{¢\, g}{¢\, Z_i'})^*}{\sqrt{\sum_{i=1}^{n}(\frac{¢\, g}{¢\, Z_i'})^{2*}}}$$

The value of the design point in the original space can be returned by using equation:

$$x_i^* = «_{X_i} - \sim_i . \quad ±_{X_i}$$

The procedure to find out the design point was suggested by Rackwitz is given in the following sequential form:

i) Determination of the appropriate limit state function.

ii) Making of preliminary guess for the design point. Usually it is recommended to use the mean values of the random variables as the preliminary guess.

iii) Calculation of the transformed random variable by using equation: $Z_i = \frac{X_i - «_{X_i}}{±_{X_i}}, i = 1, 2, 3......n$.

iv) Calculation of the derivative $(\frac{¢\, g}{¢\, Z_i'})^*$ at the design point as well as the directional cosine $\sim_i$

v) Using equation $z_i'^* = -\sim_i .$ to obtain the design point $z_i'^*$ in terms of reliability index.

vi) Substituting the value obtained in the previous step in the limit state function (LSF), And solve it to find (note that LSF is in terms of , and by solving the LSF for the reliability index is obtained).

vii) Using the value obtained in the previous step, calculate a new design point by utilising equation $z_i'^* = -\sim_i .$.

viii) Repetition of steps iii) to vii) until the reliability index value converges.

The failure surface will be given by $f(z_1, z_2, z_3, ...z_n) = 0$

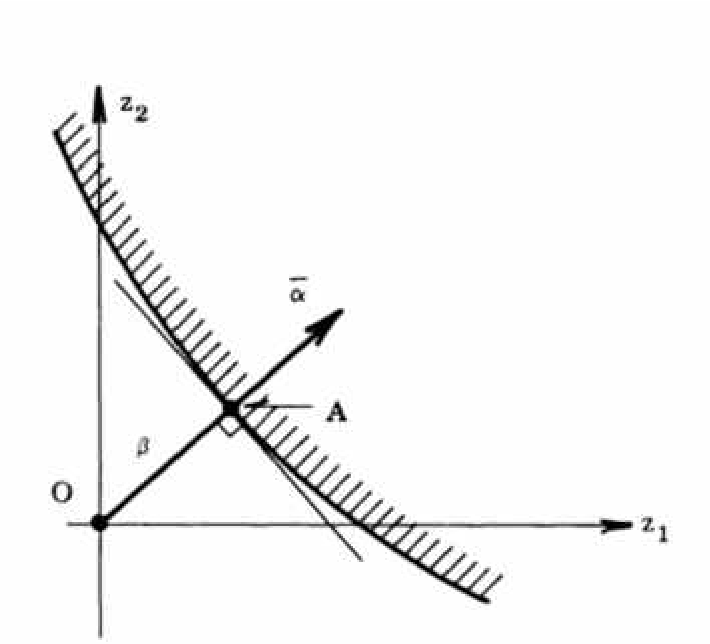


Fig: 3.4 Non-linear failure surface $f(z_1, z_2) = 0$ in the two dimensional reduced variable space

Matrix procedure to determine component reliability index of any structural element:

1. Formulation of appropriate Limit State Function (Performance Function) of the failure element and determination of appropriate parameters(Expected value, Standard Deviation, Correlation coefficients etc) for all associated random variables.
2. Obtaining initial design points (x_i^*) by assuming values for (n-1) random variables X_i (mean value will be reasonable as a initial choice). Solving the limit state equation g=0 for the remaining random variables. This is ensure that design point lies in the failure boundary.
3. Calculation of the transformed random variables(reduced variates) corresponding to the design points x_i^* by using equation: $Z_i = \dfrac{X_i - \mu_{X_i}}{\sigma_{X_i}}, i = 1, 2, 3......n$
4. Determination of the partial derivatives of the limit state function with respect to the reduced variates using the equation $(\dfrac{\partial g}{\partial Z_i}) = (\dfrac{\partial g}{\partial X_i}).(\dfrac{\partial X_i}{\partial Z_i}) = (\dfrac{\partial g}{\partial X_i}).\sigma_{X_i}$

$$G = \begin{Bmatrix} G_1 \\ G_2 \\ G_3 \\ . \\ . \\ . \\ G_n \end{Bmatrix}$$ where $G_i = -\frac{¢\, g}{¢\, Z_i}$ to be evaluated at design point.

5. Estimation of Reliability Index using following formula:

$$= \frac{(G)^T.(z^*)}{\sqrt{(G)^T.(G)}}$$, where $$z^* = \begin{Bmatrix} z_1^* \\ z_2^* \\ z_3^* \\ . \\ . \\ . \\ z_n^* \end{Bmatrix}$$

6. Calculation of column vector containing the sensitivity factors using following formula:

$$\{\sim\} = \frac{(G)}{\sqrt{(G)^T.(G)}}$$

7. Determination of new design point in the reduced variates for (n-1) variables using

$$z_i^* = \sim_i .$$

8. Determination of corresponding design point in the original coordinate system for (n-1) values using $x_i^* = «_{X_i} + z_i^* .±_{X_i}$
9. Determination of remaining random variables by solving limit state function g=0
10. Repetition of steps 3 to 9 until and design points x_i^* converges.

3.6 System Reliability Evaluation of Truss Structures

Procedure for component level reliability analysis by using Hasofer-Lind Method is formed in the previous article. The system reliability evaluation of the structure is very complex in nature and it has been developed for idealized structure. System reliability evaluation is very essential part when repair optimization of structure is required. According to system reliability evaluation of structure it may be decided which elements are more important against repair and renovation work. Computation of system reliability and defining proper failure modes is dependent on the material resistance model and behavior of the elements. The material can be assumed elasto-plastic and the failure can be brittle, semi-brittle or ductile. All of these factors are crucial in the determination of system reliability.

Using -Unzipping method evaluation of system reliability of structure is done at number of different levels. -Unzipping method is applicable both for two and three dimensional framed and truss structures.

3.6.1 System Reliability Evaluation at Level-Zero:

Estimation of the system reliability of the structure on the basis of failure of single structural element (Element with lowest reliability index of all elements) will be called system reliability at level zero. At level zero the reliability of the structural system is equals to the lowest reliability index of the failure element. Evaluation of system reliability at level zero is actually element reliability analysis and no the system reliability analysis. At level zero each element is considered isolated from each other and the interaction between the elements is not taken into account in estimating the reliability. If the structure consist of n failure elements and reliability index for failure element i be denoted by $_i$. Then at level 0 the systems reliability index $_s$ is simply given as:

$$_s = \min_{i=1,n} \; _s$$

3.6.2 **System Reliability Evaluation at Level-one:**

More accurate estimate of reliability of structural system can be obtained at level one. In that case mostly dominant failure modes of the failure element are taken into consideration by modeling the structural system as a series system with the failure elements as elements. The probability of failure of that series system is then calculated and corresponding system reliability has been evaluated as per component level reliability index of the elements i.e $_i, i = 1, 2, ..., n$, and considering the correlation among the safety margins of the failure elements. At level 1 system failure occurs as the failure of one element.

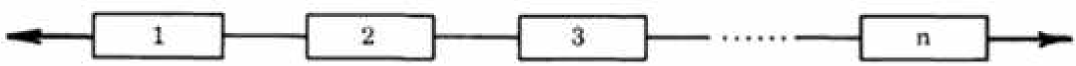


Fig: 3.5 system modeling at reliability level 1

In the above figure the series system contains n failure elements. The estimation of probability of failure can be obtained with satisfactory accuracy by considering failure elements with low -values. Selection of such failure elements can e.g. be performed by choosing those failure elements with – values in an interval $[[\ _{min},\ _{min} + \Delta\ _1]$. $\Delta\ _1$ will be choosing in proper way. These considered failure elements are referred as critical failure elements.

It is possible to get sufficiently accurate value of P_f if the safety margins $M_i \quad i = 1, 2, 3...., n$ are perfectly correlated i.e correlation coefficient $°_{ij}$ is very close to unity $[°_{ij} \approx 1]$ or the correlation coefficient between the safety margins of any two elements is very small $[°_{ij} \approx 0]$

Lower Bound of Probability of failure:

When the correlation coefficient $°_{ij}$ is very close to unity $[°_{ij} \approx 1]$

$$P_f = \max_{i=1,2,3,...n} P(F_i)$$

Upper Bound of Probability of failure:

When the correlation coefficient $°_{ij}$ is very close to unity $[°_{ij} \approx 0]$

$$P_f \leq 1 - \sum_{i=1}^{n} [1 - P(F_i)]$$

3.7 GENERATION OF SAFETY MARGIN FOR TRUSS STRUCTURE:

Considering space truss structures which consist of n axially loaded element. The structural configuration and material of the truss is assumed to be specific. The truss element will fail when internal axial force is exceeding the strength of the element. The safety margin is the difference between strength and internal force which is given in the following form:

$$M_i = R_i(C_{yi}, A_i) - S_i(A_1, A_2, ...A_n; L_1, L_2, ...L_{3l}; \mathrm{l}_1, \mathrm{l}_2, ...\mathrm{l}_n; E_1, E_2, ...E_n)$$

Where:

M_i =Safety margin of the ith member

R_i =Strength of the ith member

S_i = Internal force of the ith member

C_{yi} =Allowable stress of the ith member determined by the material to be used and the dimension of the member.

A_i =Cross sectional area of the ith member.

l_i =Length of the ith member

L_j =External load applied to the structure (j = 1,2, ... , 3l)

n=Number of members

l=Number of nodes

E_i =Modulus of elasticity of the ith member.

The strength of an element R_i both for tension and compression can easily determine by specifying the material properties and geometrical properties of the member. Whereas internal force S_i in the truss element is very complex to evaluate and that can be calculated by linear elastic analysis using finite element method.

Let $\overline{x}_i$ and $\overline{¢}_i$ expressing nodal force and displacement vector of i-th element with respect to local coordinate system which is shown in following figure:

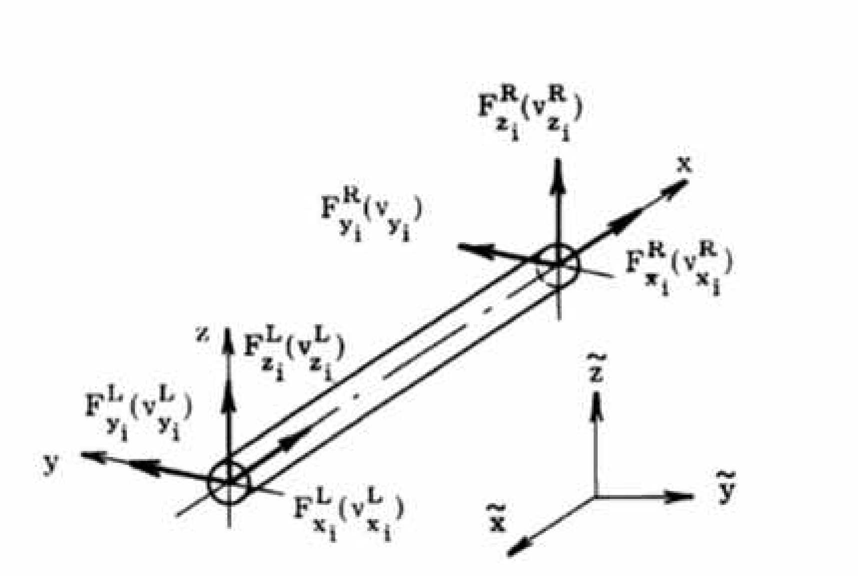


Fig: 3.6 Member end forces and member end displacements w.r.t global coordinate system for 3d space truss.

The member stiffness equation will be:

$$\overline{x_i} = k_i.\overline{\text{¢}_i}$$

Where $\overline{x_i} = (F^L_{X_i}, F^L_{Y_i}, F^L_{Z_i}, F^R_{X_i}, F^R_{Y_i}, F^R_{Z_i})$

$$\overline{\text{¢}_i} = (\text{v}^L_{X_i}, \text{v}^L_{Y_i}, \text{v}^L_{Z_i}, \text{v}^R_{X_i}, \text{v}^R_{Y_i}, \text{v}^R_{Z_i})$$

k_i =member stiffness matrix in local coordinate system.

$$\{k_i\} = E_i A_i / \text{l}_i \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The nodal displacement vector of ith member $\{d_i\}$ with respect to global coordinate system and $\{\text{¢}_i\}$ can be related by transformation using following equation:

$$\overline{\text{¢}_i} = \overline{\overline{T_i}}.\overline{d_i} \ \&$$

$$\bar{T}_i = \begin{bmatrix} C_x^2 & C_x.C_y & C_x.C_z & -C_x^2 & -C_x.C_y & -C_x.C_z \\ C_x.C_y & C_y^2 & C_y.C_z & -C_y.C_x & -C_y^2 & -C_y.C_z \\ C_z.C_x & C_y.C_z & C_z^2 & -C_z.C_x & -C_y.C_z & -C_z^2 \\ -C_x^2 & -C_x.C_y & -C_x.C_z & C_x^2 & C_x.C_y & C_x.C_z \\ -C_y.C_x & -C_y^2 & -C_y.C_z & C_x.C_y & C_y^2 & C_y.C_z \\ -C_z.C_x & -C_y.C_z & -C_z^2 & C_z.C_x & C_y.C_z & C_z^2 \end{bmatrix}$$

Where $C_x = \cos^{-}{}_{x}; C_y = \cos^{-}{}_{y}; C_z = \cos^{-}{}_{z}$ are the cosines of angles of the member with respect to global coordinate system.

The nodal force vector of ith member $\{X_i\}$ with respect to global coordinate system and $\{x_i\}$ can be related by transformation using following equation:

$$\bar{x}_i = \bar{\bar{T}}_i.\bar{X}_i$$

$\bar{d}_i$ =displacement vector of the ith member w.r.t global coordinate system and

$\bar{X}_i$ =Nodal force vector of the ith member w.r.t global coordinate system.

Consequently, the member stiffness equation in the global coordinate system is given by

$$\bar{X}_i = \bar{\bar{K}}_i \bar{d}_i$$

Where $\bar{\bar{K}}_i = \bar{\bar{T}}^{-1}.\bar{\bar{k}}_i.\bar{\bar{T}}_i = \bar{\bar{T}}^{T}.\bar{\bar{k}}_i.\bar{\bar{T}}_i$

The stiffness equations of all the members are formed in a similar manner and they are transformed from the local coordinate system to the global. Next, the global nodal displacement vector $\bar{d}$ is formed by rearranging the displacement vectors $\bar{d}_i$ of the individual members. The global nodal force vector $\bar{L}$ corresponding to $\bar{d}$ is also defined. Further, the total structure stiffness matrix $\bar{\bar{K}}$ is generated by superimposing the individual member stiffness matrices.

Then, the total structure stiffness equation is written as:

$\bar{\bar{K}}.\bar{d} = \bar{L}$ where $\bar{\bar{K}}$ is given by:

$$\bar{\bar{K}} = \sum_{i=1}^{n} \bar{\bar{K}}_i = \sum_{i=1}^{n} \bar{\bar{T}}^{-1}.\bar{\bar{k}}_i.\bar{\bar{T}}_i = \sum_{i=1}^{n} \bar{\bar{T}}^{T}.\bar{\bar{k}}_i.\bar{\bar{T}}_i$$

In the above equation $\sum_{i=1}^{n}$ denotes superimposing the member stiffness matrices of all the members.

Solving equation with respect to the nodal displacement vector yields-

$$\{d\} = [K]^{-1}\{L\}$$

The displacement of ith member $\overline{\text{¢}}_i$ in local coordinate system can be found out by using equation $\overline{\text{¢}}_i = \bar{\bar{T}}_i.\bar{d}_i$.

Consequently, the nodal force vector $\bar{x}_i$ of ith member in local coordinate system can be found out by following equation:

$$\bar{x}_i = \bar{\bar{C}}_i.\bar{L}_i$$

Where $\bar{\bar{C}}_i = \bar{\bar{k}}_i.\bar{\bar{T}}_i.\bar{\bar{K}}_i^{-1}$

$\bar{\bar{K}}_i^{-1}$ is the matrix formed by extracting the elements concerned with the ith member from the matrix $\bar{\bar{K}}^{-1}$.

In case of the truss structure the internal force to be considered is the axial force

$$S_i = F_{X_i}^{R} = -F_{X_i}^{L}$$

$$S_i = \sum_{j=1}^{3l} b_{ij} L_j$$

Where b_{ij} is the element of the matrix $\bar{\bar{C}}_i$. It should be noted that the coefficients b_{ij} of a statically determinate truss are constant while those of a statically indeterminate truss become functions of e.g. the cross-sectional areas A_i of the element.

Now limit state equation becomes:

$$M_i = R_i(C_{yi}, A_i) - sign(S_i)\sum_{j=1}^{3l} b_{ij}.L_j$$

The yield stress σ_y is taken as the allowable stress C_{yi} in above equation when the member fails in tension or compression while the buckling stress σ_c is taken when instability in the compression member is considered.

Next consider a failure criterion of the structural system. In case of a statically determinate truss, structural failure arises when anyone member is subjected to failure. Consequently, the structural failure criterion is given by

$$M_i \leq 0 \, for \forall i \in [1, 2, 3, ...n]$$

where $\forall i \in$ means anyone element contained in the set {l, 2, ... , n}.

In case of a statically indeterminate truss structure, failure in anyone member does not necessarily result in structural failure. Structural failure is defined to occur when the structure is turned into a mechanism. Failure mode is generated as in the following manner. When anyone member fails, redistribution of the internal forces arises among the members in survival and a member next to fail is determined. For the stress analysis after failure in any member, the residual strength $R_i = (C_{yi}, A_i)$ corresponding the type of failure is applied as an artificial force representing the post-failure load-carrying capacity of the member, and its member stiffness matrix is put to zero. After repeating the similar processes, structural failure results when the members up to some specified number p_q e.g. members $r_1, r_2, r_3, ...r_{p_q}$ are lost. Formation of a mechanism is determined by investigating the singularity of the total structure stiffness matrix $(\bar{\bar{K}}_{p_q})$ form with (n- p_q) members in survival.

That is, a criterion for structural failure is given by

$$[\bar{\bar{K}}_{p_q}] = 0$$

The safety margins for the members in survival after some members have failed are given in the following form:

When $r_1, r_2, r_3, ...r_{(p-1)}$ have failed, then their individual stiffness matrix $[\bar{\bar{k}}_i] = 0$ and their residual strength $R_i = (C_{yi}, A_i)$ are applied to the connected node of the failed member as artificial force corresponding to the mode of failure. When a member of a brittle material fails in tension, the residual strength is put to zero while in case of a ductile material the yield strength of the member is taken as the residual strength. In case of a buckling failure, the treatment is similar to that of a brittle member. Then, the stress analysis of the structure is carried out once again by using the matrix method, and the internal forces of the members in survival are determined as follows:

$$S^p_{i(r_1,r_2,.......r_{(p-1)})} = \sum_{j=1}^{3l} b^p_{ij}.L^p_j = \sum_{j=1}^{3l} b^p_{ij}.L_j - a^p_{i_{r_1}}.R_{r_1} - a^p_{i_{r_2}}.R_{r_2} - ....- a^p_{i_{r(p-1)}}.R_{r_{(p-1)}}$$

Where a^p_{ij} are the co-efficient of influence and where suffix $(r_1, r_2, r_3, ...r_{(p-1)})$ denotes a set of failed members and the sequential order of failure. Consequently, the safety margins are given by:

$$M^p_{i(r_1,r_2,.......r_{(p-1)})} = C_{yi}.A_i - S^p_{i(r_1,r_2,.......r_{(p-1)})}$$

Structural failure of the redundant truss occurs when all of the p_q members, e.g. $r_1, r_2, r_3, ...r_{p_q}$ are subjected to failure. Hence, a criterion of structural failure is also expressed by using the safety margins of the failed members:

$M^p_{\mathrm{r}_p(r_1,r_2,.......r_{(p-1)})} \leq 0$ (p= 1, 2, ... , p_q)

Chapter 4

COMPONENT LEVEL RELIABILITY ANALYSIS OF TRUSS

4.1 General

In this chapter the focus is to develop computer algorithm for determination of Reliability Index for different limit state functions both for statically determinate and statically indeterminate truss. First-Order Second Moment Method (FOSM) of reliability analysis is used to determine the component level reliability analysis of truss element.

4.1.1 Flow chart for evaluation of component reliability of truss structure.

Following flowchart showing the methodology to determine the component reliability of a truss element:

Selection of geometrical configuration of Truss

↓

Discretization of truss structure

(Truss subdivided into convenient number of smaller element)

↓

Numbering the nodes and elements

Defining joint coordinates and member connectivity between the nodes

Finding total number of nodes and number of members of the selected truss model

↓

Define the Material behavior

(i.e Cross sectional area of member, Moment of Inertia, modulus of elasticity and density of material)

↓

Elemental Stiffness matrix

Stiffness properties of each member are calculated based on nature of member (axial, bending or both) and DOF of each node.

[Elemental Stiffness matrix (6x6) depending on length of the member, modulus of elasticity, c/s area and cosines of the member w.r.t global coordinate system.]

↓

Assembled stiffness matrix

Augmentation of element stiffness matrix into a single matrix which govern the entire idealized structure

↓

Applying Boundary condition

Supporting condition are applied to avoid singularity problem as assembled matrix is a singular matrix

↓

Application of initial Nodal Forces(Mean forces) at the various nodes as per load calculation of primary load cases i.e DL,LL,WL

↓

Linear Elastic Analysis of Truss Structure due to incremental load from (Mean-3*SD) to (Mean+3*SD) with incremental load of 0.50*SD for each primary load cases.

$(«_{DL} - 3*\pm_{DL})$ to $(«_{DL} + 3*\pm_{DL})$ with increment of load $0.50*\pm_{DL}$

$(«_{LL} - 3*\pm_{LL})$ to $(«_{LL} + 3*\pm_{LL})$ with increment of load $0.50*\pm_{LL}$

$(«_{WL} - 3*\pm_{WL})$ to $(«_{WL} + 3*\pm_{WL})$ with increment of load $0.50*\pm_{WL}$

Solution of unknown displacements in all nodes for each load increment for all load cases for a particular nodal force.

e.g displacements $¢^{j}_{DL_i}$ in all nodes due to nodal load at node i.

$(«_{DL_i} - 3*±_{DL_i})$ to $(«_{DL_i} + 3*±_{DL_i})$ with increment of load $0.50*±_{DL_i}$

$(«_{LL_i} - 3*±_{LL_i})$ to $(«_{LL_i} + 3*±_{LL_i})$ with increment of load $0.50*±_{LL_i}$

$(«_{WL_i} - 3*±_{WL_i})$ to $(«_{WL_i} + 3*±_{WL_i})$ with increment of load $0.50*±_{WL_i}$

↓

Solution of member end forces in all members for each load increment for all load cases for a particular nodal force.

e.g member end forces $F^{j}_{DL_i}$ in all members due to nodal load at node i.

$(«^{j}_{DL_i} - 3*±^{j}_{DL_i})$ to $(«^{j}_{DL_i} + 3*±^{j}_{DL_i})$ with increment of load $0.50*±^{j}_{DL_i}$

$(«^{j}_{LL_i} - 3*±^{j}_{LL_i})$ to $(«^{j}_{LL_i} + 3*±^{j}_{LL_i})$ with increment of load $0.50*±^{j}_{LL_i}$

$(«^{j}_{WL_i} - 3*±^{j}_{WL_i})$ to $(«^{j}_{WL_i} + 3*±^{j}_{WL_i})$ with increment of load $0.50*±^{j}_{WL_i}$

↓

Using Method of Least Square, correlation between Member end forces and joint forces are determined

$$F^{j}_{DL_i} = a^{j}_{i} + b^{i}_{i} P^{j}_{DL}$$

$$F^{j}_{LL_i} = a^{j}_{i} + b^{j}_{i} P^{j}_{LL}$$

$$F^{j}_{WL_i} = a^{j}_{i} + b^{j}_{i} P^{j}_{WL}$$

$F^{j}_{DL_i}$ = Member end force in member i due to joint load at node j for primary load case DL

$F^{j}_{LL_i}$ = Member end force in member i due to joint load at node j for primary load case LL

$F^{j}_{WL_i}$ = Member end force in member i due to joint load at node j for primary load case WL

Total member end forces of the i[th] member for all nodal forces in terms of j[th] nodal forces for a particular load case.

F_{DL_i} = Member end force in i[th] member due to all joint loads for primary load case DL

$$F_{DL_i} = \sum_{j=1}^{n} b_i^i . P_{DL_i}^j \quad \text{similarly}$$

$$F_{LL_i} = \sum_{j=1}^{n} c_i^i . P_{LL_i}^j \ \& \ F_{WL_i} = \sum_{j=1}^{n} d_i^i . P_{WL_i}^j$$

Total member end forces of the i-th member for all nodal forces in terms of j-th nodal forces due to combination of primary load cases.

$F_{(DL+LL)_i}$ = Member end force in ith member due to all joint loads due to combination of primary load cases DL & LL

$$F_{(DL+LL)_i} = \sum_{j=1}^{n} b_i^i . P_{DL_i}^j + \sum_{j=1}^{n} c_i^i . P_{LL_i}^j \quad \text{similarly}$$

$$F_{(DL+WL)_i} = \sum_{j=1}^{n} b_i^i . P_{DL_i}^j + \sum_{j=1}^{n} d_i^i . P_{WL_i}^j$$

Component Reliability Analysis of Truss Element by Hasofer Lind Method

Formulation of appropriate Limit State Function (Performance Function) of the failure element and determination of appropriate parameters (Expected value, Standard Deviation, Correlation coefficients etc) for all associated random variables.

$G(X_1, X_2, X_3) = R_i - S_i$ for Tension Member

$G(A, f_y, S) = A_i . f_{yi} - S_i$

$G(X_1, X_2, X_3) = R_i + S_i$ for Compression Member

$G(A, f_y, S) = factor.A_i . f_{yi} + S_i$

Considering $A, f_y \,\&\, S$ are the random variables.

Calculation of Mean and Standard deviation of ith Member end forces due to various load cases and load combinations using following formula:

e.g $F_{DL_i} = b_0 + b_1.X_1 + b_2.X_2 + b_3.X_3 + ... + b_n.X_n$

$$«_{FDL_i} = b_0 + b_1.«_{F1} + b_2.«_{F2} + b_3.«_{F3} + ... + b_n.«_{Fn} = b_0 + \sum_{i=1}^{n} b_i.«_{Fi}$$

$$±^2_{FG} = (b_1 ±_{F1})^2 + (b_2 ±_{F2})^2 + (b_3 ±_{F3})^2 + ... + (b_n ±_{Fn})^2 = \sum_{i=1}^{n} (b_i ±_{Fi})^2$$

When the normally distributed basic variables are correlated, then $«_M$ will remain unchanged but $±_M$ will be changed in the following form:

$$±^2_{FG} = (b_1 ±_{F1})^2 + (b_2 ±_{F2})^2 + (b_3 ±_{F3})^2 + ... + (b_n ±_{Fn})^2 + \sum_{i=1}^{n} . \sum_{j=1, j \neq i}^{n} °_{X_i X_j} b_i b_j ±_{FX_i} ±_{FX_j}$$

Transformation of all random variables into standard normal variables space with its mean equals to zero and Standard Deviation equals to unit.

$$Z_i = \frac{X_i - «_{X_i}}{±_{X_i}}, i = 1, 2, 3......n$$

Obtaining initial design points (x_i^*) by assuming values for (n-1) random variables X_i (mean value will be reasonable as a initial choice). Solving the limit state equation g=0 for the remaining random variables.

$$G = \begin{Bmatrix} G_1 \\ G_2 \\ G_3 \\ . \\ . \\ . \\ G_n \end{Bmatrix}$$ Where $G_i = -\frac{\partial g}{\partial Z_i}$ to be evaluated at design point.

Estimation of Reliability Index using following formula:

$$= \frac{(G)^T.(z^*)}{\sqrt{(G)^T.(G)}}$$, where $z^* = \begin{Bmatrix} z_1^* \\ z_2^* \\ z_3^* \\ . \\ . \\ . \\ z_n^* \end{Bmatrix}$

Calculation of column vector containing the sensitivity factors using following formula:

$$\{\alpha\} = \frac{(G)}{\sqrt{(G)^T.(G)}}$$

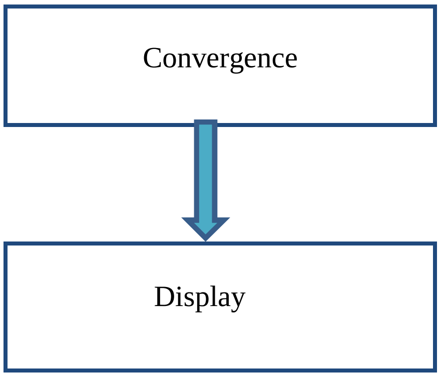
Determination of new design point in the reduced variates for (n-1) variables using

$z_i^* = \alpha_i .$

Determination of corresponding design point in the original coordinate system for (n-1) values using

$$x_i^* = \mu_{X_i} + z_i^* .\sigma_{X_i}$$

Determination of remaining random variables by solving limit state function g=0



4.2 FORMULATION FOR COMPONENT RELIABILITY OF TRUSS ELEMENT:

Estimation of Reliability Index at component level against Ultimate Limit States of Failure:

The first step of component reliability analysis is to determine the co-efficient of Influence of all relevant nodal forces acting at different nodes of the truss. Let S_i is the Member end force of the ith element due the effect of nodal forces $P_j, \; j = 1, 2, 3..., k$ acting at 1 to k-th node.

Then, $S_i = \sum_{j=1}^{k} a_{ij} P_j$, where a_{ij} is the coefficient of influence is determined by linear elastic analysis using finite element method.

In that case, C/S area of the truss element "$A_i = X_1$" , Mechanical property of the steel metal i.e yield stress "$f_y = X_2$" and member end force of the truss element $S_i = X_3$ are taken as random variables for component level reliability analysis.

Initially, using following formula the mean and standard deviation of the load effect i.e MEF are determined:

$$«_S = a_0 + a_1.«_1 + a_2.«_2 + a_3.«_3 + ... + a_n.«_n = a_0 + \sum_{i=1}^{n} a_i.«_i$$

And $$±_S^2 = (a_1.±_1)^2 + (a_2.±_2)^2 + (a_3.±_3)^2 + ... + (a_n.±_n)^2 = \sum_{i=1}^{n} (a_i.±_i)^2$$

Limit state function against tension failure is given:

$$g(X_1, X_2, X_3) = R_i - S_i = A_i . f_{yi} - S_i = A_i . f_{yi} - \sum_{j=1}^{k} a_{ij} . P_j = X_1 . X_2 - X_3$$

Limit state function against compression failure is given:

$$g(X_1, X_2, X_3) = R_i + S_i = A_i . f_{yi} + S_i = A_i . f_{yi} + \sum_{j=1}^{k} a_{ij} . P_j = X_1 . X_2 + X_3$$

Here tensile force is taken as positive and compressive force is taken as negative.

The next step is transformation of all random variables into standard normal variables with its mean equals to zero and Standard Deviation equals to unit. $Z_i = \frac{X_i - \text{«}_{X_i}}{\pm_{X_i}}, i = 1, 2, 3......n$

$$Z_1^* = \frac{x_1^* - \text{«}_{X_1}}{\pm_{X_1}}$$

$$Z_2^* = \frac{x_2^* - \text{«}_{X_2}}{\pm_{X_2}}$$

$$Z_3^* = \frac{x_3^* - \text{«}_{X_3}}{\pm_{X_3}}$$

For first iteration

$$x_1^* = \text{«}_{X_1}$$

$$x_2^* = \text{«}_{X_2}$$

&

$$x_2^* = \text{«}_{X_1} . \text{«}_{X_2}$$

For limit state function

$$g = X_1 . X_2 - X_3 = 0 \Rightarrow X_3 = X_1 . X_2$$

Now partial derivatives of Limit State Function with respect to reduced variates is given by:

$$G_1 = -\frac{¢ g}{¢ z_1} = -\frac{¢ g}{¢ x_1}.\frac{¢ x_1}{¢ z_1} = -X_2 ± _{X_1}$$

$$G_2 = -\frac{¢ g}{¢ z_2} = -\frac{¢ g}{¢ x_2}.\frac{¢ x_2}{¢ z_2} = -X_1 ± _{X_2}$$

$$G_3 = -\frac{¢ g}{¢ z_3} = -\frac{¢ g}{¢ x_3}.\frac{¢ x_3}{¢ z_3} = -(-1).± _{X_3} = ± _{X_3} (Tension)$$

$$G_3 = -\frac{¢ g}{¢ z_3} = -\frac{¢ g}{¢ x_3}.\frac{¢ x_3}{¢ z_3} = -(1).± _{X_3} = -± _{X_3} (compression)$$

$$G = \begin{Bmatrix} G_1 \\ G_2 \\ G_3 \end{Bmatrix}$$

4.3 Flow chart for reliability based evaluation of critical failure path of truss elements and system reliability of the truss upto level at zero.

Determination of coefficient of influence on member end forces of the truss elements due to all nodal forces acting on different nodes

a_{ij} Coefficient of influence on member end forces of the i^{th} truss elements due to nodal force acting at j^{th} node

↓

S_i is the stochastic variable describing the load effect of the i^{th} element.

$S_i = \sum_{j=1}^{k} a_{ij} P_j$, where a_{ij} the coefficient of influence is determined by linear elastic analysis using finite element method.

↓

Formation of safety margin M_i for the failure element i

$M_i = \min[(R_i^+ - S_i), (R_i^- + S_i)]$

Failure criteria for failure element “i”

$M_i \leq 0$

↓

Component Level Reliability Index of element i=

$$_{1} = \frac{«_{M_i}}{\pm_{M_i}}$$

System Reliability at Level zero

$$_{S} = \min_{i=1..to...n}(\ _{i})$$

Where n is the number of failure element.

Identification of critical failure element whose component level reliability index is Minimum.

Removing the failure element from member connectivity matrix.
Similarly modifying the all input vector i.e area vector, E-vector , Elemental stiffness matrix etc.

Modifying the global stiffness matrix after eliminating the stiffness of the failure element.

Calculation of modified nodal displacements and member end forces for different load cases as per their variations as described earlier.

Modifying the influence factor with respect to external loads

Formation of appropriate limit state function.
LSF is the function of c/s area of the truss element, yield stress of the material and nodal forces acting at different nodes on the truss.

Reliability analysis of the remaining failure element.

Similar procedure may follow to get next failure element.
The procedure may continue until structure become determinate due to reduction of truss element one by one.
The said structure will be in failure state when any one of the remaining truss elements fails further.

Chapter 5

RESULT & DISCUSSION

5.1 Component Level Reliability Analysis of statically determinate Truss

5.1.1 (Example: 01) Reliability Analysis of the 21-bar statically determinate truss model:

In the first case study a statically determinate 21 bar steel truss has been considered which are made of structural steel of rectangular and square hollow sections. The detailed structural model with node numbers, element numbers are shown in the following figures:

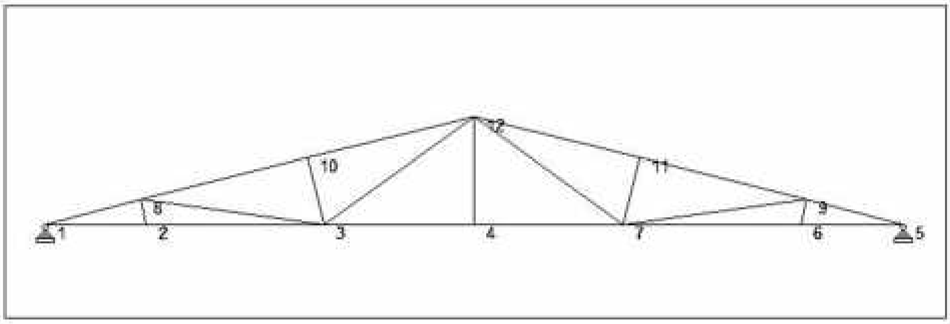


Figure-5.1 joint/node numbers of 21 bar truss.

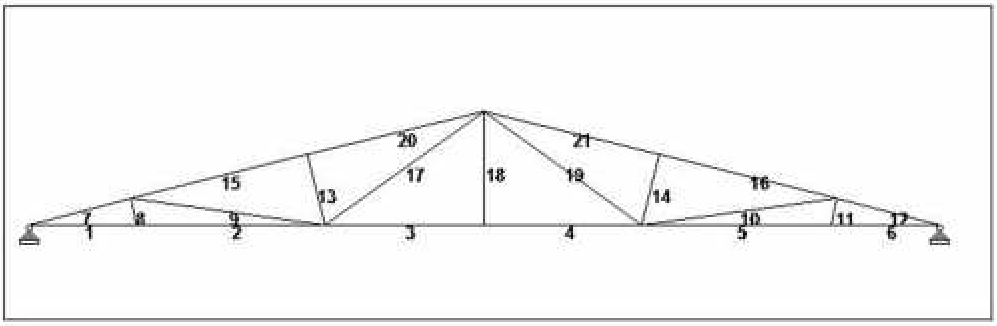
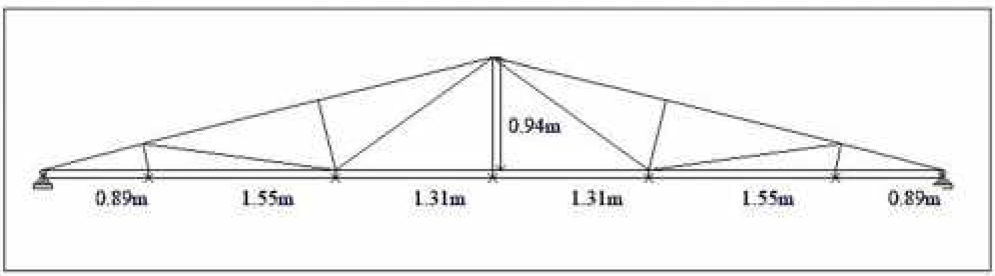


Figure-5.2 Element numbers of 21 bar truss.



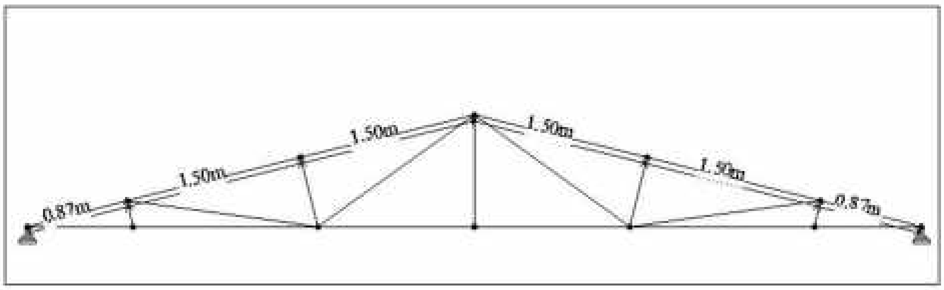


Figure-5.3 (a) & (b) showing dimension of 21 bar truss

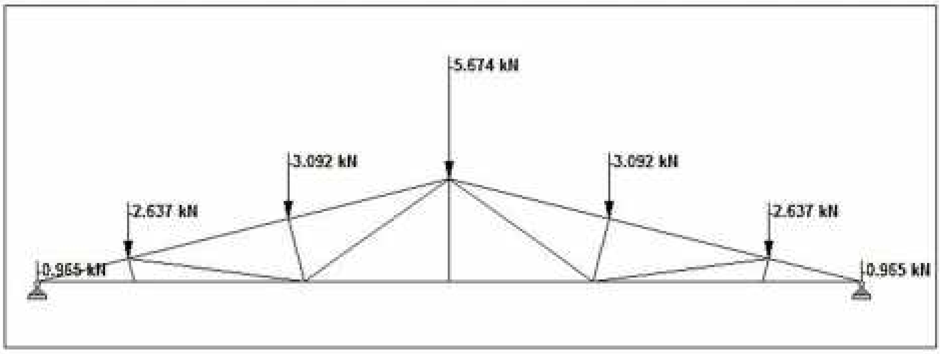


Figure-5.4 Mean Nodal load for DL condition.

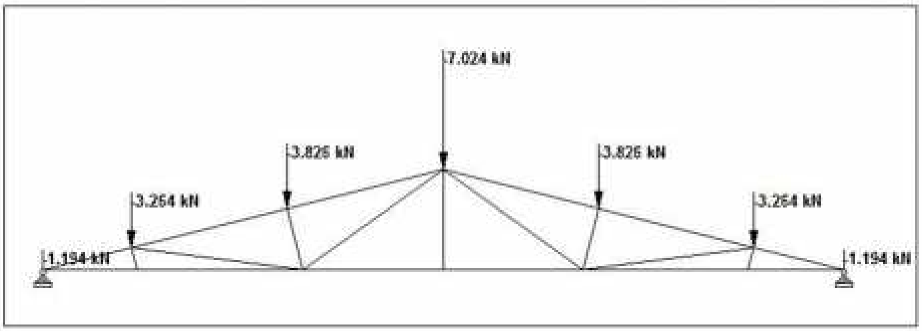


Figure-5.5 Mean Nodal load for LL condition.

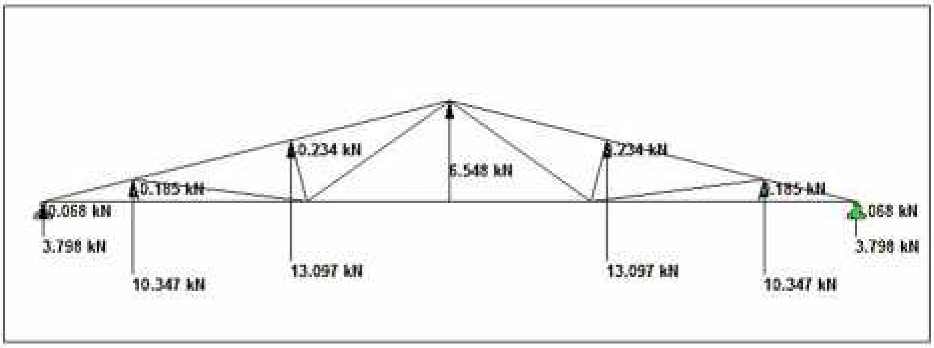


Figure-5.6 Mean Nodal load for WL condition.

5.1.2 Finite element modeling of the 21 bar statically determinate truss in MATLAB platform to obtain Component Level Reliability Index.:

Table-5.1 Nodal coordinate

joint coordinate			
Node No	X-coordinate (in m)	Y-coordinate (in m)	Z-coordinate (in m)
1	0	0	0
2	0.892	0	0
3	2.4382	0	0
4	3.75	0	0
5	7.5	0	0
6	6.608	0	0
7	5.0618	0	0
8	0.8395	0.2099	0
9	6.6605	0.2099	0
10	2.2948	0.5737	0
11	5.2052	0.5737	0
12	3.75	0.9375	0

Table-5.2 Member connectivity between

Member Connectivity		
Member No	Starting Node	Ending Node
1	1	2
2	2	3
3	3	4
4	7	4
5	6	7
6	5	6
7	1	8
8	2	8
9	3	8
10	7	9
11	6	9
12	5	9
13	3	10
14	7	11
15	8	10
16	9	11
17	12	3
18	4	12
19	12	7
20	10	12
21	11	12

Table-5.3 c/s area of bars & bar designation

Member No	Member area(mean) in m2	Remarks
1	6.71E-04	SHS 60X60X2.6
2	6.71E-04	SHS 60X60X2.6
3	6.71E-04	SHS 60X60X2.6
4	6.71E-04	SHS 60X60X2.6
5	6.71E-04	SHS 60X60X2.6
6	6.71E-04	SHS 60X60X2.6
7	4.76E-04	SHS 50x50x2.6
8	2.16E-04	SHS 25x25x2.6
9	2.88E-04	SHS 32X32X2.6
10	2.88E-04	SHS 32X32X2.6
11	2.16E-04	SHS 25x25x2.6
12	4.76E-04	SHS 50x50x2.6
13	2.16E-04	SHS 25x25x2.6
14	2.16E-04	SHS 25x25x2.6
15	4.76E-04	SHS 50x50x2.6
16	4.76E-04	SHS 50x50x2.6
17	5.25E-04	SHS 32X32X3.2
18	2.16E-04	SHS 25x25x2.6
19	5.25E-04	SHS 32X32X3.2
20	4.76E-04	SHS 50x50x2.6
21	4.76E-04	SHS 50x50x2.6

Table-5.4 E-value of truss elements

Moduls of Elasticity of truss members	
Member No	E-value in kN/m2
1	2.05E+08
2	2.05E+08
3	2.05E+08
4	2.05E+08
5	2.05E+08
6	2.05E+08
7	2.05E+08
8	2.05E+08
9	2.05E+08
10	2.05E+08
11	2.05E+08
12	2.05E+08
13	2.05E+08
14	2.05E+08
15	2.05E+08
16	2.05E+08
17	2.05E+08
18	2.05E+08
19	2.05E+08
20	2.05E+08
21	2.05E+08

Table-5.5 applied load (DL) at different nodes

Mean Nodal Forces in kN under DL calculation			
Node No	Nodal force in X-dir	Nodal force in Y-dir	Nodal force in Z-dir
1	0	-0.965	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	-0.965	0
6	0	0	0
7	0	0	0
8	0	-2.637	0
9	0	-2.637	0
10	0	-3.091	0
11	0	-3.091	0
12	0	-5.674	0

Table-5.6 applied load (LL) at different nodes

Mean Nodal Forces in kN under LL calculation			
Node No	Nodal force in X-dir	Nodal force in Y-dir	Nodal force in Z-dir
1	0	-1.194	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	-1.194	0
6	0	0	0
7	0	0	0
8	0	-3.264	0
9	0	-3.264	0
10	0	-3.826	0
11	0	-3.826	0
12	0	-7.024	0

Randomness of the Design variables(normal):

Mean Yield Stress(f_y)	310 Mpa
COV of f_y	0.1
COV of C/S area of element (A_i)	0.1
COV of Load P_i	0.1

Table-5.7 applied load (WL) at different nodes

Mean Nodal Forces in kN under WL calculation			
Node No	Nodal force in X-dir	Nodal force in X-dir	Nodal force in X-dir
1	-0.068	3.798	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0.068	3.798	0
6	0	0	0
7	0	0	0
8	-0.185	10.347	0
9	0.185	10.347	0
10	-0.234	13.097	0
11	0.234	13.097	0
12	0	6.548	0

Table-5.8 Standard Deviation of applied load (DL) at different nodes

SD of Nodal Forces under DL calculation			
Node No	SD of Nodal force in X-dir	SD of Nodal force in Y-dir	SD of Nodal force in Z-dir
1	0	0.097	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0.097	0
6	0	0	0
7	0	0	0
8	0	0.264	0
9	0	0.264	0
10	0	0.309	0
11	0	0.309	0
12	0	0.284	0

Table-5.9 Standard Deviation of applied load (LL) at different nodes

SD of Nodal Forces under LL calculation			
Node No	SD of Nodal force in X-dir	SD of Nodal force in Y-dir	SD of Nodal force in Z-dir
1	0	0.119	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0.119	0
6	0	0	0
7	0	0	0
8	0	0.326	0
9	0	0.326	0
10	0	0.383	0
11	0	0.383	0
12	0	0.351	0

Table-5.10 Standard Deviation of applied load (WL) at different nodes

SD of Nodal Forces under WL calculation			
Node No	SD of Nodal force in X-dir	SD of Nodal force in Y-dir	SD of Nodal force in Z-dir
1	0.007	0.38	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0.007	0.38	0
6	0	0	0
7	0	0	0
8	0.019	1.035	0
9	0.019	1.035	0
10	0.023	1.31	0
11	0.023	1.31	0
12	0.012	0.327	0

Table-5.11 (a) Section properties and resistance properties of 21 bar Truss

BAR NO	DESIGNA-TION	THICKNESS	C/S AREA IN cm2	Moment of Inertia in cm4		Radius of Gyration in cm			
				Ixx about XX- axis	Iyy about YY-axis	rxx about xx axis	ryy about yy axis	Lemda λ	Fy N/mm2 (Mean Value)
1	SHS 60X60X2.6	2.6	5.8	31.33	31.33	2.33	2.33	0.468	310
2	SHS 60X60X2.6	2.6	5.8	31.33	31.33	2.33	2.33	0.812	310
3	SHS 60X60X2.6	2.6	5.8	31.33	31.33	2.33	2.33	0.689	310
4	SHS 60X60X2.6	2.6	5.8	31.33	31.33	2.33	2.33	0.689	310
5	SHS 60X60X2.6	2.6	5.8	31.33	31.33	2.33	2.33	0.812	310
6	SHS 60X60X2.6	2.6	5.8	31.33	31.33	2.33	2.33	0.468	310
7	SHS 50x50x2.6	2.6	4.76	17.47	17.47	1.92	1.92	0.551	310
8	SHS 25x25x2.6	2.6	2.16	1.72	1.72	0.89	0.89	0.297	310
9	SHS 32X32X2.6	2.6	2.88	4.02	4.02	1.18	1.18	1.671	310
10	SHS 32X32X2.6	2.6	2.88	4.02	4.02	1.18	1.18	1.671	310
11	SHS 25x25x2.6	2.6	2.16	1.72	1.72	0.89	0.89	0.297	310
12	SHS 50x50x2.6	2.6	4.76	17.47	17.47	1.92	1.92	0.551	310
13	SHS 25x25x2.6	2.6	2.16	1.72	1.72	0.89	0.89	0.813	310
14	SHS 25x25x2.6	2.6	2.16	1.72	1.72	0.89	0.89	0.813	310
15	SHS 50x50x2.6	2.6	4.76	17.47	17.47	1.92	1.92	0.956	310
16	SHS 50x50x2.6	2.6	4.76	17.47	17.47	1.92	1.92	0.956	310
17	SHS 32X32X3.2	3.2	3.42	4.54	4.54	1.15	1.15	1.715	310
18	SHS 25x25x2.6	2.6	2.16	1.72	1.72	0.89	0.89	1.288	310
19	SHS 32X32X3.2	3.2	3.42	4.54	4.54	1.15	1.15	1.715	310
20	SHS 50x50x2.6	2.6	4.76	17.47	17.47	1.92	1.92	0.955	310
21	SHS 50x50x2.6	2.6	4.76	17.47	17.47	1.92	1.92	0.955	310

Table-5.11 (b) Section properties and resistance properties of 21 bar Truss

BAR NO	DESIGNATION	K	LENGTH IN Mtr	R min in cm	E in KN/M2	α alpha	ϕ phai	stress reduction factor	safety factor for strength	design compressive stress in N/mm2 f_{cd}
1	SHS 60X60X2.6	1	0.892	2.33	210000	0.49	0.675	0.861	1	266.91
2	SHS 60X60X2.6	1	1.5462	2.33	210000	0.49	0.98	0.654	1	202.74
3	SHS 60X60X2.6	1	1.3118	2.33	210000	0.49	0.857	0.732	1	226.92
4	SHS 60X60X2.6	1	1.3118	2.33	210000	0.49	0.857	0.732	1	226.92
5	SHS 60X60X2.6	1	1.5462	2.33	210000	0.49	0.98	0.654	1	202.74
6	SHS 60X60X2.6	1	0.892	2.33	210000	0.49	0.675	0.861	1	266.91
7	SHS 50x50x2.6	1	0.865343	1.92	210000	0.49	0.738	0.814	1	252.34

BAR NO	DESIGNATION	K	LENGTH IN Mtr	R min in cm	E in KN/M2	α alpha	ϕ phai	Stress reduction factor	Safety factor for strength	design compressive stress in N/mm2 f_{cd}
8	SHS 25x25x2.6	1	0.216366	0.89	210000	0.49	0.568	0.95	1	294.5
9	SHS 32X32X2.6	1	1.61242	1.18	210000	0.49	2.257	0.265	1	82.15
10	SHS 32X32X2.6	1	1.61242	1.18	210000	0.49	2.257	0.265	1	82.15
11	SHS 25x25x2.6	1	0.216366	0.89	210000	0.49	0.568	0.95	1	294.5
12	SHS 50x50x2.6	1	0.865343	1.92	210000	0.49	0.738	0.814	1	252.34
13	SHS 25x25x2.6	1	0.59135	0.89	210000	0.49	0.981	0.654	1	202.74
14	SHS 25x25x2.6	1	0.59135	0.89	210000	0.49	0.981	0.654	1	202.74
15	SHS 50x50x2.6	1	1.500083	1.92	210000	0.49	1.142	0.566	1	175.46
16	SHS 50x50x2.6	1	1.500083	1.92	210000	0.49	1.142	0.566	1	175.46
17	SHS 32X32X3.2	1	1.612366	1.15	210000	0.49	2.342	0.254	1	78.74
18	SHS 25x25x2.6	1	0.9375	0.89	210000	0.49	1.596	0.394	1	122.14
19	SHS 32X32X3.2	1	1.612366	1.15	210000	0.49	2.342	0.254	1	78.74
20	SHS 50x50x2.6	1	1.499986	1.92	210000	0.49	1.141	0.566	1	175.46
21	SHS 50x50x2.6	1	1.499986	1.92	210000	0.49	1.141	0.566	1	175.46

Table -5.12 Member end force (axial force) of element no-01 due to variation of load (DL) at different nodes.

MEMBER END FORCES OF THE TRUSS ELEMENTS AGAINST DL CONDITION									
MEMBER END FORCE(IN KN) OF MEM 1 AGAINST DL CONDITION									
NODAL FORCE AT NODE 8 IN KN in Y-dir	NODAL FORCE AT NODE 9 IN KN in Y-dir	NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	MEMBER END FORCE AT NODE 8 IN KN	MEMBER END FORCE AT NODE 9 IN KN	MEMBER END FORCE AT NODE 10 IN KN	MEMBER END FORCE AT NODE 11 IN KN	MEMBER END FORCE AT NODE 12 IN KN
-3.428	-3.428	-4.018	-4.018	-7.376	7.182	-3.460	4.209	-2.028	-0.001
-3.296	-3.296	-3.864	-3.864	-7.093	6.906	-3.326	4.047	-1.950	-0.001
-3.164	-3.164	-3.709	-3.709	-6.809	6.629	-3.193	3.885	-1.872	-0.001
-3.033	-3.033	-3.555	-3.555	-6.525	6.353	-3.060	3.723	-1.794	-0.001
-2.901	-2.901	-3.400	-3.400	-6.241	6.077	-2.927	3.561	-1.716	-0.001
-2.769	-2.769	-3.246	-3.246	-5.958	5.801	-2.794	3.399	-1.638	0.000
-2.637	-2.637	-3.091	-3.091	-5.674	5.525	-2.661	3.238	-1.560	0.000
-2.505	-2.505	-2.936	-2.936	-5.390	5.248	-2.528	3.076	-1.482	0.000
-2.373	-2.373	-2.782	-2.782	-5.107	4.972	-2.395	2.914	-1.404	0.000
-2.241	-2.241	-2.627	-2.627	-4.823	4.696	-2.262	2.752	-1.326	0.000
-2.110	-2.110	-2.473	-2.473	-4.539	4.420	-2.129	2.590	-1.248	0.000
-1.978	-1.978	-2.318	-2.318	-4.256	4.143	-1.996	2.428	-1.170	0.000
-1.846	-1.846	-2.164	-2.164	-3.972	3.867	-1.863	2.266	-1.092	0.000
-2.637	**-2.637**	**-3.091**	**-3.091**	**-5.674**	Mean nodal force in KN				
0.264	**0.264**	**0.309**	**0.309**	**0.567**	SD OF NODAL FORCE				

Table -5.13 Member end force (axial force) of element no-01 due to variation of load (LL) at different nodes.

MEMBER END FORCES IN ALL TRUSS ELEMENTS AGAINST LL CONDITION									
MEMBER END FORCE(IN KN) OF MEM 1 AGAINST LL CONDITION									
NODAL FORCE AT NODE 8 IN KN in Y-dir	NODAL FORCE AT NODE 9 IN KN in Y-dir	NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	MEMBER END FORCE AT NODE 8 IN KN	MEMBER END FORCE AT NODE 9 IN KN	MEMBER END FORCE AT NODE 10 IN KN	MEMBER END FORCE AT NODE 11 IN KN	MEMBER END FORCE AT NODE 12 IN KN
-4.243	-4.243	-4.974	-4.974	-9.131	8.890	-4.282	5.210	-2.510	-0.001
-4.080	-4.080	-4.783	-4.783	-8.780	8.548	-4.117	5.009	-2.413	-0.001
-3.917	-3.917	-4.591	-4.591	-8.429	8.206	-3.953	4.809	-2.317	-0.001
-3.660	-3.660	-4.290	-4.290	-7.875	7.864	-3.788	4.609	-2.220	-0.001
-3.590	-3.590	-4.209	-4.209	-7.726	7.522	-3.623	4.408	-2.124	-0.001
-3.427	-3.427	-4.017	-4.017	-7.375	7.180	-3.459	4.208	-2.027	-0.001
-3.264	-3.264	-3.826	-3.826	-7.024	6.838	-3.294	4.007	-1.931	-0.001
-3.101	-3.101	-3.635	-3.635	-6.673	6.496	-3.129	3.807	-1.834	-0.001
-2.938	-2.938	-3.443	-3.443	-6.322	6.154	-2.965	3.607	-1.738	-0.001
-2.774	-2.774	-3.252	-3.252	-5.970	5.812	-2.800	3.406	-1.641	0.000
-2.611	-2.611	-3.061	-3.061	-5.619	5.470	-2.635	3.206	-1.544	0.000
-2.448	-2.448	-2.870	-2.870	-5.268	5.129	-2.470	3.006	-1.448	0.000
-2.285	-2.285	-2.678	-2.678	-4.917	4.787	-2.306	2.805	-1.351	0.000
-3.264	**-3.264**	**-3.826**	**-3.826**	**-7.024**	Mean nodal force in KN				
0.326	**0.326**	**0.383**	**0.383**	**0.702**	SD OF NODAL FORCE				

Table -5.14 Member end force (axial force) of element no-01 due to variation of load (WL) at different nodes.

MEMBER END FORCES IN ALL TRUSS ELEMENTS AGAINST WL CONDITION									
MEMBER END FORCE(IN KN) OF MEM 1 AGAINST WL CONDITION									
NODAL FORCE AT NODE 8 IN KN in x-dir	NODAL FORCE AT NODE 8 IN KN in Y-dir	NODAL FORCE AT NODE 9 IN KN in x-dir	NODAL FORCE AT NODE 9 IN KN in Y-dir	NODAL FORCE AT NODE 10 IN KN in x-dir	NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in x-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	Remarks
-0.241	7.243	0.130	7.243	-0.304	9.168	0.164	9.168	4.584	(MEAN-3.0*SD):
-0.231	7.760	0.139	7.760	-0.293	9.823	0.176	9.823	4.911	(MEAN-2.5*SD):
-0.222	8.278	0.148	8.278	-0.281	10.478	0.187	10.478	5.238	(MEAN-2.0*SD):
-0.213	8.795	0.157	8.795	-0.269	11.132	0.199	11.132	5.566	(MEAN-1.5*SD):
-0.204	9.312	0.167	9.312	-0.257	11.787	0.211	11.787	5.893	(MEAN-1.0*SD):
-0.194	9.830	0.176	9.830	-0.246	12.442	0.222	12.442	6.221	(MEAN-0.5*SD):
-0.185	10.347	0.185	10.347	-0.234	13.097	0.234	13.097	6.548	(MEAN):
-0.176	10.864	0.194	10.864	-0.222	13.752	0.246	13.752	6.875	(MEAN-+0.5*SD):
-0.167	11.382	0.204	11.382	-0.211	14.407	0.257	14.407	7.203	(MEAN+1.0*SD):
-0.157	11.899	0.213	11.899	-0.199	15.062	0.269	15.062	7.530	(MEAN+1.5*SD):
-0.148	12.416	0.222	12.416	-0.187	15.716	0.281	15.716	7.858	(MEAN+2.0*SD):
-0.139	12.934	0.231	12.934	-0.176	16.371	0.293	16.371	8.185	(MEAN-+2.5*SD):
-0.130	13.451	0.241	13.451	-0.164	17.026	0.304	17.026	8.512	(MEAN-+3.0*SD):
-0.185	**10.347**	**0.185**	**10.347**	**-0.234**	**13.097**	**0.234**	**13.097**	**6.548**	Mean nodal force in KN
0.019	**1.035**	**0.019**	**1.035**	**0.023**	**1.310**	**0.023**	**1.310**	**0.655**	SD OF NODAL FORCE

Table -5.15 Member end force (axial force) of element no-01 due to variation of load (WL) at different nodes.

MEMBER END FORCE AT NODE 8 IN KN in x-dir	MEMBER END FORCE AT NODE 8 IN KN in Y-dir	MEMBER END FORCE AT NODE 9 IN KN in x-dir	MEMBER END FORCE AT NODE 9 IN KN in Y-dir	MEMBER END FORCE AT NODE 10 IN KN in x-dir	MEMBER END FORCE AT NODE 10 IN KN in Y-dir	MEMBER END FORCE AT NODE 11 IN KN in x-dir	MEMBER END FORCE AT NODE 11 IN KN in Y-dir	MEMBER END FORCE AT NODE 12 IN KN in Y-dir
-0.126	-15.174	0.033	7.309	-0.080	-9.603	0.021	4.626	0.000
-0.121	-16.258	0.035	7.831	-0.077	-10.289	0.022	4.957	0.000
-0.116	-17.342	0.037	8.353	-0.074	-10.974	0.024	5.287	0.000
-0.111	-18.425	0.040	8.876	-0.070	-11.660	0.025	5.617	0.000
-0.107	-19.509	0.042	9.398	-0.067	-12.346	0.027	5.948	0.000
-0.102	-20.593	0.044	9.920	-0.064	-13.032	0.028	6.278	0.001
-0.097	-21.677	0.047	10.442	-0.061	-13.718	0.030	6.609	0.001
-0.092	-22.761	0.049	10.964	-0.058	-14.404	0.031	6.939	0.001
-0.087	-23.845	0.051	11.486	-0.055	-15.090	0.032	7.270	0.001
-0.082	-24.929	0.054	12.008	-0.052	-15.776	0.034	7.600	0.001
-0.078	-26.012	0.056	12.530	-0.049	-16.462	0.035	7.931	0.001
-0.073	-27.096	0.058	13.052	-0.046	-17.148	0.037	8.261	0.001
-0.068	-28.180	0.061	13.574	-0.043	-17.834	0.038	8.591	0.001

Table -5.16 Member end force (axial force) of all elements due to variation of all joint load (DL and LL) at different nodes.

NODAL LOAD IN ALL CONSIDERED NODAL POINT	MEMBER END FORCE IN KN									
	(DL+LL) condition									
(MEAN-3.0*SD):	13.210	13.210	-24.552	-24.552	13.210	13.210	-102.724	0.000	-20.280	-20.280
(MEAN-2.5*SD):	12.702	12.702	-23.608	-23.608	12.702	12.702	-98.773	0.000	-19.500	-19.500
(MEAN-2.0*SD):	12.193	12.193	-22.664	-22.664	12.193	12.193	-94.822	0.000	-18.720	-18.720
(MEAN-1.5*SD):	11.685	11.685	-21.719	-21.719	11.685	11.685	-90.872	0.000	-17.940	-17.940
(MEAN-1.0*SD):	11.177	11.177	-20.775	-20.775	11.177	11.177	-86.921	0.000	-17.160	-17.160
(MEAN-0.5*SD):	10.669	10.669	-19.831	-19.831	10.669	10.669	-82.970	0.000	-16.380	-16.380
(MEAN):	10.161	10.161	-18.886	-18.886	10.161	10.161	-79.019	0.000	-15.600	-15.600
(MEAN-+0.5*SD):	9.653	9.653	-17.942	-17.942	9.653	9.653	-75.068	0.000	-14.820	-14.820
(MEAN+1.0*SD):	9.145	9.145	-16.998	-16.998	9.145	9.145	-71.117	0.000	-14.040	-14.040
(MEAN+1.5*SD):	8.637	8.637	-16.053	-16.053	8.637	8.637	-67.166	0.000	-13.260	-13.260
(MEAN+2.0*SD):	8.129	8.129	-15.109	-15.109	8.129	8.129	-63.215	0.000	-12.480	-12.480
(MEAN-+2.5*SD):	7.621	7.621	-14.165	-14.165	7.621	7.621	-59.264	0.000	-11.700	-11.700
(MEAN-+3.0*SD):	7.113	7.113	-13.220	-13.220	7.113	7.113	-55.313	0.000	-10.920	-10.920
MEMBER NO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

NODAL LOAD IN ALL CONSIDERED NODAL POINT	MEMBER END FORCE IN KN										
	(DL+LL) condition										
(MEAN-3.0*SD):	0.000	-102.724	-8.725	-8.725	-81.997	-81.997	19.098	0.000	19.098	-79.816	-79.816
(MEAN-2.5*SD):	0.000	-98.773	-8.389	-8.389	-78.843	-78.843	18.364	0.000	18.364	-76.746	-76.746
(MEAN-2.0*SD):	0.000	-94.822	-8.054	-8.054	-75.689	-75.689	17.629	0.000	17.629	-73.676	-73.676
(MEAN-1.5*SD):	0.000	-90.872	-7.718	-7.718	-72.536	-72.536	16.895	0.000	16.895	-70.607	-70.607
(MEAN-1.0*SD):	0.000	-86.921	-7.383	-7.383	-69.382	-69.382	16.160	0.000	16.160	-67.537	-67.537
(MEAN-0.5*SD):	0.000	-82.970	-7.047	-7.047	-66.228	-66.228	15.426	0.000	15.426	-64.467	-64.467
(MEAN):	0.000	-79.019	-6.712	-6.712	-63.074	-63.074	14.691	0.000	14.691	-61.397	-61.397
(MEAN-+0.5*SD):	0.000	-75.068	-6.376	-6.376	-59.921	-59.921	13.956	0.000	13.956	-58.327	-58.327
(MEAN+1.0*SD):	0.000	-71.117	-6.040	-6.040	-56.767	-56.767	13.222	0.000	13.222	-55.257	-55.257
(MEAN+1.5*SD):	0.000	-67.166	-5.705	-5.705	-53.613	-53.613	12.487	0.000	12.487	-52.188	-52.188
(MEAN+2.0*SD):	0.000	-63.215	-5.369	-5.369	-50.460	-50.460	11.753	0.000	11.753	-49.118	-49.118
(MEAN-+2.5*SD):	0.000	-59.264	-5.034	-5.034	-47.306	-47.306	11.018	0.000	11.018	-46.048	-46.048
(MEAN-+3.0*SD):	0.000	-55.313	-4.698	-4.698	-44.152	-44.152	10.284	0.000	10.284	-42.978	-42.978
MEMBER NO	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**

Table -5.17 Member end force (axial force) of all elements due to variation of all joint loads (DL and WL) at different nodes

NODAL LOAD IN ALL CONSIDERED NODAL POINT	MEMBER END FORCE IN KN									
	(DL+WL)									
(MEAN-3.0*SD):	-7.090	-7.090	13.047	13.047	-6.950	-6.950	31.144	-0.152	10.247	10.173
(MEAN-2.5*SD):	-8.223	-8.223	15.174	15.174	-8.105	-8.105	38.426	-0.205	11.957	11.896
(MEAN-2.0*SD):	-9.355	-9.355	17.301	17.301	-9.261	-9.261	45.708	0.049	13.667	13.618
(MEAN-1.5*SD):	-10.488	-10.488	19.428	19.428	-10.417	-10.417	52.991	-0.027	15.377	15.341
(MEAN-1.0*SD):	-11.620	-11.620	21.554	21.554	-11.573	-11.573	60.273	0.136	17.088	17.063
(MEAN-0.5*SD):	-12.753	-12.753	23.681	23.681	-12.729	-12.729	67.556	0.047	18.798	18.786
(MEAN):	-13.885	-13.885	25.808	25.808	-13.885	-13.885	74.838	0.052	20.508	20.508
(MEAN-+0.5*SD):	-15.018	-15.018	27.935	27.935	-15.041	-15.041	82.121	-0.033	22.219	22.231
(MEAN+1.0*SD):	-16.150	-16.150	30.061	30.061	-16.197	-16.197	89.403	-0.018	23.929	23.954
(MEAN+1.5*SD):	-17.283	-17.283	32.188	32.188	-17.353	-17.353	96.686	0.149	25.639	25.676
(MEAN+2.0*SD):	-18.415	-18.415	34.315	34.315	-18.509	-18.509	103.968	-0.035	27.350	27.399
(MEAN-+2.5*SD):	-19.548	-19.548	36.442	36.442	-19.665	-19.665	111.251	-0.099	29.060	29.121
(MEAN-+3.0*SD):	-20.680	-20.680	38.568	38.568	-20.821	-20.821	118.533	-0.129	30.770	30.844
MEMBER NO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

NODAL LOAD IN ALL CONSIDERED NODAL POINT	MEMBER END FORCE IN KN (DL+WL)										
(MEAN-3.0*SD):	-0.054	31.258	5.070	5.036	20.919	20.994	-10.753	0.000	-10.680	19.966	19.904
(MEAN-2.5*SD):	0.133	38.521	5.852	5.824	26.444	26.506	-12.442	0.000	-12.381	25.283	25.232
(MEAN-2.0*SD):	0.085	45.785	6.635	6.612	31.969	32.019	-14.130	0.000	-14.082	30.600	30.559
(MEAN-1.5*SD):	-0.110	53.048	7.417	7.400	37.494	37.531	-15.819	0.000	-15.782	35.917	35.887
(MEAN-1.0*SD):	0.000	60.312	8.200	8.189	43.019	43.044	-17.507	0.000	-17.483	41.235	41.214
(MEAN-0.5*SD):	-0.127	67.575	8.982	8.977	48.544	48.556	-19.196	0.000	-19.184	46.552	46.542
(MEAN):	-0.140	74.838	9.765	9.765	54.069	54.069	-20.885	0.000	-20.885	51.869	51.869
(MEAN-+0.5*SD):	-0.133	82.102	10.547	10.553	59.594	59.581	-22.573	0.000	-22.585	57.187	57.197
(MEAN+1.0*SD):	-0.257	89.365	11.330	11.341	65.118	65.094	-24.262	0.000	-24.286	62.504	62.524
(MEAN+1.5*SD):	-0.177	96.629	12.112	12.129	70.643	70.606	-25.950	0.000	-25.987	67.821	67.852
(MEAN+2.0*SD):	-0.046	103.892	12.895	12.918	76.168	76.118	-27.639	0.000	-27.687	73.138	73.179
(MEAN-+2.5*SD):	-0.078	111.156	13.677	13.706	81.693	81.631	-29.327	0.000	-29.388	78.456	78.507
(MEAN-+3.0*SD):	0.000	118.419	14.460	14.494	87.218	87.143	-31.016	0.000	-31.089	83.773	83.834
MEMBER NO	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**

Table: 5.18 Component Level Reliability Indices and probability of failure of the truss elements for different load cases:

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL	Probability of failure FOR DL+LL	Probability of failure FOR DL+WL
1	9.397	8.865	0.0000	0.0000
2	10.613	8.462	0.0000	0.0000
3	8.444	8.642	0.0000	0.0000
4	8.444	8.642	0.0000	0.0000
5	10.613	8.462	0.0000	0.0000
6	10.613	8.866	0.0000	0.0000
7	2.633	3.785	0.0493	0.0493
8	10.000	10.000	0.0000	0.0000
9	2.904	6.763	0.0000	0.0000
10	2.904	6.763	0.0000	0.0000
11	10.000	10.000	0.0000	0.0000
12	2.633	3.785	0.0493	0.0493
13	8.298	8.290	0.0000	0.0000
14	8.298	8.290	0.0000	0.0000
15	1.880	5.252	0.0014	0.0014
16	1.880	5.252	0.0014	0.0014
17	8.784	1.715	0.0000	0.0000
18	INFINITE	INFINITE	-	-
19	8.784	1.715	0.0000	0.0000
20	2.049	5.439	0.0009	0.0009
21	2.049	5.439	0.0009	0.0009

Table: 5.19 MEF condition of the truss elements for different load cases

MEMBER NO	Condition against DL+LL load case
1	Tension
2	Tension
3	Compression
4	Compression
5	Tension
6	Tension
7	Compression
8	Tension
9	Compression
10	Compression
11	Compression
12	Compression
13	Compression
14	Compression
15	Compression
16	Compression
17	Tension
18	Tension
19	Tension
20	Compression
21	Compression

MEMBER NO	Condition against DL+WL load case
1	Compression
2	Compression
3	Tension
4	Tension
5	Compression
6	Compression
7	Compression
8	Tension
9	Tension
10	Tension
11	Tension
12	Tension
13	Tension
14	Tension
15	Tension
16	Tension
17	Compression
18	Tension
19	Compression
20	Tension
21	Tension

Table: 5.20 Coefficient of Influence of nodal loads(DL/LL) on member end force of truss elements

MEMBER NO	C/S Area of the member in sqm	Coefficient of influence against MEF when NODAL load (DL/LL) acting at NODE 8 in Y-dir	Coefficient of influence against MEF when NODAL load (DL/LL) acting at NODE 9 in Y-dir	Coefficient of influence against MEF when NODAL load (DL/LL) acting at NODE 10 in Y-dir	Coefficient of influence against MEF when NODAL load (DL/LL) acting at NODE 11 in Y-dir	Coefficient of influence against MEF when NODAL load (DL/LL) acting at NODE 12 in Y-dir
1	0.00058	-2.095	1.009	-1.047	0.500	0.000
2	0.00058	-2.095	1.009	-1.047	0.500	0.000
3	0.00029	1.009	1.009	0.504	0.500	0.000
4	0.00029	1.009	1.009	0.504	0.500	0.000
5	0.00058	1.009	-2.095	0.505	-1.050	0.000
6	0.00058	1.009	-2.095	0.505	-1.050	0.000
7	0.000238	3.661	0.461	2.861	1.260	2.061
8	0.000216	0.000	0.000	0.000	0.000	0.000
9	0.000144	2.645	0.000	0.000	0.000	0.000
10	0.000144	0.000	2.645	0.000	0.000	0.000
11	0.000108	0.000	0.000	0.000	0.000	0.000
12	0.000238	0.461	3.661	1.261	2.860	2.061
13	0.000108	0.000	0.000	0.970	0.000	0.000
14	0.000108	0.000	0.000	0.000	0.970	0.000

15	0.000238	0.958	0.462	2.862	1.260	2.062
16	0.000238	0.462	0.958	1.262	2.860	2.062
17	0.000342	-0.592	0.000	-1.619	0.000	0.000
18	0.000216	0.000	0.000	0.000	0.000	0.000
19	0.000342	0.000	-0.592	0.000	-1.620	0.000
20	0.000238	0.958	0.462	2.619	1.260	2.062
21	0.000238	0.462	0.958	1.262	2.620	2.062
Mean Nodal Load(DL)		**-2.637**	**-2.637**	**-3.091**	**-3.091**	**-5.674**

Table:5.21 Mean and standard deviation of axial force of truss elements

BAR NO	Mean of member end force against DL in KN	Mean of member end force against LL in KN	Mean of member end force against WL in KN	Mean of member end force against DL+LL in KN	Mean of member end force against DL+WL in KN	SD of member end force against DL in KN	SD of member end force against LL in KN	SD of member end force against WL in KN	SD of member end force against DL+LL in KN	SD of member end force against DL+WL in KN
1	4.541	5.62	-18.426	10.161	-13.885	0.711	0.88	2.847	1.131	2.935
2	4.541	5.62	-18.426	10.161	-13.885	0.711	0.88	2.847	1.131	2.935
3	-8.44	-10.446	34.248	-18.886	25.808	0.436	0.54	1.747	0.694	1.801
4	-8.44	-10.446	34.248	-18.886	25.808	0.436	0.54	1.747	0.694	1.801
5	4.541	5.62	-18.426	10.161	-13.885	0.711	0.88	2.847	1.131	2.935
6	4.541	5.62	-18.426	10.161	-13.885	0.711	0.88	2.847	1.131	2.935
7	-35.31	-43.708	110.149	-79.019	74.838	1.803	2.231	5.76	2.868	6.035
8	0	0	0	0	0	0	0	0	0	0
9	-6.971	-8.629	27.48	-15.6	20.508	0.697	0.863	2.737	1.11	2.824
10	-6.971	-8.629	27.48	-15.6	20.508	0.697	0.863	2.737	1.11	2.824
11	0	0	0	0	0	0	0	0	0	0
12	-35.31	-43.708	110.149	-79.019	74.838	1.803	2.231	5.76	2.868	6.035
13	-2.999	-3.712	12.764	-6.711	9.765	0.3	0.371	1.271	0.477	1.306
14	-2.999	-3.712	12.764	-6.711	9.765	0.3	0.371	1.271	0.477	1.306
15	-28.185	-34.889	82.254	-63.074	54.069	1.543	1.91	4.451	2.456	4.711
16	-28.185	-34.889	82.254	-63.074	54.069	1.543	1.91	4.451	2.456	4.711
17	6.565	8.126	-27.449	14.691	-20.884	0.524	0.649	2.207	0.834	2.268
18	0	0	0	0	0	0	0	0	0	0
19	6.565	8.126	-27.449	14.691	-20.884	0.524	0.649	2.207	0.834	2.268
20	-27.436	-33.961	79.305	-61.397	51.869	1.501	1.859	4.187	2.389	4.448
21	-27.436	-33.961	79.305	-61.397	51.869	1.501	1.859	4.187	2.389	4.448

Table: 5.22 coefficient of influence of nodal loads against member end forces of truss element for primary load cases (WL).

MEMBER NO	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 8 in X-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 8 in Y-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 9 in X-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 9 in Y-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 10 in X-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 10 in Y-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 11 in X-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 11 in Y-dir	Coefficient of influence against MEF when NODAL load (WL) acting at NODE 12 in X-dir
1	0.524	-2.095	0.252	1.009	0.262	-1.047	0.126	0.505	0.000
2	0.524	-2.095	0.252	1.009	0.262	-1.047	0.126	0.505	0.000
3	-0.252	1.009	0.252	1.009	-0.126	0.504	0.126	0.504	0.000
4	-0.252	1.009	0.252	1.009	-0.126	0.504	0.126	0.504	0.000
5	-0.252	1.009	-0.524	-2.095	-0.126	0.505	-0.262	-1.047	0.000
6	-0.252	1.009	-0.524	-2.095	-0.126	0.505	-0.262	-1.047	0.000
7	0.115	3.661	0.115	0.461	0.315	2.861	0.315	1.261	2.061
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	-0.661	2.645	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.661	2.645	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	-0.115	0.461	-0.115	3.661	-0.315	1.261	-0.315	2.861	2.061
13	0.000	0.000	0.000	0.000	-0.243	0.970	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.243	0.970	0.000
15	-0.240	0.958	0.115	0.462	0.315	2.862	0.315	1.262	2.062
16	-0.115	0.462	0.240	0.958	-0.315	1.262	-0.315	2.862	2.062
17	0.148	-0.592	0.000	0.000	0.405	-1.619	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	-0.148	-0.592	0.000	0.000	-0.405	-1.619	0.000
20	-0.240	0.958	0.115	0.462	-0.655	2.619	0.315	1.262	2.062
21	-0.115	0.462	0.240	0.958	-0.315	1.262	0.655	2.619	2.062
Mean Nodal Load(WL)	**-0.185**	**10.347**	**0.185**	**10.347**	**-0.234**	**13.097**	**0.234**	**13.097**	**6.548**

Table: 5.23 Limit State Equations of truss elements for different failure mode (DD+LL CONDITION):

LSF_Member_1-DLLL	**$A_1xf_y\pm[(-2.095)xP_{8yDL} +(1.009)x\ P_{9yDL} +(-1.047)xP_{10yDL} +(0.5)xP_{11yDL}+(0)x\ P_{12yDL}+(-2.095)xP_{8yLL} +(1.009)x\ P_{9yLL}+(-1.047)xP_{10yLL}+(0.5)xP_{11yLL}+(0)x\ P_{12yLL}]$**
LSF_Member_2-DLLL	**$A_2xf_y\pm[(-2.095)xP_{8yDL} +(1.009)x\ P_{9yDL} +(-1.047)xP_{10yDL} +(0.5)xP_{11yDL}+(0)x\ P_{12yDL}+(-2.095)xP_{8yLL} +(1.009)x\ P_{9yLL}+(-1.047)xP_{10yLL}+(0.5)xP_{11yLL}+(0)x\ P_{12yLL}]$**
LSF_Member_3-DLLL	**$A_3xf_y\pm[(1.009)xP_{8yDL} +(1.009)x\ P_{9yDL} +(0.504)xP_{10yDL} +(0.5)xP_{11yDL}+(0)x\ P_{12yDL}+(1.009)xP_{8yLL} +(1.009)x\ P_{9yLL}+(0.504)xP_{10yLL}+(0.5)xP_{11yLL}+(0)x\ P_{12yLL}]$**
LSF_Member_4-DLLL	**$A_4xfy\pm[(1.009)xP_{8yDL} +(1.009)x\ P_{9yDL} +(0.504)xP_{10yDL} +(0.5)xP_{11yDL}+(0)x\ P_{12yDL}+(1.009)xP_{8yLL} +(1.009)x\ P_{9yLL}+(0.504)xP_{10yLL}+(0.5)xP_{11yLL}+(0)x\ P_{12yLL}]$**
LSF_Member_5-DLLL	**$A_5xf_y\pm[(1.009)xP_8y_{DL} +(-2.095)x\ P_{9yDL} +(0.505)xP_{10yDL} +(-1.05)xP_{11yDL}+(0)x\ P_{12yDL}+(1.009)xP_{8yLL} +(-2.095)x\ P_{9yLL}+(0.505)xP_{10yLL}+(-1.05)xP_{11yLL}+(0)x\ P_{12yLL}]$**
LSF_Member_6-DLLL	**$A_6xf_y\pm[(1.009)xP_{8yDL} +(-2.095)x\ P_{9yDL} +(0.505)xP_{10yDL} +(-1.05)xP_{11yDL}+(0)x\ P_{12yDL}+(1.009)xP_{8yLL} +(-2.095)x\ P_{9yLL}+(0.505)xP_{10yLL}+(-1.05)xP_{11yLL}+(0)x\ P_{12yLL}]$**
LSF_Member_7-DLLL	$A7xfy\pm[(3.661)xP_{8yDL} +(0.461)x\ P_{9yDL} +(2.861)xP_{10yD}L +(1.26)xP_{11yDL}+(2.061)x\ P_{12yDL}+(3.661)xP_{8yLL} +(0.461)x\ P_{9yLL}+(2.861)xP_{10yLL}+(1.26)xP_{11yLL}+(2.061)x\ P_{12yL}L]$
LSF_Member_8-DLLL	A8xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8yLL +(0)x P9yLL+(0)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_9-DLLL	A9xfy±[(2.645)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(2.645)xP8yLL +(0)x P9yLL+(0)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_10-DLLL	A10xfy±[(0)xP8yDL +(2.645)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8yLL +(2.645)x P9yLL+(0)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_11-DLLL	A11xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8yLL +(0)x P9yLL+(0)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_12-DLLL	A12xfy±[(0.461)xP8yDL +(3.661)x P9yDL +(1.261)xP10yDL +(2.86)xP11yDL+(2.061)x P12yDL+(0.461)xP8yLL +(3.661)x P9yLL+(1.261)xP10yLL+(2.86)xP11yLL+(2.061)x P12yLL]
LSF_Member_13-DLLL	A13xfy±[(0)xP8yDL +(0)x P9yDL +(0.97)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8yLL +(0)x P9yLL+(0.97)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_14-DLLL	A14xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0.97)xP11yDL+(0)x P12yDL+(0)xP8yLL +(0)x P9yLL+(0)xP10yLL+(0.97)xP11yLL+(0)x P12yLL]
LSF_Member_15-DLLL	A15xfy±[(0.958)xP8yDL +(0.462)x P9yDL +(2.862)xP10yDL +(1.26)xP11yDL+(2.062)x P12yDL+(0.958)xP8yLL +(0.462)x P9yLL+(2.862)xP10yLL+(1.26)xP11yLL+(2.062)x P12yLL]
LSF_Member_16-DLLL	A16xfy±[(0.462)xP8yDL +(0.958)x P9yDL +(1.262)xP10yDL +(2.86)xP11yDL+(2.062)x P12yDL+(0.462)xP8yLL +(0.958)x P9yLL+(1.262)xP10yLL+(2.86)xP11yLL+(2.062)x P12yLL]
LSF_Member_17-DLLL	A17xfy±[(-0.592)xP8yDL +(0)x P9yDL +(-1.619)xP10yDL +(0)xP11yDL+(0)x P12yDL+(-0.592)xP8yLL +(0)x P9yLL+(-1.619)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_18-DLLL	A18xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8yLL +(0)x P9yLL+(0)xP10yLL+(0)xP11yLL+(0)x P12yLL]
LSF_Member_19-DLLL	A19xfy±[(0)xP8yDL +(-0.592)x P9yDL +(0)xP10yDL +(-1.62)xP11yDL+(0)x P12yDL+(0)xP8yLL +(-0.592)x P9yLL+(0)xP10yLL+(-1.62)xP11yLL+(0)x P12yLL]
LSF_Member_20-DLLL	A20xfy±[(0.958)xP8yDL +(0.462)x P9yDL +(2.619)xP10yDL +(1.26)xP11yDL+(2.062)x P12yDL+(0.958)xP8yLL +(0.462)x P9yLL+(2.619)xP10yLL+(1.26)xP11yLL+(2.062)x P12yLL]
LSF_Member_21-DLLL	A21xfy±[(0.462)xP8yDL +(0.958)x P9yDL +(1.262)xP10yDL +(2.62)xP11yDL+(2.062)x P12yDL+(0.462)xP8yLL +(0.958)x P9yLL+(1.262)xP10yLL+(2.62)xP11yLL+(2.062)x P12yLL]

Table: 5.24 Limit State Equations of truss elements for different failure mode (DD+WL CONDITION):

LSF_Member_1-DLWL	A1xfy±[(-2.095)xP8yDL +(1.009)x P9yDL +(-1.047)xP10yDL +(0.5)xP11yDL+(0)x P12yDL+(0.524)xP8xWL +(-2.095)x P8yWL +(0.252)xP9xWL +(1.009)x P9yWL +(0.262)xP10xWL +-1.047x P10yWL +0.126xP11xWL +0.505x P11yWL +0x P11yWL +0x P11yWL +0x P12yWL]
LSF_Member_2-DLWL	A2xfy±[(-2.095)xP8yDL +(1.009)x P9yDL +(-1.047)xP10yDL +(0.5)xP11yDL+(0)x P12yDL+(0.524)xP8xWL +(-2.095)x P8yWL +(0.252)xP9xWL +(1.009)x P9yWL +(0.262)xP10xWL +-1.047x P10yWL +0.126xP11xWL +0.505x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_3-DLWL	A3xfy±[(1.009)xP8yDL +(1.009)x P9yDL +(0.504)xP10yDL +(0.5)xP11yDL+(0)x P12yDL+(-0.252)xP8xWL +(1.009)x P8yWL +(0.252)xP9xWL +(1.009)x P9yWL +(-0.126)xP10xWL +0.504x P10yWL +0.126xP11xWL +0.504x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_4-DLWL	A4xfy±[(1.009)xP8yDL +(1.009)x P9yDL +(0.504)xP10yDL +(0.5)xP11yDL+(0)x P12yDL+(-0.252)xP8xWL +(1.009)x P8yWL +(0.252)xP9xWL +(1.009)x P9yWL +(-0.126)xP10xWL +0.504x P10yWL +0.126xP11xWL +0.504x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_5-DLWL	A5xfy±[(1.009)xP8yDL +(-2.095)x P9yDL +(0.505)xP10yDL +(-1.05)xP11yDL+(0)x P12yDL+(-0.252)xP8xWL +(1.009)x P8yWL +(-0.524)xP9xWL +(-2.095)x P9yWL +(-0.126)xP10xWL +0.505x P10yWL +-0.262xP11xWL +-1.047x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_6-DLWL	A6xfy±[(1.009)xP8yDL +(-2.095)x P9yDL +(0.505)xP10yDL +(-1.05)xP11yDL+(0)x P12yDL+(-0.252)xP8xWL +(1.009)x P8yWL +(-0.524)xP9xWL +(-2.095)x P9yWL +(-0.126)xP10xWL +0.505x P10yWL +-0.262xP11xWL +-1.047x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_7-DLWL	A7xfy±[(3.661)xP8yDL +(0.461)x P9yDL +(2.861)xP10yDL +(1.26)xP11yDL+(2.061)x P12yDL+(0.115)xP8xWL +(3.661)x P8yWL +(0.115)xP9xWL +(0.461)x P9yWL +(0.315)xP10xWL +2.861x P10yWL +0.315xP11xWL +1.261x P11yWL +2.061x P11yWL +2.061x+2.061x P12yWL]
LSF_Member_8-DLWL	A8xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(0)xP9xWL +(0)x P9yWL +(0)xP10xWL +0x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_9-DLWL	A9xfy±[(2.645)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(-0.661)xP8xWL +(2.645)x P8yWL +(0)xP9xWL +(0)x P9yWL +(0)xP10xWL +0x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_10-DLWL	A10xfy±[(0)xP8yDL +(2.645)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(0.661)xP9xWL +(2.645)x P9yWL +(0)xP10xWL +0x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_11-DLWL	A11xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(0)xP9xWL +(0)x P9yWL +(0)xP10xWL +0x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_12-DLWL	A12xfy±[(0.461)xP8yDL +(3.661)x P9yDL +(1.261)xP10yDL +(2.86)xP11yDL+(2.061)x P12yDL+(-0.115)xP8xWL +(0.461)x P8yWL +(-0.115)xP9xWL +(3.661)x P9yWL +(-0.315)xP10xWL +1.261x P10yWL +-0.315xP11xWL +2.861x P11yWL +2.061x P11yWL +2.061x+2.061x P12yWL]
LSF_Member_13-DLWL	A13xfy±[(0)xP8yDL +(0)x P9yDL +(0.97)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(0)xP9xWL +(0)x P9yWL +(-0.243)xP10xWL +0.97x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_14-DLWL	A14xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0.97)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(0)xP9xWL +(0)x P9yWL +(0)xP10xWL +0x P10yWL +0.243xP11xWL +0.97x P11yWL +0x P11yWL +0x+0x P12yWL]

LSF_Member_15-DLWL	A15xfy±[(0.958)xP8yDL +(0.462)x P9yDL +(2.862)xP10yDL +(1.26)xP11yDL+(2.062)x P12yDL+(-0.24)xP8xWL +(0.958)x P8yWL +(0.115)xP9xWL +(0.462)x P9yWL +(0.315)xP10xWL +2.862x P10yWL +0.315xP11xWL +1.262x P11yWL +2.062x P11yWL +2.062x+2.062x P12yWL]
LSF_Member_16-DLWL	A16xfy±[(0.462)xP8yDL +(0.958)x P9yDL +(1.262)xP10yDL +(2.86)xP11yDL+(2.062)x P12yDL+(-0.115)xP8xWL +(0.462)x P8yWL +(0.24)xP9xWL +(0.958)x P9yWL +(-0.315)xP10xWL +1.262x P10yWL +-0.315xP11xWL +2.862x P11yWL +2.062x P11yWL +2.062x+2.062x P12yWL]
LSF_Member_17-DLWL	A17xfy±[(-0.592)xP8yDL +(0)x P9yDL +(-1.619)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0.148)xP8xWL +(-0.592)x P8yWL +(0)xP9xWL +(0)x P9yWL +(0.405)xP10xWL +-1.619x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_18-DLWL	A18xfy±[(0)xP8yDL +(0)x P9yDL +(0)xP10yDL +(0)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(0)xP9xWL +(0)x P9yWL +(0)xP10xWL +0x P10yWL +0xP11xWL +0x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_19-DLWL	A19xfy±[(0)xP8yDL +(-0.592)x P9yDL +(0)xP10yDL +(-1.62)xP11yDL+(0)x P12yDL+(0)xP8xWL +(0)x P8yWL +(-0.148)xP9xWL +(-0.592)x P9yWL +(0)xP10xWL +0x P10yWL +-0.405xP11xWL +-1.619x P11yWL +0x P11yWL +0x+0x P12yWL]
LSF_Member_20-DLWL	A20xfy±[(0.958)xP8yDL +(0.462)x P9yDL +(2.619)xP10yDL +(1.26)xP11yDL+(2.062)x P12yDL+(-0.24)xP8xWL +(0.958)x P8yWL +(0.115)xP9xWL +(0.462)x P9yWL +(-0.655)xP10xWL +2.619x P10yWL +0.315xP11xWL +1.262x P11yWL +2.062x P11yWL +2.062x+2.062x P12yWL]
LSF_Member_21-DLWL	A21xfy±[(0.462)xP8yDL +(0.958)x P9yDL +(1.262)xP10yDL +(2.62)xP11yDL+(2.062)x P12yDL+(-0.115)xP8xWL +(0.462)x P8yWL +(0.24)xP9xWL +(0.958)x P9yWL +(-0.315)xP10xWL +1.262x P10yWL +0.655xP11xWL +2.619x P11yWL +2.062x P11yWL +2.062x+2.062x P12yWL]

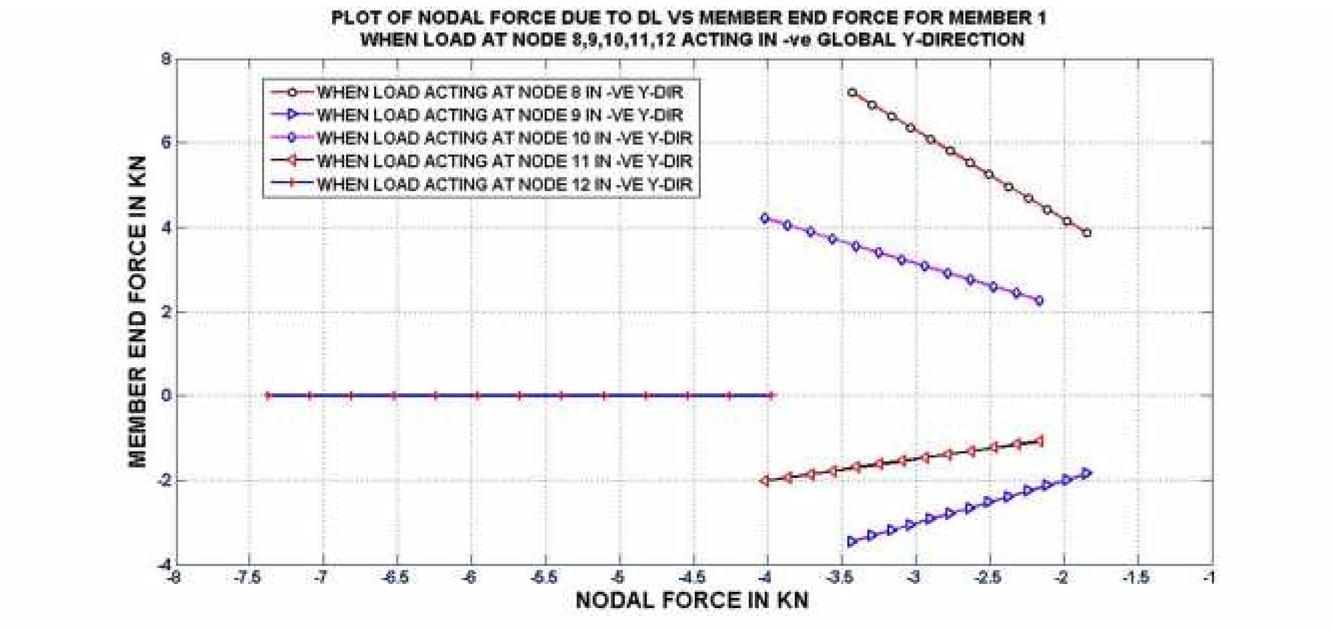


Fig: 5.7 variation of MEF of element 1 due to variation of nodal loads(DL)

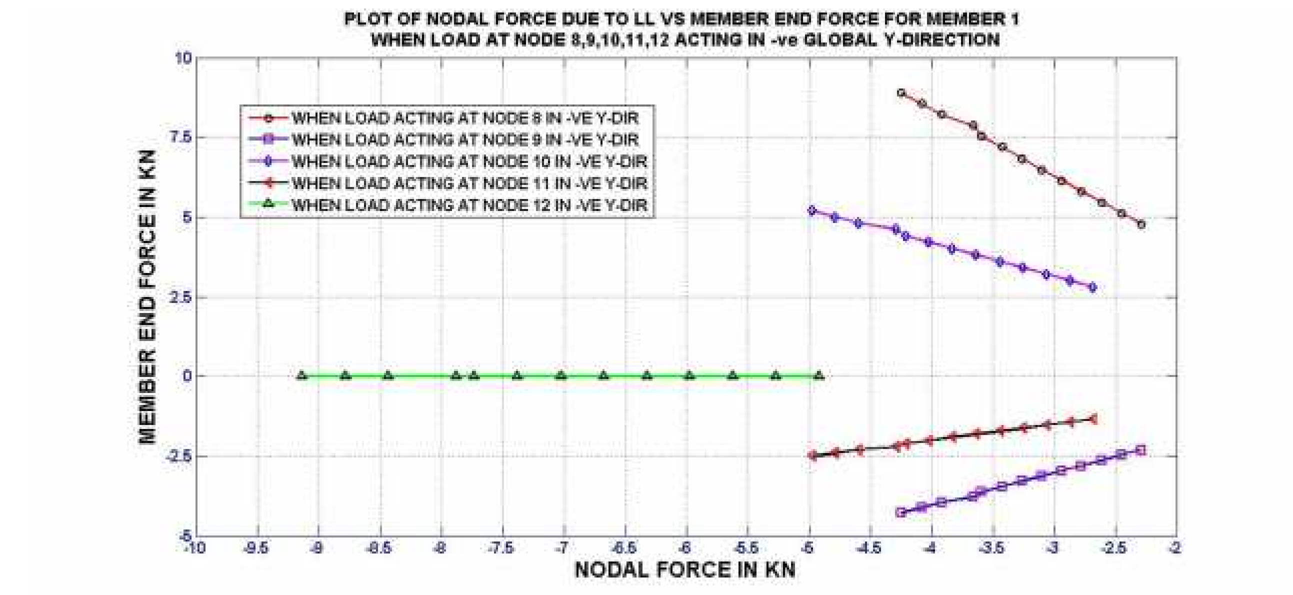


Fig: 5.8 variation of MEF of element 1 due to variation of nodal loads(LL)

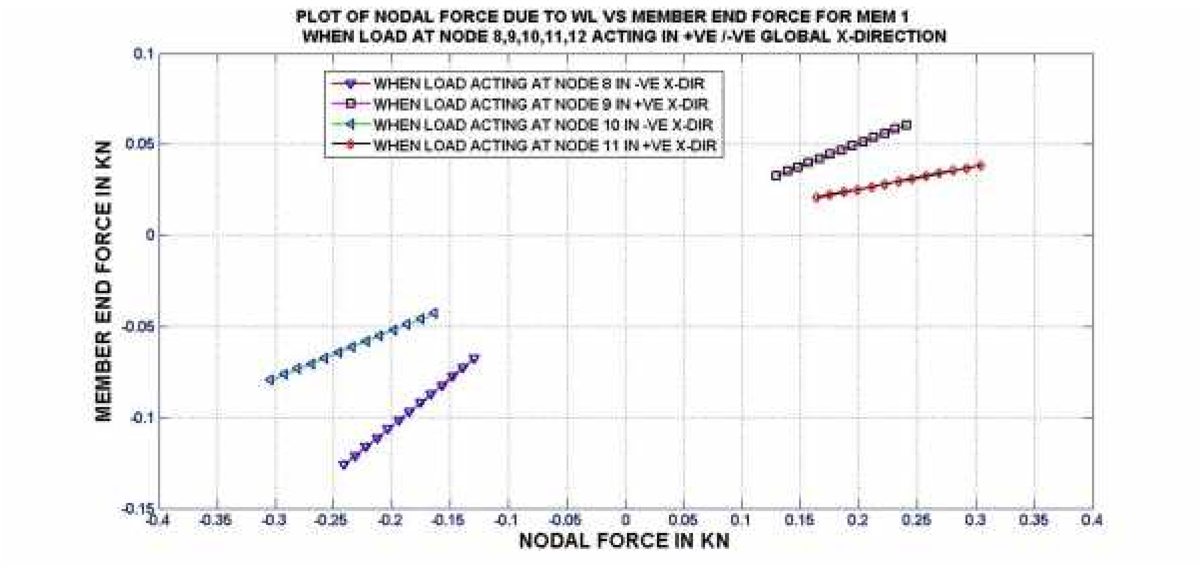


Fig: 5.9 variation of MEF of element 1 due to variation of nodal loads in X-dir (WL)

Fig: 5.10 variation of MEF of element 1 due to variation of nodal loads in Y-dir (WL)

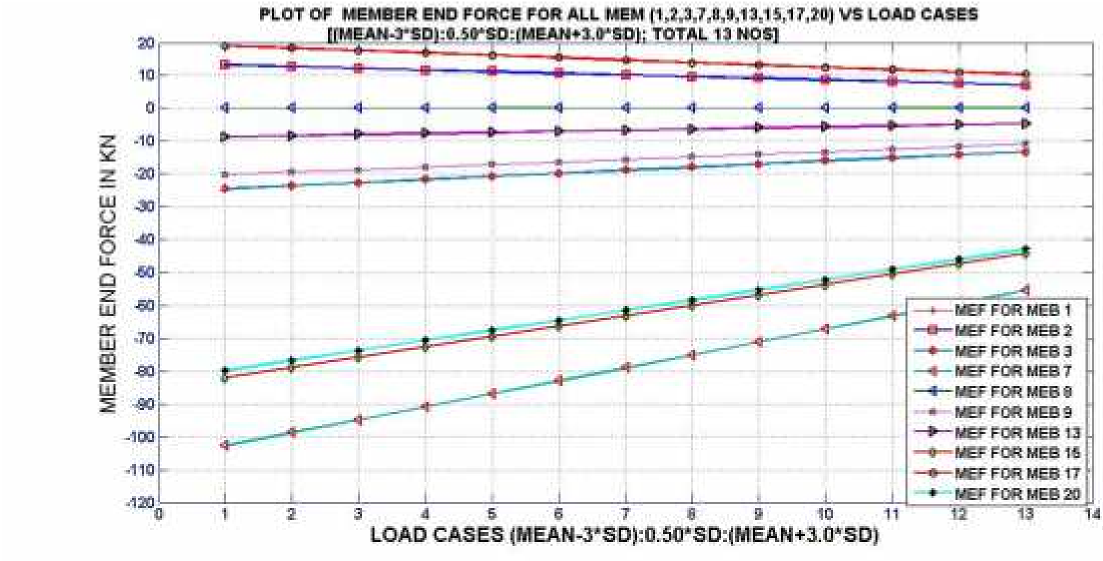


Fig: 5.11(a) Variation of MEF of elements due to combined effect of all nodal loads (variable) For (DL+LL) condition

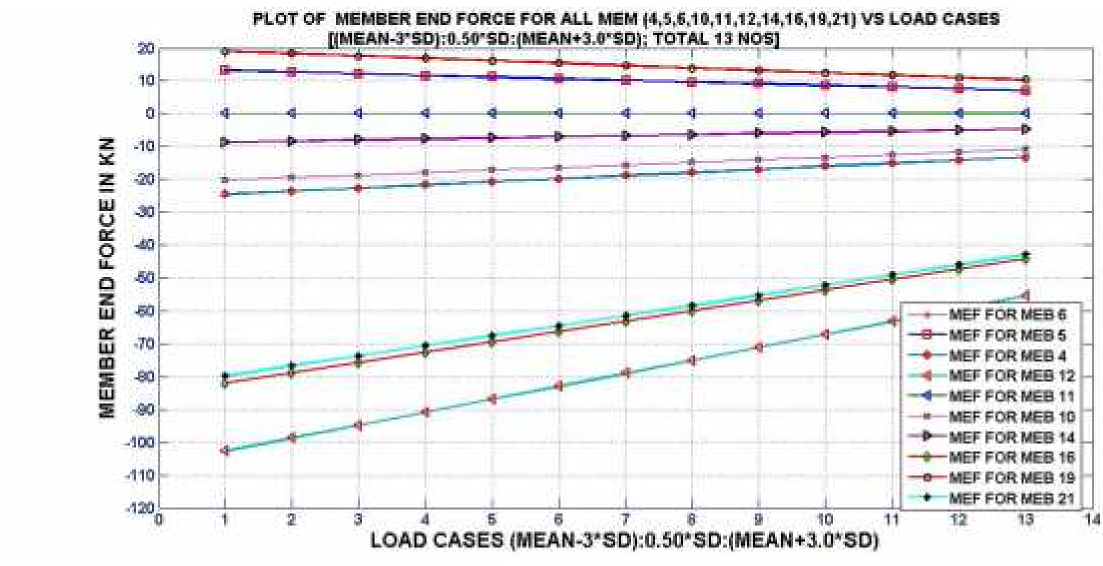


Fig: 5.11 (b) Variation of MEF of elements due to combined effect of all nodal loads (variable) For (DL+LL) condition

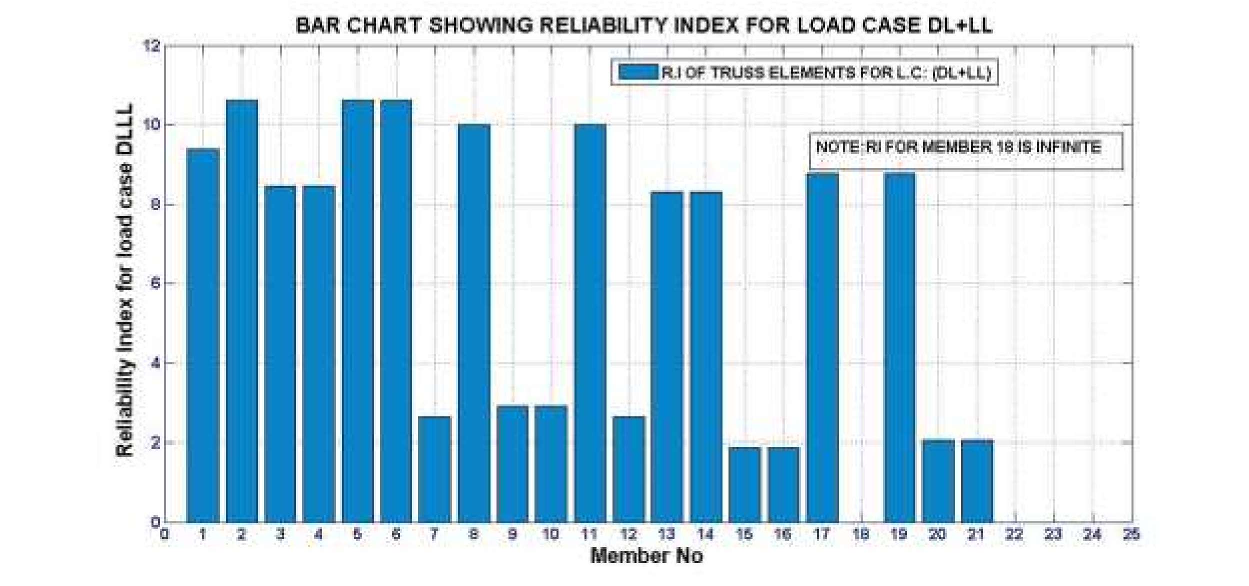


Fig: 5.12 Reliability Index of Truss Element for (Dl+LL) case

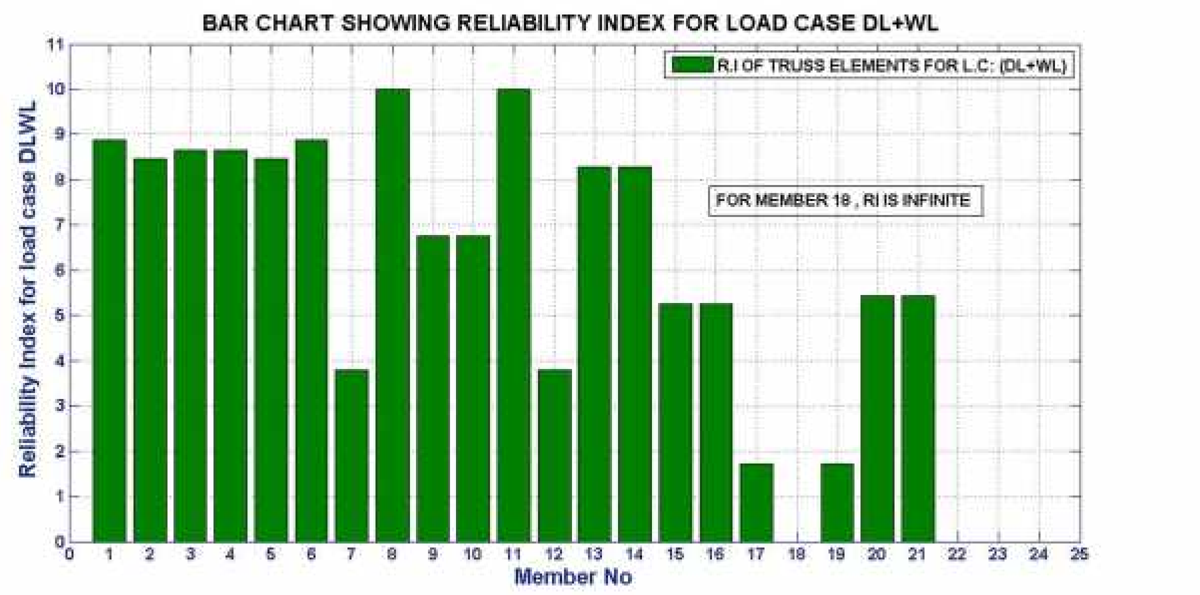


Fig: 5.13 Reliability Index of Truss Element for (Dl+WL) case

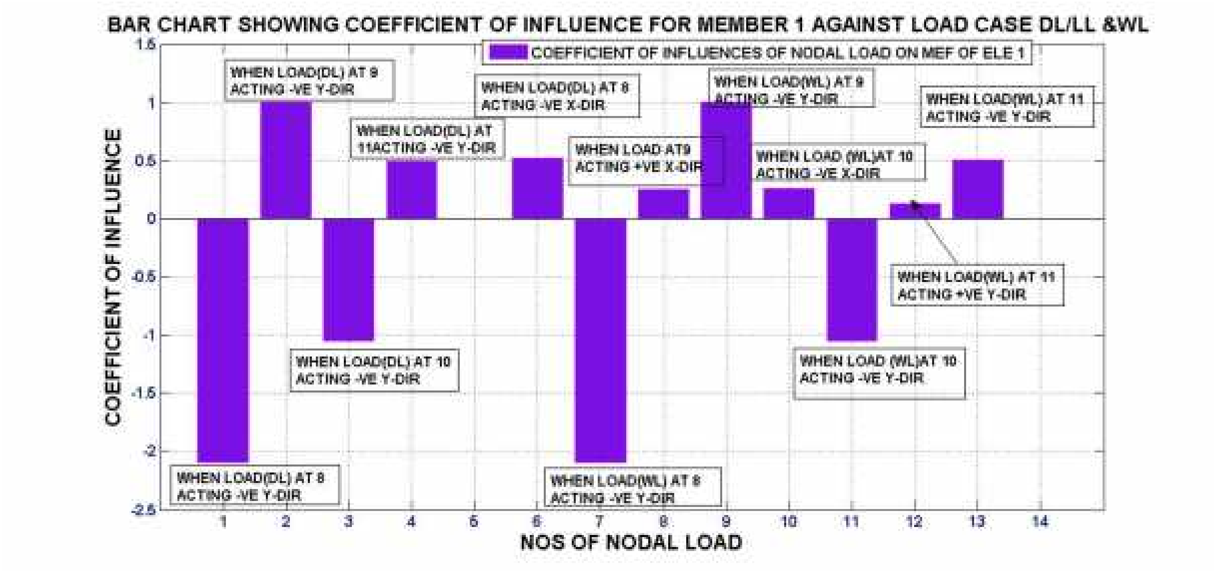


Fig: 5.14 Coefficient of influence of nodal loads on axial force of element 1 for all primary load cases (Dl,LL,WL)

5.1.3 System Reliability at level 1

For the analysis result, the system reliability of the said truss at level 1

The Ditlevsen bound for the system failure probability at level one are...:

The lower bound is: 0.030087

The upper bound is: 0.10787

Ditlevsen bounds for the system reliability at level one are :

The Upper RI Bound is: 1.8795

The Lower RI Bound is: 1.2379

Here Δ =3.00

Critical failure elements are

7	9	10	12	15	16	20	21

Here correlation coefficient $°_{ij}$ of the safety margin between any two failure element in very near to zero, for evaluation of system reliability upper bound value is taken

Upper Bound of Probability of failure:

$P_f \leq 1 - \sum_{i=1}^{n}[1 - P(F_i)]$ =0.10787 and corresponding Reliability index is 1.8795

5.1.4 Discussion on Result of Example 1

In Example 1, a 7.50 m span statically determinate truss which is made of rectangular and square hollow section is considered. One algorithm has been prepared for reliability analysis the truss type structure. As per structural input and variability of the various design parameters, reliability analysis has been made and accordingly Reliability indices are determined for all elements for different load cases. As per analysis result of the said truss, it has been found that element no 17 and 19 have minimum reliability index of value 1.715 which is governed under load case (DL+WL).

The system reliability at level 1 of the said structure is 1.8795 and corresponding probability of failure is 0.108.

Reliability estimation of truss elements depends on types of failure mode; numbers of variable considered and limit state equation used. i.e for different failure mode of the element different reliability index is observed.

5.2 Evaluation of critical failure path of a statically indeterminate truss based on reliability approach

5.2.1 (Example 02) Reliability Analysis of the 26-bar statically indeterminate truss model:

In case study 2, one statically indeterminate 26 bar steel truss has been considered which are made of structural steel ISA. The detailed structural model with node numbers, element numbers, loads etc are shown in the following figures:

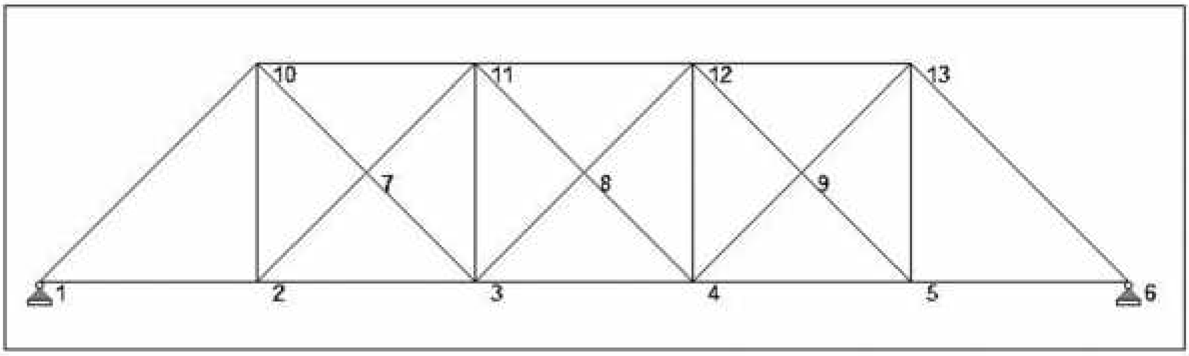


Fig:5.15 Joint numbers of the 26-bars truss

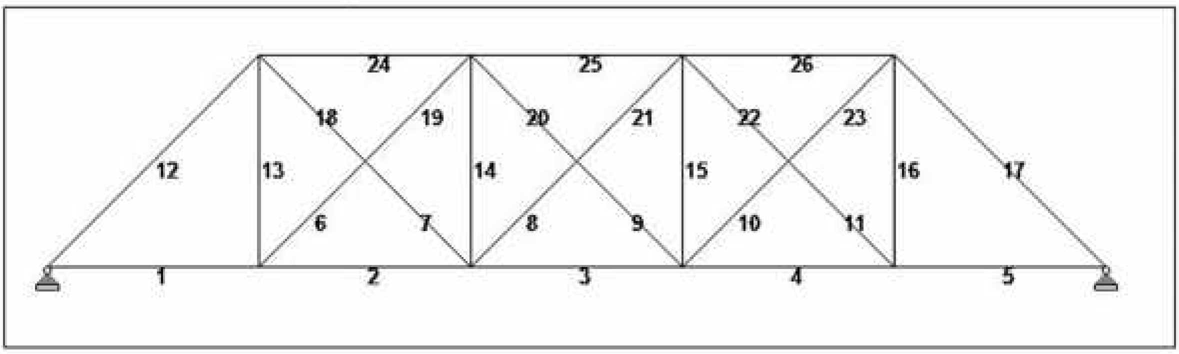


Fig:5.16 Element numbers of the 26-bars truss

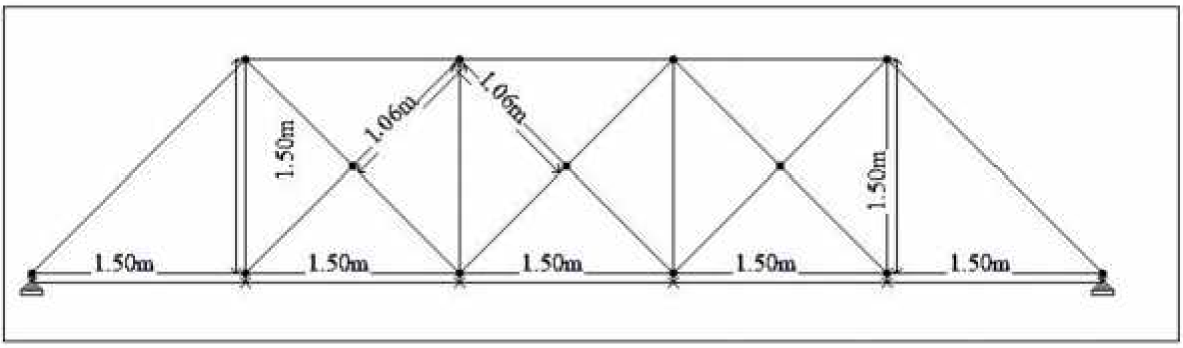


Fig: 5.17 Dimension of the 26-bars truss

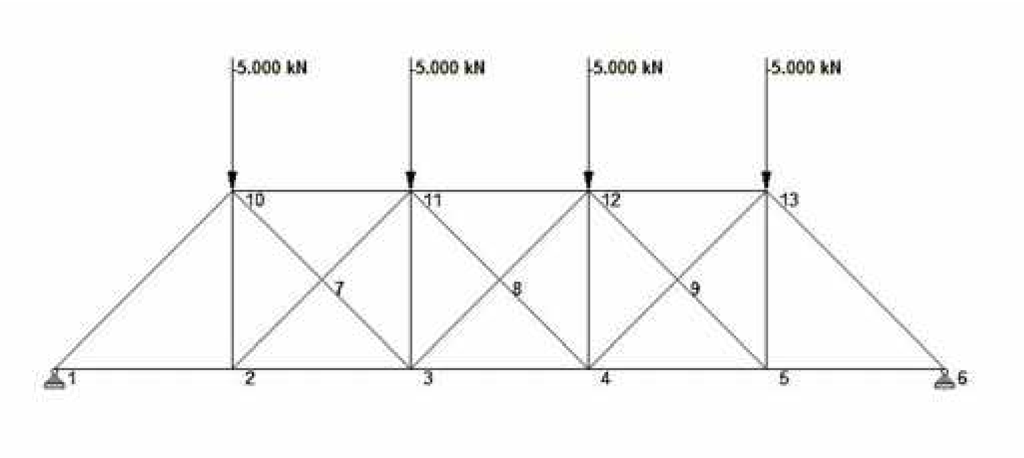


Fig: 5.18 Mean Nodal load for DL condition of the 26-bars truss.

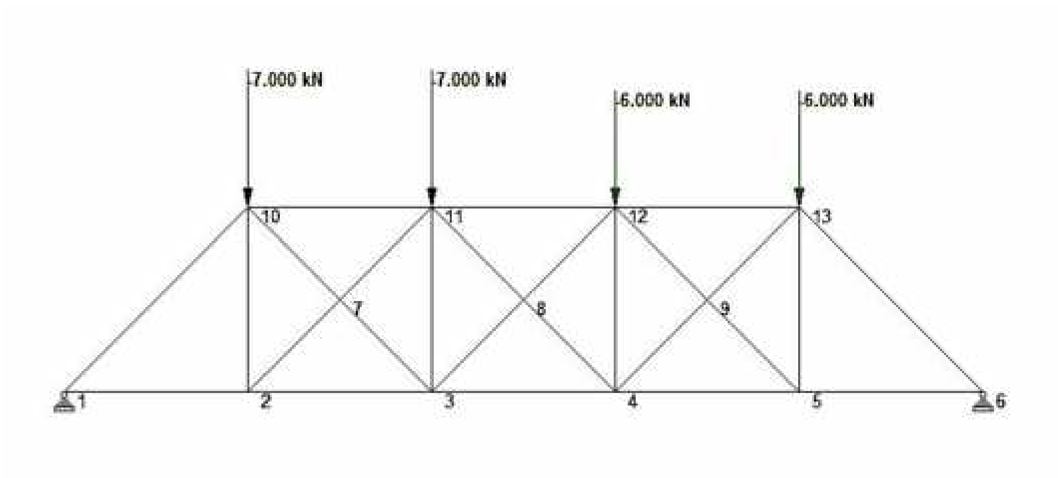


Fig: 5.19 Mean Nodal load for LL condition of the 26-bars truss.

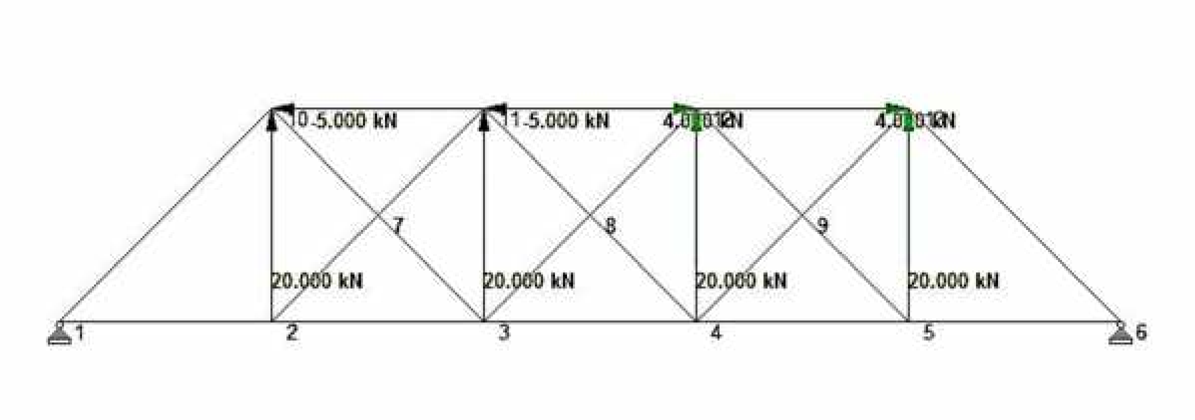


Fig: 5.20 Mean Nodal load for WL condition of the 26-bars truss.

5.2.2 Finite element modeling of the 26 bar statically indeterminate truss in MATLAB platform to obtain Component Level Reliability Index.:

Table-5.25 Nodal coordinate

Joint Coordinate in mtr			
Node No	X-coordinate	Y-coordinate	Z-coordinate
1	0	0	0
2	1.5	0	0
3	3	0	0
4	4.5	0	0
5	6	0	0
6	7.5	0	0
7	2.25	0.75	0
8	3.75	0.75	0
9	5.25	0.75	0
10	1.5	1.5	0
11	3	1.5	0
12	4.5	1.5	0
13	6	1.5	0

Table-5.26 Member connectivity between

Member Connectivity		
Member No	Starting Node	Ending Node
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	2	7
7	7	3
8	3	8
9	8	4
10	4	9
11	9	5
12	1	10
13	10	2
14	11	3
15	12	4
16	13	5
17	13	6
18	10	7
19	7	11
20	11	8
21	8	12
22	12	9
23	9	13
24	11	10
25	12	11
26	13	12

Randomness of the Design variables:

Mean Yield Stress(f_y)	**250 Mpa**
COV of f_y	**0.05**
COV of C/S area of element (A_i)	**0.05**
COV of Load P_i	**0.05**

Table-5.27 Mean of applied load (DL) at different nodes

Mean Nodal Forces(in kN) under DL condition			
Node No	Nodal force in X-dir	Nodal force in Y-dir	Nodal force in Z-dir
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	-5	0
11	0	-5	0
12	0	-5	0
13	0	-5	0

Table-5.28 Mean of applied load (LL) at different nodes

Mean Nodal Forces(in kN) under LL condition			
Node No	Nodal force in X-dir	Nodal force in Y-dir	Nodal force in Z-dir
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	-7	0
11	0	-7	0
12	0	-6	0
13	0	-6	0

Table-5.29 Mean of applied load (WL) at different nodes

Mean Nodal Forces(in kN) under WL condition			
Node No	Nodal force in X-dir	Nodal force in X-dir	Nodal force in X-dir
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	-5	20	0
11	-5	20	0
12	4	20	0
13	4	20	0

Table-5.30 SD of applied load (DL) at different nodes

SD of Nodal Forces(in kN) under DL condition			
Node No	Nodal force in X-dir	Nodal force in Y-dir	Nodal force in Z-dir
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0.25	0
11	0	0.25	0
12	0	0.25	0
13	0	0.25	0

Table-5.31 SD of applied load (LL) at different nodes

SD Nodal Forces under LL condition			
Node No	*Nodal force in X-dir*	*Nodal force in Y-dir*	*Nodal force in Z-dir*
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0.35	0
11	0	0.35	0
12	0	0.3	0
13	0	0.3	0

Table-5.32 SD of applied load (WL) at different nodes

SD of Nodal Forces under WL condition			
Node No	Nodal force in X-dir	Nodal force in Y-dir	Nodal force in Z-dir
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0.25	1	0
11	0.25	1	0
12	0.2	1	0
13	0.2	1	0

Table-5.33 (a) Section properties and resistance properties of 26 bar Truss

Member No	Member area(mean) in m2	Member Designation	E-value in kN/m2	Length of truss element in m
1	0.000929	ISA 80X80X6	2.05E+08	1.500
2	0.000929	ISA 80X80X6	2.05E+08	1.500
3	0.000929	ISA 80X80X6	2.05E+08	1.500
4	0.000929	ISA 80X80X6	2.05E+08	1.500
5	0.000929	ISA 80X80X6	2.05E+08	1.500
6	0.002022	ISA 130X130X8	2.05E+08	1.061
7	0.002022	ISA 130X130X8	2.05E+08	1.061
8	0.000929	ISA 80X80X6	2.05E+08	1.061
9	0.000929	ISA 80X80X6	2.05E+08	1.061
10	0.002022	ISA 130X130X8	2.05E+08	1.061
11	0.002022	ISA 130X130X8	2.05E+08	1.061
12	0.003459	ISA 150X150X12	2.05E+08	2.121
13	0.000929	ISA 80X80X6	2.05E+08	1.500
14	0.000929	ISA 80X80X6	2.05E+08	1.500
15	0.000929	ISA 80X80X6	2.05E+08	1.500
16	0.000929	ISA 80X80X6	2.05E+08	1.500
17	0.003459	ISA 150X150X12	2.05E+08	2.121
18	0.002022	ISA 130X130X8	2.05E+08	1.061
19	0.002022	ISA 130X130X8	2.05E+08	1.061
20	0.000929	ISA 80X80X6	2.05E+08	1.061
21	0.000929	ISA 80X80X6	2.05E+08	1.061
22	0.002022	ISA 130X130X8	2.05E+08	1.061
23	0.002022	ISA 130X130X8	2.05E+08	1.061
24	0.002022	ISA 130X130X8	2.05E+08	1.500
25	0.003459	ISA 150X150X12	2.05E+08	1.500
26	0.002022	ISA 130X130X8	2.05E+08	1.500

Table-5.33(b) Section properties and resistance properties of 26 bar Truss

SL No	DESIGNATION	C/S AREA IN cm2	Fy (Mean-Yield Stress) in N/mm2	Stress Reduction Factor	Mean Design Compressive Stress in N/mm2
1	ISA 80X80X6	9.290	250.000	0.575	143.750
2	ISA 80X80X6	9.290	250.000	0.575	143.750
3	ISA 80X80X6	9.290	250.000	0.575	143.750
4	ISA 80X80X6	9.290	250.000	0.575	143.750
5	ISA 80X80X6	9.290	250.000	0.575	143.750
6	ISA 130X130X8	20.220	250.000	0.867	216.750
7	ISA 130X130X8	20.220	250.000	0.867	216.750
8	ISA 80X80X6	9.290	250.000	0.746	186.500
9	ISA 80X80X6	9.290	250.000	0.746	186.500
10	ISA 130X130X8	20.220	250.000	0.867	216.750
11	ISA 130X130X8	20.220	250.000	0.867	216.750
12	ISA 150X150X12	34.590	250.000	0.665	166.250
13	ISA 80X80X6	9.290	250.000	0.575	143.750
14	ISA 80X80X6	9.290	250.000	0.575	143.750
15	ISA 80X80X6	9.290	250.000	0.575	143.750
16	ISA 80X80X6	9.290	250.000	0.575	143.750
17	ISA 150X150X12	34.590	250.000	0.665	166.250
18	ISA 130X130X8	20.220	250.000	0.867	216.750
19	ISA 130X130X8	20.220	250.000	0.867	216.750
20	ISA 80X80X6	9.290	250.000	0.746	186.500
21	ISA 80X80X6	9.290	250.000	0.746	186.500
22	ISA 130X130X8	20.220	250.000	0.867	216.750
23	ISA 130X130X8	20.220	250.000	0.867	216.750
24	ISA 130X130X8	20.220	250.000	0.591	147.750
25	ISA 150X150X12	34.590	250.000	0.665	166.250
26	ISA 130X130X8	20.220	250.000	0.591	147.750

Table -5.34 Member end force (axial force) of element no-10 due to variation of load (DL) at different nodes.

MEMBER END FORCE OF ELEMENT NO 10 IN KN AGAINST DL CONDITION							
NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	NODAL FORCE AT NODE 13 IN KN in Y-dir	MEMBER END FORCE AT NODE 10 IN KN	MEMBER END FORCE AT NODE 11 IN KN	MEMBER END FORCE AT NODE 12 IN KN	MEMBER END FORCE AT NODE 13 IN KN
-5.750	-5.750	-5.750	-5.750	0.482	1.415	1.909	-1.123
-5.625	-5.625	-5.625	-5.625	0.471	1.384	1.867	-1.099
-5.500	-5.500	-5.500	-5.500	0.461	1.353	1.826	-1.074
-5.375	-5.375	-5.375	-5.375	0.450	1.322	1.784	-1.050
-5.250	-5.250	-5.250	-5.250	0.440	1.292	1.743	-1.025
-5.125	-5.125	-5.125	-5.125	0.429	1.261	1.701	-1.001
-5.000	-5.000	-5.000	-5.000	0.419	1.230	1.660	-0.977
-4.875	-4.875	-4.875	-4.875	0.408	1.199	1.618	-0.952
-4.750	-4.750	-4.750	-4.750	0.398	1.169	1.577	-0.928
-4.625	-4.625	-4.625	-4.625	0.387	1.138	1.535	-0.903
-4.500	-4.500	-4.500	-4.500	0.377	1.107	1.494	-0.879
-4.375	-4.375	-4.375	-4.375	0.366	1.076	1.452	-0.854
-4.250	-4.250	-4.250	-4.250	0.356	1.046	1.411	-0.830
-5.000	-5.000	-5.000	-5.000	Mean nodal force in KN			
0.250	0.250	0.250	0.250	SD OF NODAL FORCE			

Table -5.35 Member end force (axial force) of element no-10 due to variation of load (LL) at different nodes.

MEMBER END FORCE OF ELEMENT NO 10 IN KN AGAINST LIVE LOAD CONDITION							
NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	NODAL FORCE AT NODE 13 IN KN in Y-dir	MEMBER END FORCE AT NODE 10 IN KN	MEMBER END FORCE AT NODE 11 IN KN	MEMBER END FORCE AT NODE 12 IN KN	MEMBER END FORCE AT NODE 13 IN KN
-8.050	-8.050	-6.900	-6.900	0.674	1.981	2.290	-1.348
-7.875	-7.875	-6.750	-6.750	0.659	1.938	2.241	-1.318
-7.700	-7.700	-6.600	-6.600	0.645	1.895	2.191	-1.289
-7.525	-7.525	-6.450	-6.450	0.630	1.851	2.141	-1.260
-7.350	-7.350	-6.300	-6.300	0.616	1.808	2.091	-1.230
-7.175	-7.175	-6.150	-6.150	0.601	1.765	2.041	-1.201
-7.000	-7.000	-6.000	-6.000	0.586	1.722	1.992	-1.172
-6.825	-6.825	-5.850	-5.850	0.572	1.679	1.942	-1.143
-6.650	-6.650	-5.700	-5.700	0.557	1.636	1.892	-1.113
-6.475	-6.475	-5.550	-5.550	0.542	1.593	1.842	-1.084
-6.300	-6.300	-5.400	-5.400	0.528	1.550	1.792	-1.055
-6.125	-6.125	-5.250	-5.250	0.513	1.507	1.743	-1.025
-5.950	-5.950	-5.100	-5.100	0.498	1.464	1.693	-0.996
-7	-7	-6	-6	Mean nodal force in KN			
0.350	0.350	0.300	0.300	SD OF NODAL FORCE			

Table -5.36 Member end force (axial force) of element no-10 due to variation of load (WL) at different nodes.

NODAL FORCE IN KN								
NODAL FORCE AT NODE 10 IN KN in x-dir	NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in x-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in x-dir	NODAL FORCE AT NODE 13 IN KN in x-dir	NODAL FORCE AT NODE 13 IN KN in Y-dir	
-5.750	17.000	-5.750	17.000	3.400	17.000	3.400	17.000	(MEAN-3.0*SD):
-5.625	17.500	-5.625	17.500	3.500	17.500	3.500	17.500	(MEAN-2.5*SD):
-5.500	18.000	-5.500	18.000	3.600	18.000	3.600	18.000	(MEAN-2.0*SD):
-5.375	18.500	-5.375	18.500	3.700	18.500	3.700	18.500	(MEAN-1.5*SD):
-5.250	19.000	-5.250	19.000	3.800	19.000	3.800	19.000	(MEAN-1.0*SD):
-5.125	19.500	-5.125	19.500	3.900	19.500	3.900	19.500	(MEA-0.50*SD):
-5.000	20.000	-5.000	20.000	4.000	20.000	4.000	20.000	(MEAN):
-4.875	20.500	-4.875	20.500	4.100	20.500	4.100	20.500	(MEAN+0.5*SD):
-4.750	21.000	-4.750	21.000	4.200	21.000	4.200	21.000	(MEAN+1.0*SD):
-4.625	21.500	-4.625	21.500	4.300	21.500	4.300	21.500	(MEAN+1.5*SD):
-4.500	22.000	-4.500	22.000	4.400	22.000	4.400	22.000	(MEAN+2.0*SD):
-4.375	22.500	-4.375	22.500	4.500	22.500	4.500	22.500	(MEAN+2.5*SD):
-4.250	23.000	-4.250	23.000	4.600	23.000	4.600	23.000	(MEAN+3.0*SD):
-5.000	20.000	-5.000	20.000	4.000	20.000	4.000	20.000	MEAN OF NODAL FORCE
0.250	1.000	0.250	1.000	0.200	1.000	0.200	1.000	SD OF NODAL FORCE

MEMBER END FORCE AT NODE 10	MEMBER END FORCE AT NODE 10	MEMBER END FORCE AT NODE 11	MEMBER END FORCE AT NODE 11	MEMBER END FORCE AT NODE 13	MEMBER END FORCE AT NODE 13
	IN KN in x-dir	IN KN in X-dir	IN KN in x-dir	IN KN in X-dir	IN KN in Y-dir
-0.482	-1.424	-0.512	-4.183	0.281	-5.643
-0.471	-1.466	-0.501	-4.306	0.290	-5.809
-0.461	-1.507	-0.490	-4.429	0.298	-5.975
-0.450	-1.549	-0.479	-4.552	0.306	-6.141
-0.440	-1.591	-0.468	-4.675	0.314	-6.307
-0.429	-1.633	-0.456	-4.798	0.323	-6.473
-0.419	-1.675	-0.445	-4.921	0.331	-6.639
-0.408	-1.717	-0.434	-5.044	0.339	-6.805
-0.398	-1.759	-0.423	-5.167	0.348	-6.971
-0.387	-1.801	-0.412	-5.290	0.356	-7.137
-0.377	-1.842	-0.401	-5.413	0.364	-7.303
-0.366	-1.884	-0.390	-5.536	0.372	-7.469
-0.356	-1.926	-0.379	-5.659	0.381	-7.635

Table -5.37 Member end force (axial force) of element no-10 due to variation of load (DL+LL) at different nodes.

MEMBER END FORCE OF MEM 10 IN KN AGAINST (DL+LL) CONDITION							
NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in Y-dir	NODAL FORCE AT NODE 13 IN KN in Y-dir	MEMBER END FORCE AT NODE 10 IN KN	MEMBER END FORCE AT NODE 11 IN KN	MEMBER END FORCE AT NODE 12 IN KN	MEMBER END FORCE AT NODE 13 IN KN
-13.800	-13.800	-12.650	-12.650	1.156	3.395	4.199	-2.471
-13.500	-13.500	-12.375	-12.375	1.131	3.322	4.108	-2.417
-13.200	-13.200	-12.100	-12.100	1.105	3.248	4.017	-2.363
-12.375	-12.375	-11.375	-11.375	1.080	3.174	3.925	-2.310
-12.600	-12.600	-11.550	-11.550	1.055	3.100	3.834	-2.256
-12.300	-12.300	-11.275	-11.275	1.030	3.026	3.743	-2.202
-12.000	-12.000	-11.000	-11.000	1.005	2.952	3.651	-2.148
-11.700	-11.700	-10.725	-10.725	0.980	2.879	3.560	-2.095
-11.400	-11.400	-10.450	-10.450	0.955	2.805	3.469	-2.041
-11.100	-11.100	-10.175	-10.175	0.930	2.731	3.378	-1.987
-10.800	-10.800	-9.900	-9.900	0.904	2.657	3.286	-1.934
-10.500	-10.500	-9.625	-9.625	0.879	2.583	3.195	-1.880
-10.200	-10.200	-9.350	-9.350	0.854	2.510	3.104	-1.826
-12.000	-12.000	-11.000	-11.000	MEAN OF NODAL FORCE			
0.6	0.6	0.55	0.55	SD OF NODAL FORCE			

Table -5.38 Member end force (axial force) of element no-10 due to variation of load (DL+WL) at different nodes.

MEMBER END FORCE OF MEM 10 IN KN AGAINST (DL+WL) CONDITION								
NODAL FORCE AT NODE 10 IN KN in x-dir	NODAL FORCE AT NODE 10 IN KN in Y-dir	NODAL FORCE AT NODE 11 IN KN in x-dir	NODAL FORCE AT NODE 11 IN KN in Y-dir	NODAL FORCE AT NODE 12 IN KN in x-dir	NODAL FORCE AT NODE 12 IN KN in y-dir	NODAL FORCE AT NODE 13 IN KN in x-dir	NODAL FORCE AT NODE 13 IN KN in Y-dir	
-5.750	12.750	-5.750	12.750	3.400	12.750	3.400	12.750	(MEAN-3.0*SD):
-5.625	13.125	-5.625	13.125	3.500	13.125	3.500	13.125	(MEAN-2.5*SD):
-5.500	13.500	-5.500	13.500	3.600	13.500	3.600	13.500	(MEAN-2.0*SD):
-5.375	14.625	-5.375	14.625	3.625	14.625	3.625	14.625	(MEAN-1.5*SD):
-5.250	14.250	-5.250	14.250	3.800	14.250	3.800	14.250	(MEAN-1.0*SD):
-5.125	14.625	-5.125	14.625	3.900	14.625	3.900	14.625	(MEA-0.50*SD):
-5.000	15.000	-5.000	15.000	4.000	15.000	4.000	15.000	(MEAN):
-4.875	15.375	-4.875	15.375	4.100	15.375	4.100	15.375	(MEAN+0.5*SD):
-4.750	15.750	-4.750	15.750	4.200	15.750	4.200	15.750	(MEAN+1.0*SD):
-4.625	16.125	-4.625	16.125	4.300	16.125	4.300	16.125	(MEAN+1.5*SD):
-4.500	16.500	-4.500	16.500	4.400	16.500	4.400	16.500	(MEAN+2.0*SD):
-4.375	16.875	-4.375	16.875	4.500	16.875	4.500	16.875	(MEAN+2.5*SD):
-4.250	17.250	-4.250	17.250	4.600	17.250	4.600	17.250	(MEAN+3.0*SD):
-5.000	15.000	-5.000	15.000	4.000	15.000	4.000	15.000	MEAN OF NODAL FORCE
0.250	0.750	0.250	0.750	0.200	0.750	0.200	0.750	SD OF NODAL FORCE

MEMBER END FORCE AT NODE 10	MEMBER END FORCE AT NODE 10	MEMBER END FORCE AT NODE 11	MEMBER END FORCE AT NODE 11	MEMBER END FORCE AT NODE 12	MEMBER END FORCE AT NODE 12	MEMBER END FORCE AT NODE 13	MEMBER END FORCE AT NODE 13
	IN KN in Y-dir	IN KN in x-dir	IN KN in Y-dir	IN KN in x-dir	IN KN in Y-dir	IN KN in x-dir	IN KN in Y-dir
-0.482	-0.942	-0.512	-2.768	0.281	-3.734	0.664	2.197
-0.471	-0.994	-0.501	-2.922	0.290	-3.942	0.684	2.319
-0.461	-1.047	-0.490	-3.075	0.298	-4.149	0.703	2.441
-0.450	-1.099	-0.479	-3.229	0.306	-4.357	0.723	2.563
-0.440	-1.151	-0.468	-3.383	0.314	-4.564	0.742	2.686
-0.429	-1.204	-0.456	-3.537	0.323	-4.772	0.762	2.808
-0.419	-1.256	-0.445	-3.691	0.331	-4.979	0.781	2.930
-0.408	-1.309	-0.434	-3.844	0.339	-5.187	0.801	3.052
-0.398	-1.361	-0.423	-3.998	0.348	-5.394	0.820	3.174
-0.387	-1.413	-0.412	-4.152	0.356	-5.602	0.840	3.296
-0.377	-1.466	-0.401	-4.306	0.364	-5.809	0.859	3.418
-0.366	-1.518	-0.390	-4.459	0.372	-6.016	0.879	3.540
-0.356	-1.570	-0.379	-4.613	0.381	-6.224	0.898	3.662

Table:5.39 Coefficient of Influence of nodal loads(DL/LL) on member end force of truss elements

MEMBER NO	C/S Area of the member in sqm	Coefficient of influence for NODAL load (LL)when acting at10 IN KN in Y-dir	Coefficient of influence for NODAL load (LL)when acting at 11 IN KN in Y-dir	Coefficient of influence for NODAL load (LL)when acting at 12	Coefficient of influence for NODAL load (LL)when acting at 13 IN KN in Y-dir
1	0.000929	-0.288	0.121	0.321	0.310
2	0.000929	-0.212	-0.221	0.105	0.190
3	0.000929	0.002	-0.327	-0.327	0.000
4	0.000929	0.186	0.105	-0.221	-0.210
5	0.000929	0.312	0.321	0.121	-0.290
6	0.002022	-0.107	0.484	0.306	0.180
7	0.002022	0.176	-0.364	-0.260	-0.100
8	0.000929	-0.126	-0.215	0.351	0.160
9	0.000929	0.157	0.351	-0.215	-0.130
10	0.002022	-0.104	-0.260	-0.364	0.180
11	0.002022	0.179	0.306	0.484	-0.110
12	0.003459	1.131	0.849	0.566	0.280
13	0.000929	0.076	-0.342	-0.216	-0.130
14	0.000929	-0.035	0.409	-0.065	-0.040
15	0.000929	-0.037	-0.065	0.409	-0.040
16	0.000929	-0.126	-0.216	-0.342	0.080
17	0.003459	0.283	0.566	0.849	1.130
18	0.002022	0.176	-0.364	-0.260	-0.100
19	0.002022	-0.107	0.484	0.306	0.180
20	0.000929	0.157	0.351	-0.215	-0.130
21	0.000929	-0.126	-0.215	0.351	0.160
22	0.002022	0.179	0.306	0.484	-0.110
23	0.002022	-0.104	-0.260	-0.364	0.180
24	0.002022	0.676	0.858	0.584	0.270
25	0.003459	0.489	0.952	0.952	0.490
26	0.002022	0.274	0.584	0.858	0.680

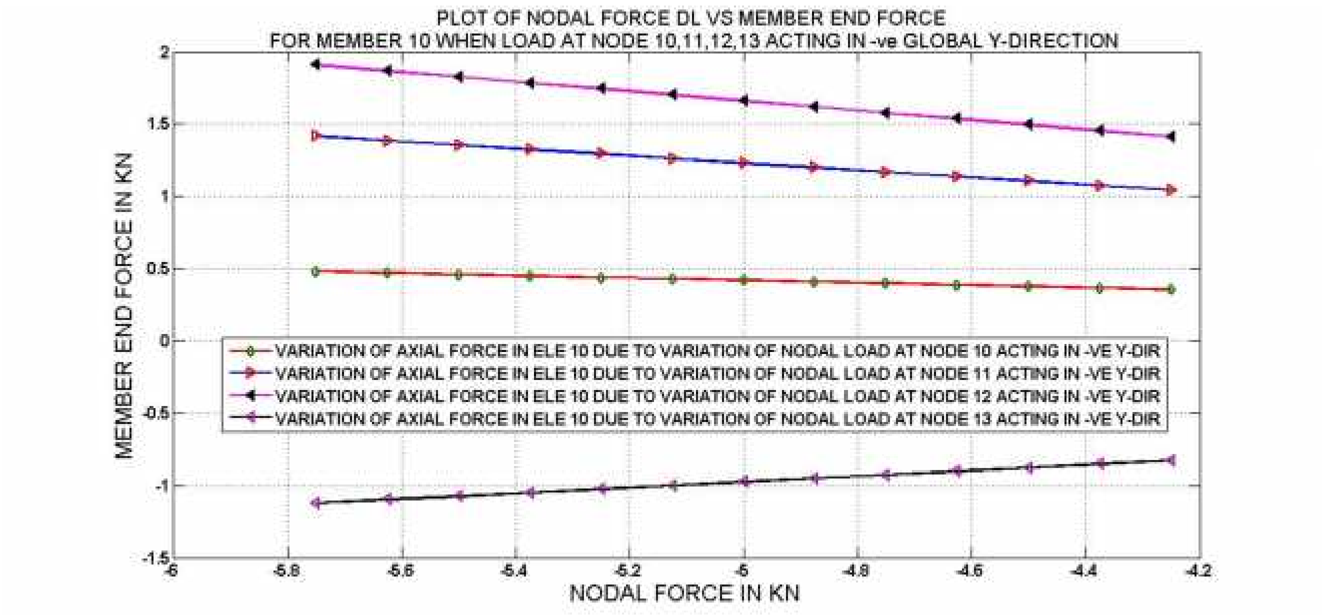


Fig: 5.21 variation of MEF of element 10 due to variation of nodal loads (DL)

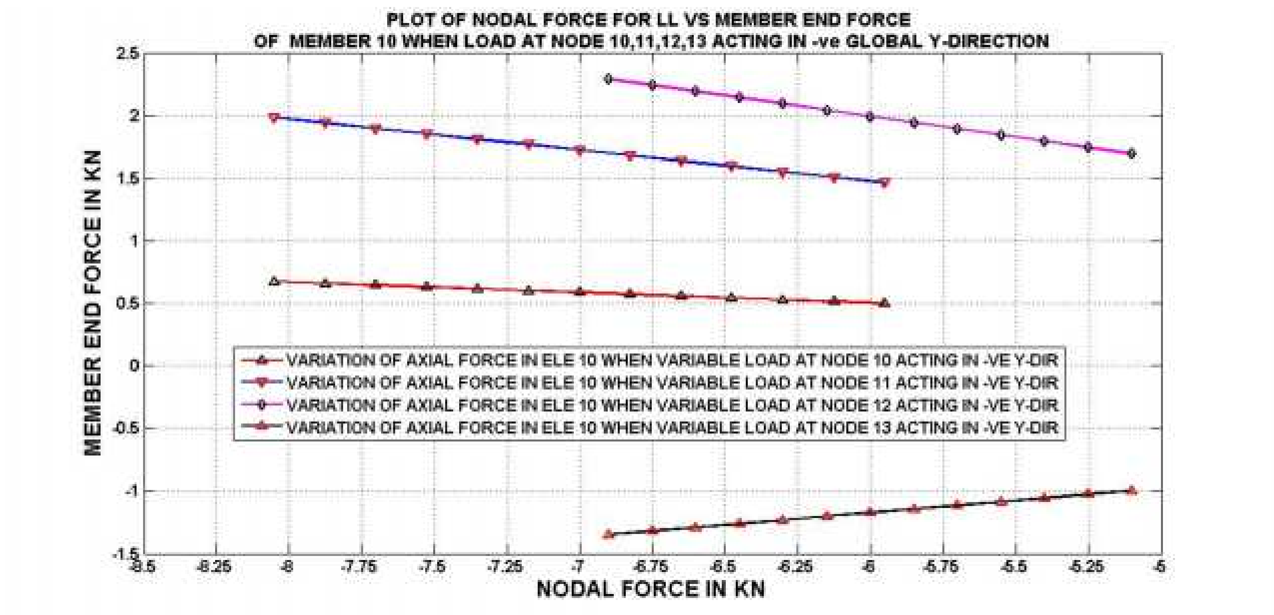


Fig: 5.22 variation of MEF of element 10 due to variation of nodal loads (LL)

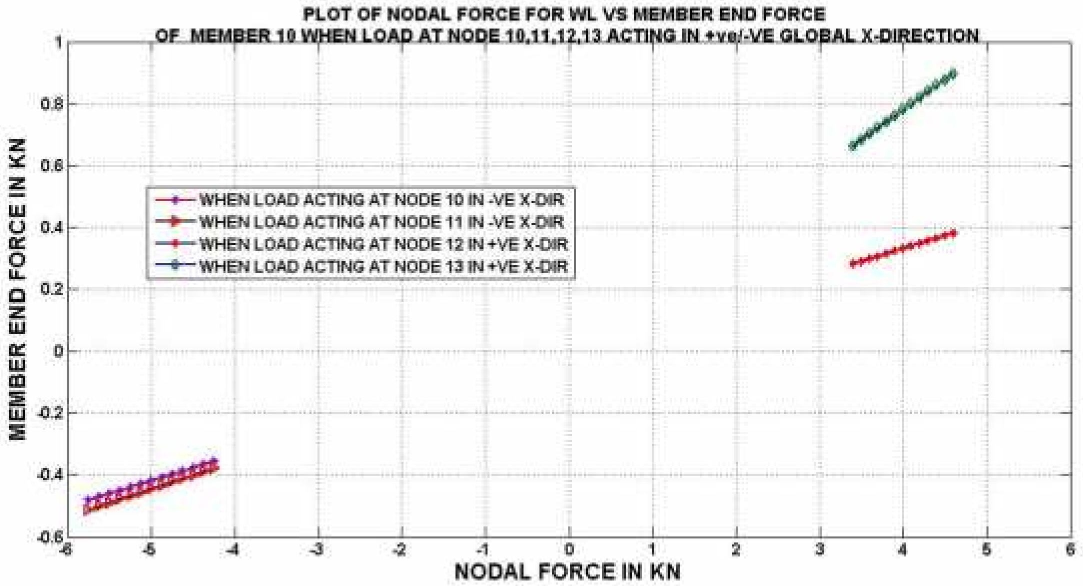


Fig: 5.23 (a) variation of MEF of element 10 due to variation of nodal loads (WL)

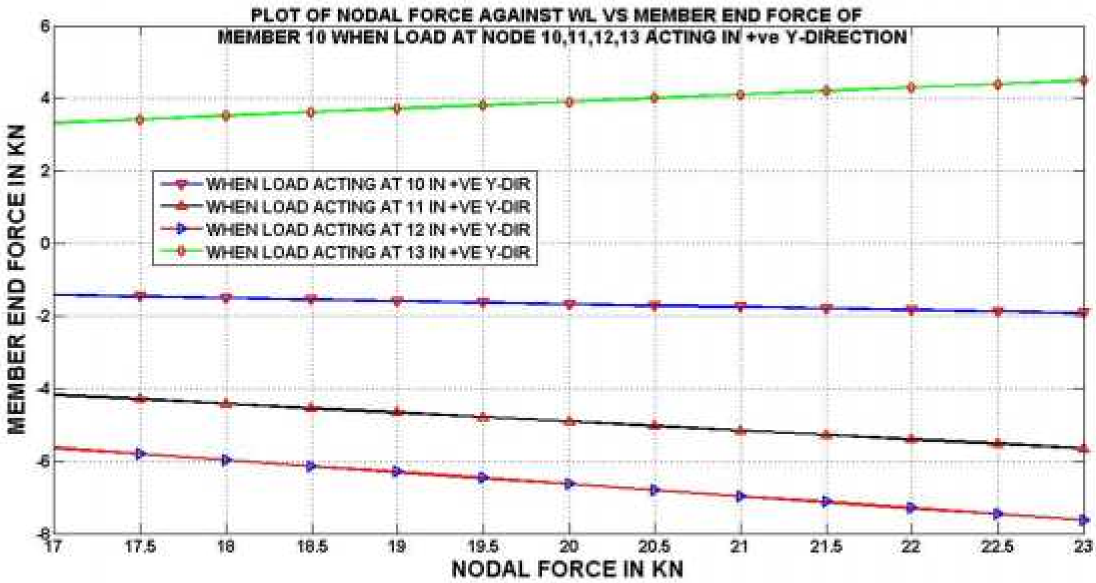


Fig: 5.23 (b) variation of MEF of element 10 due to variation of nodal loads (WL)

Fig: 5.24(a) variation of MEF of element 10 due to variation of all nodal loads (for DL+LL)

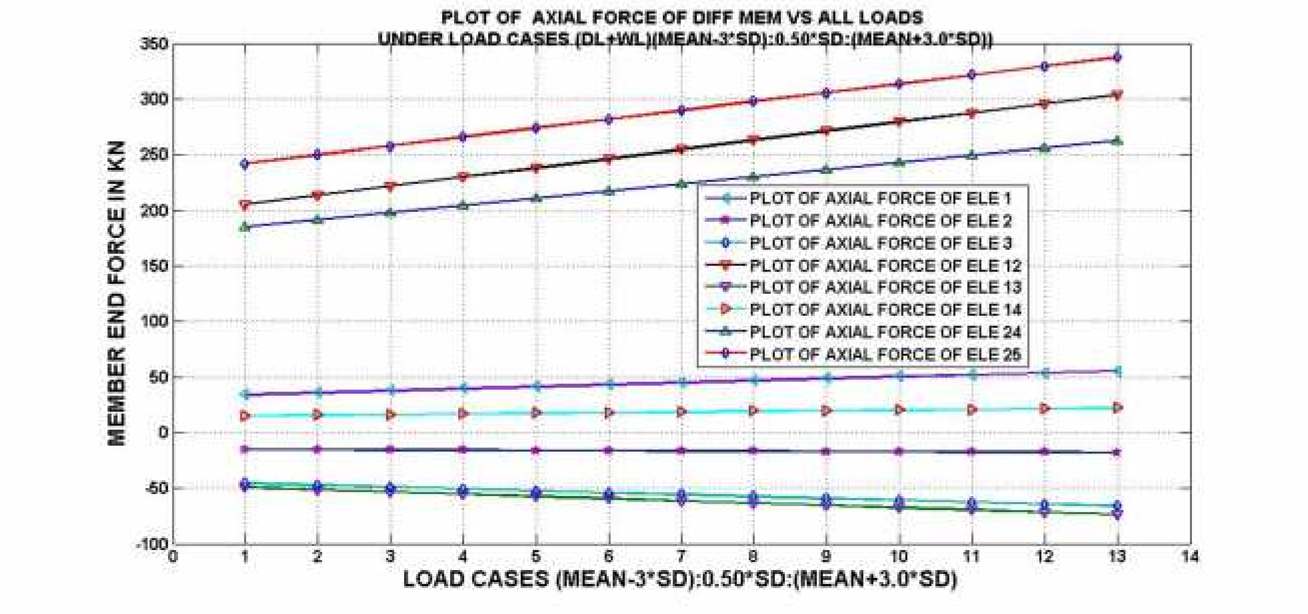


Fig:5.24 (b) variation of MEF of element 10 due to variation of all nodal loads (for DL+WL)

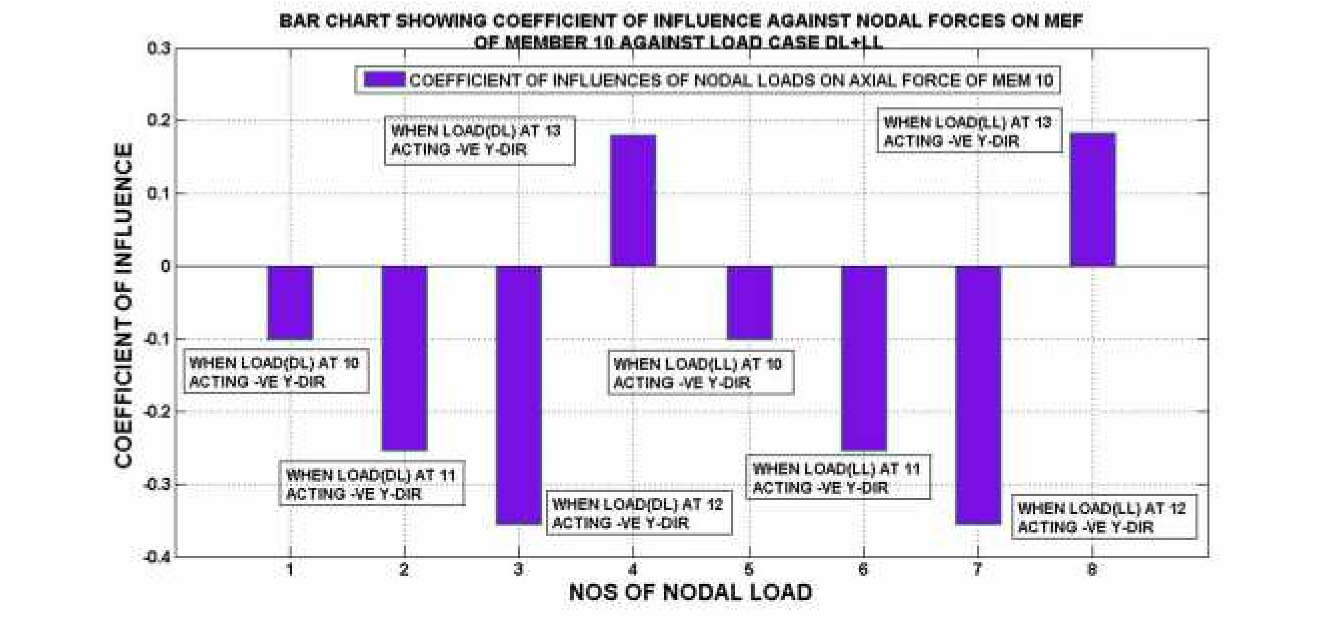


Fig: 5.25 coefficient of influence of nodal loads on axial force of element 10 for all primary load cases (Dl & LL)

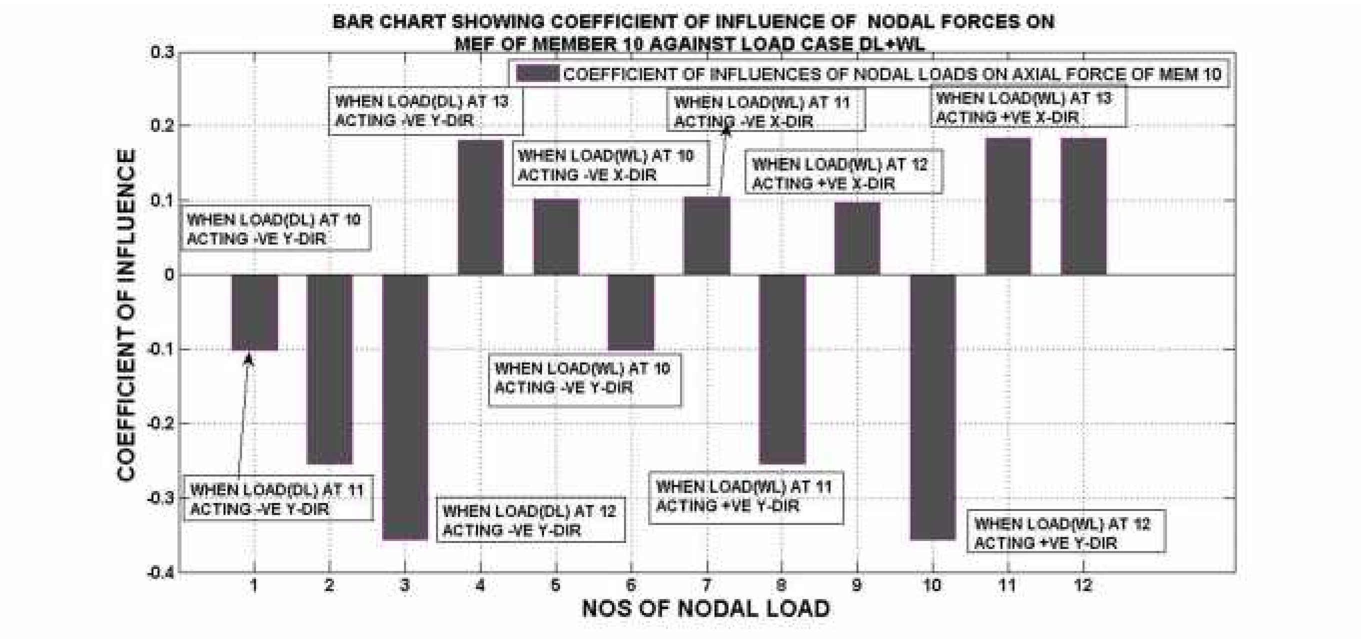


Fig: 5.26 coefficient of influence of nodal loads on axial force of element 10 for all primary load cases (Dl & WL)

Table: 5.40 Limit State Equations of truss elements for different failure mode (DD+LL CONDITION):

LSF_Member_1-DLLL	A1xfy±[(-0.288)xP10yDL +(0.121)xP11yDL +(0.321)xP12yDL +(0.31)xP13yDL +()xP10yLL +(-0.288)xP11yLL +(0.121)xP12yLL +(0.321)xP13yLL]
LSF_Member_2-DLLL	A2xfy±[(-0.212)xP10yDL +(-0.221)xP11yDL +(0.105)xP12yDL +(0.19)xP13yDL +()xP10yLL +(-0.212)xP11yLL +(-0.221)xP12yLL +(0.105)xP13yLL]
LSF_Member_3-DLLL	A3xfy±[(0.002)xP10yDL +(-0.327)xP11yDL +(-0.327)xP12yDL +(0)xP13yDL +()xP10yLL +(0.002)xP11yLL +(-0.327)xP12yLL +(-0.327)xP13yLL]
LSF_Member_4-DLLL	A4xfy±[(0.186)xP10yDL +(0.105)xP11yDL +(-0.221)xP12yDL +(-0.21)xP13yDL +()xP10yLL +(0.186)xP11yLL +(0.105)xP12yLL +(-0.221)xP13yLL]
LSF_Member_5-DLLL	A5xfy±[(0.312)xP10yDL +(0.321)xP11yDL +(0.121)xP12yDL +(-0.29)xP13yDL +()xP10yLL +(0.312)xP11yLL +(0.321)xP12yLL +(0.121)xP13yLL]
LSF_Member_6-DLLL	A6xfy±[(-0.107)xP10yDL +(0.484)xP11yDL +(0.306)xP12yDL +(0.18)xP13yDL +()xP10yLL +(-0.107)xP11yLL +(0.484)xP12yLL +(0.306)xP13yLL]
LSF_Member_7-DLLL	A7xfy±[(0.176)xP10yDL +(-0.364)xP11yDL +(-0.26)xP12yDL +(-0.1)xP13yDL +()xP10yLL +(0.176)xP11yLL +(-0.364)xP12yLL +(-0.26)xP13yLL]
LSF_Member_8-DLLL	A8xfy±[(-0.126)xP10yDL +(-0.215)xP11yDL +(0.351)xP12yDL +(0.16)xP13yDL +()xP10yLL +(-0.126)xP11yLL +(-0.215)xP12yLL +(0.351)xP13yLL]
LSF_Member_9-DLLL	A9xfy±[(0.157)xP10yDL +(0.351)xP11yDL +(-0.215)xP12yDL +(-0.13)xP13yDL +()xP10yLL +(0.157)xP11yLL +(0.351)xP12yLL +(-0.215)xP13yLL]
LSF_Member_10-DLLL	A10xfy±[(-0.104)xP10yDL +(-0.26)xP11yDL +(-0.364)xP12yDL +(0.18)xP13yDL +()xP10yLL +(-0.104)xP11yLL +(-0.26)xP12yLL +(-0.364)xP13yLL]
LSF_Member_11-DLLL	A11xfy±[(0.179)xP10yDL +(0.306)xP11yDL +(0.484)xP12yDL +(-0.11)xP13yDL +()xP10yLL +(0.179)xP11yLL +(0.306)xP12yLL +(0.484)xP13yLL]
LSF_Member_12-DLLL	A12xfy±[(1.131)xP10yDL +(0.849)xP11yDL +(0.566)xP12yDL +(0.28)xP13yDL +()xP10yLL +(1.131)xP11yLL +(0.849)xP12yLL +(0.566)xP13yLL]
LSF_Member_13-DLLL	A13xfy±[(0.076)xP10yDL +(-0.342)xP11yDL +(-0.216)xP12yDL +(-0.13)xP13yDL +()xP10yLL +(0.076)xP11yLL +(-0.342)xP12yLL +(-0.216)xP13yLL]
LSF_Member_14-DLLL	A14xfy±[(-0.035)xP10yDL +(0.409)xP11yDL +(-0.065)xP12yDL +(-0.04)xP13yDL +()xP10yLL +(-0.035)xP11yLL +(0.409)xP12yLL +(-0.065)xP13yLL]
LSF_Member_15-DLLL	A15xfy±[(-0.037)xP10yDL +(-0.065)xP11yDL +(0.409)xP12yDL +(-0.04)xP13yDL +()xP10yLL +(-0.037)xP11yLL +(-0.065)xP12yLL +(0.409)xP13yLL]
LSF_Member_16-DLLL	A16xfy±[(-0.126)xP10yDL +(-0.216)xP11yDL +(-0.342)xP12yDL +(0.08)xP13yDL +()xP10yLL +(-0.126)xP11yLL +(-0.216)xP12yLL +(-0.342)xP13yLL]
LSF_Member_17-DLLL	A17xfy±[(0.283)xP10yDL +(0.566)xP11yDL +(0.849)xP12yDL +(1.13)xP13yDL +()xP10yLL +(0.283)xP11yLL +(0.566)xP12yLL +(0.849)xP13yLL]
LSF_Member_18-DLLL	A18xfy±[(0.176)xP10yDL +(-0.364)xP11yDL +(-0.26)xP12yDL +(-0.1)xP13yDL +()xP10yLL +(0.176)xP11yLL +(-0.364)xP12yLL +(-0.26)xP13yLL]
LSF_Member_19-DLLL	A19xfy±[(-0.107)xP10yDL +(0.484)xP11yDL +(0.306)xP12yDL +(0.18)xP13yDL +()xP10yLL +(-0.107)xP11yLL +(0.484)xP12yLL +(0.306)xP13yLL]
LSF_Member_20-DLLL	A20xfy±[(0.157)xP10yDL +(0.351)xP11yDL +(-0.215)xP12yDL +(-0.13)xP13yDL +()xP10yLL +(0.157)xP11yLL +(0.351)xP12yLL +(-0.215)xP13yLL]
LSF_Member_21-DLLL	A21xfy±[(-0.126)xP10yDL +(-0.215)xP11yDL +(0.351)xP12yDL +(0.16)xP13yDL +()xP10yLL +(-0.126)xP11yLL +(-0.215)xP12yLL +(0.351)xP13yLL]
LSF_Member_22-DLLL	A22xfy±[(0.179)xP10yDL +(0.306)xP11yDL +(0.484)xP12yDL +(-0.11)xP13yDL +()xP10yLL +(0.179)xP11yLL +(0.306)xP12yLL +(0.484)xP13yLL]
LSF_Member_23-DLLL	A23xfy±[(-0.104)xP10yDL +(-0.26)xP11yDL +(-0.364)xP12yDL +(0.18)xP13yDL +()xP10yLL +(-0.104)xP11yLL +(-0.26)xP12yLL +(-0.364)xP13yLL]
LSF_Member_24-DLLL	A24xfy±[(0.676)xP10yDL +(0.858)xP11yDL +(0.584)xP12yDL +(0.27)xP13yDL +()xP10yLL +(0.676)xP11yLL +(0.858)xP12yLL +(0.584)xP13yLL]
LSF_Member_25-DLLL	A25xfy±[(0.489)xP10yDL +(0.952)xP11yDL +(0.952)xP12yDL +(0.49)xP13yDL +()xP10yLL +(0.489)xP11yLL +(0.952)xP12yLL +(0.952)xP13yLL]
LSF_Member_26-DLLL	A26xfy±[(0.274)xP10yDL +(0.584)xP11yDL +(0.858)xP12yDL +(0.68)xP13yDL +()xP10yLL +(0.274)xP11yLL +(0.584)xP12yLL +(0.858)xP13yLL]

Table: 5.41 Limit State Equations of truss elements for different failure mode (DD+WL CONDITION):

LSF_Member_1-DLWL	A1xfy±[(-0.288)xP10yDL +(0.121)xP11yDL +(0.321)xP12yDL +(0.31)xP13yDL +(0.288)xP10XWL +(-0.288)xP10yWL +(0.297)xP11XWL +(0.121)xP11yWL +(0.303)xP12XDL +(0.321)xP12YWL +0.312xP13XWL +0.312xP13yWL]
LSF_Member_2-DLWL	A2xfy±[(-0.212)xP10yDL +(-0.221)xP11yDL +(0.105)xP12yDL +(0.19)xP13yDL +(0.212)xP10XWL +(-0.212)xP10yWL +(0.17)xP11XWL +(-0.221)xP11yWL +(0.178)xP12XDL +(0.105)xP12YWL +0.186xP13XWL +0.186xP13yWL]
LSF_Member_3-DLWL	A3xfy±[(0.002)xP10yDL +(-0.327)xP11yDL +(-0.327)xP12yDL +(0)xP13yDL +(-0.002)xP10XWL +(0.002)xP10yWL +(0.013)xP11XWL +(-0.327)xP11yWL +(-0.013)xP12XDL +(-0.327)xP12YWL +0.002xP13XWL +0.002xP13yWL]
LSF_Member_4-DLWL	A4xfy±[(0.186)xP10yDL +(0.105)xP11yDL +(-0.221)xP12yDL +(-0.21)xP13yDL +(-0.186)xP10XWL +(0.186)xP10yWL +(-0.178)xP11XWL +(0.105)xP11yWL +(-0.17)xP12XDL +(-0.221)xP12YWL +-0.212xP13XWL +-0.212xP13yWL]
LSF_Member_5-DLWL	A5xfy±[(0.312)xP10yDL +(0.321)xP11yDL +(0.121)xP12yDL +(-0.29)xP13yDL +(-0.312)xP10XWL +(0.312)xP10yWL +(-0.303)xP11XWL +(0.321)xP11yWL +(-0.297)xP12XDL +(0.121)xP12YWL +-0.288xP13XWL +-0.288xP13yWL]
LSF_Member_6-DLWL	A6xfy±[(-0.107)xP10yDL +(0.484)xP11yDL +(0.306)xP12yDL +(0.18)xP13yDL +(0.107)xP10XWL +(-0.107)xP10yWL +(0.18)xP11XWL +(0.484)xP11yWL +(0.176)xP12XDL +(0.306)xP12YWL +0.179xP13XWL +0.179xP13yWL]
LSF_Member_7-DLWL	A7xfy±[(0.176)xP10yDL +(-0.364)xP11yDL +(-0.26)xP12yDL +(-0.1)xP13yDL +(-0.176)xP10XWL +(0.176)xP10yWL +(-0.102)xP11XWL +(-0.364)xP11yWL +(-0.107)xP12XDL +(-0.26)xP12YWL +-0.104xP13XWL +-0.104xP13yWL]
LSF_Member_8-DLWL	A8xfy±[(-0.126)xP10yDL +(-0.215)xP11yDL +(0.351)xP12yDL +(0.16)xP13yDL +(0.126)xP10XWL +(-0.126)xP10yWL +(0.119)xP11XWL +(-0.215)xP11yWL +(0.164)xP12XDL +(0.351)xP12YWL +0.157xP13XWL +0.157xP13yWL]
LSF_Member_9-DLWL	A9xfy±[(0.157)xP10yDL +(0.351)xP11yDL +(-0.215)xP12yDL +(-0.13)xP13yDL +(-0.157)xP10XWL +(0.157)xP10yWL +(-0.164)xP11XWL +(0.351)xP11yWL +(-0.119)xP12XDL +(-0.215)xP12YWL +-0.126xP13XWL +-0.126xP13yWL]
LSF_Member_10-DLWL	A10xfy±[(-0.104)xP10yDL +(-0.26)xP11yDL +(-0.364)xP12yDL +(0.18)xP13yDL +(0.104)xP10XWL +(-0.104)xP10yWL +(0.107)xP11XWL +(-0.26)xP11yWL +(0.102)xP12XDL +(-0.364)xP12YWL +0.176xP13XWL +0.176xP13yWL]
LSF_Member_11-DLWL	A11xfy±[(0.179)xP10yDL +(0.306)xP11yDL +(0.484)xP12yDL +(-0.11)xP13yDL +(-0.179)xP10XWL +(0.179)xP10yWL +(-0.176)xP11XWL +(0.306)xP11yWL +(-0.18)xP12XDL +(0.484)xP12YWL +-0.107xP13XWL +-0.107xP13yWL]
LSF_Member_12-DLWL	A12xfy±[(1.131)xP10yDL +(0.849)xP11yDL +(0.566)xP12yDL +(0.28)xP13yDL +(0.283)xP10XWL +(1.131)xP10yWL +(0.283)xP11XWL +(0.849)xP11yWL +(0.283)xP12XDL +(0.566)xP12YWL +0.283xP13XWL +0.283xP13yWL]
LSF_Member_13-DLWL	A13xfy±[(0.076)xP10yDL +(-0.342)xP11yDL +(-0.216)xP12yDL +(-0.13)xP13yDL +(-0.076)xP10XWL +(0.076)xP10yWL +(-0.128)xP11XWL +(-0.342)xP11yWL +(-0.125)xP12XDL +(-0.216)xP12YWL +-0.126xP13XWL +-0.126xP13yWL]
LSF_Member_14-DLWL	A14xfy±[(-0.035)xP10yDL +(0.409)xP11yDL +(-0.065)xP12yDL +(-0.04)xP13yDL +(0.035)xP10XWL +(-0.035)xP10yWL +(-0.012)xP11XWL +(0.409)xP11yWL +(-0.04)xP12XDL +(-0.065)xP12YWL +-0.037xP13XWL +-0.037xP13yWL]
LSF_Member_15-DLWL	A15xfy±[(-0.037)xP10yDL +(-0.065)xP11yDL +(0.409)xP12yDL +(-0.04)xP13yDL +(0.037)xP10XWL +(-0.037)xP10yWL +(0.04)xP11XWL +(-0.065)xP11yWL +(0.012)xP12XDL +(0.409)xP12YWL +-0.035xP13XWL +-0.035xP13yWL]
LSF_Member_16-DLWL	A16xfy±[(-0.126)xP10yDL +(-0.216)xP11yDL +(-0.342)xP12yDL +(0.08)xP13yDL +(0.126)xP10XWL +(-0.126)xP10yWL +(0.125)xP11XWL +(-0.216)xP11yWL +(0.128)xP12XDL +(-0.342)xP12YWL +0.076xP13XWL +0.076xP13yWL]
LSF_Member_17-DLWL	A17xfy±[(0.283)xP10yDL +(0.566)xP11yDL +(0.849)xP12yDL +(1.13)xP13yDL +(-0.283)xP10XWL +(0.283)xP10yWL +(-0.283)xP11XWL +(0.566)xP11yWL +(-0.283)xP12XDL +(0.849)xP12YWL +-0.283xP13XWL +1.131xP13yWL]
LSF_Member_18-DLWL	A18xfy±[(0.176)xP10yDL +(-0.364)xP11yDL +(-0.26)xP12yDL +(-0.1)xP13yDL +(-0.176)xP10XWL +(0.176)xP10yWL +(-0.102)xP11XWL +(-0.364)xP11yWL +(-0.107)xP12XDL +(-0.26)xP12YWL +-0.104xP13XWL +-0.104xP13yWL]
LSF_Member_19-DLWL	A19xfy±[(-0.107)xP10yDL +(0.484)xP11yDL +(0.306)xP12yDL +(0.18)xP13yDL +(0.107)xP10XWL +(-0.107)xP10yWL +(0.18)xP11XWL +(0.484)xP11yWL +(0.176)xP12XDL +(0.306)xP12YWL +0.179xP13XWL +0.179xP13yWL]
LSF_Member_20-DLWL	A20xfy±[(0.157)xP10yDL +(0.351)xP11yDL +(-0.215)xP12yDL +(-0.13)xP13yDL +(-0.157)xP10XWL +(0.157)xP10yWL +(-0.164)xP11XWL +(0.351)xP11yWL +(-0.119)xP12XDL +(-0.215)xP12YWL +-0.126xP13XWL +-0.126xP13yWL]
LSF_Member_21-DLWL	A21xfy±[(-0.126)xP10yDL +(-0.215)xP11yDL +(0.351)xP12yDL +(0.16)xP13yDL +(0.126)xP10XWL +(-0.126)xP10yWL +(0.119)xP11XWL +(-0.215)xP11yWL +(0.164)xP12XDL +(0.351)xP12YWL +0.157xP13XWL +0.157xP13yWL]

LSF_Member_22-DLWL	A22xfy±[(0.179)xP10yDL +(0.306)xP11yDL +(0.484)xP12yDL +(-0.11)xP13yDL +(-0.179)xP10XWL +(0.179)xP10yWL +(-0.176)xP11XWL +(0.306)xP11yWL +(-0.18)xP12XDL +(0.484)xP12YWL +-0.107xP13XWL +-0.107xP13yWL]
LSF_Member_23-DLWL	A23xfy±[(-0.104)xP10yDL +(-0.26)xP11yDL +(-0.364)xP12yDL +(0.18)xP13yDL +(0.104)xP10XWL +(-0.104)xP10yWL +(0.107)xP11XWL +(-0.26)xP11yWL +(0.102)xP12XDL +(-0.364)xP12YWL +0.176xP13XWL +0.176xP13yWL]
LSF_Member_24-DLWL	A24xfy±[(0.676)xP10yDL +(0.858)xP11yDL +(0.584)xP12yDL +(0.27)xP13yDL +(-0.676)xP10XWL +(0.676)xP10yWL +(0.272)xP11XWL +(0.858)xP11yWL +(0.275)xP12XDL +(0.584)xP12YWL +0.274xP13XWL +0.274xP13yWL]
LSF_Member_25-DLWL	A25xfy±[(0.489)xP10yDL +(0.952)xP11yDL +(0.952)xP12yDL +(0.49)xP13yDL +(-0.489)xP10XWL +(0.489)xP10yWL +(-0.484)xP11XWL +(0.952)xP11yWL +(0.484)xP12XDL +(0.952)xP12YWL +0.489xP13XWL +0.489xP13yWL]
LSF_Member_26-DLWL	A26xfy±[(0.274)xP10yDL +(0.584)xP11yDL +(0.858)xP12yDL +(0.68)xP13yDL +(-0.274)xP10XWL +(0.274)xP10yWL +(-0.275)xP11XWL +(0.584)xP11yWL +(-0.272)xP12XDL +(0.858)xP12YWL +0.676xP13XWL +0.676xP13yWL]

Table 5.42 Component Level Reliability Indices of all truss elements for different load condition/ modes of failure.

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL	Probability of failure FOR DL+LL	Probability of failure FOR DL+WL
1	19.195	19.369	2.04E-82	7.06E-84
2	25.275	19.481	3.04E-141	7.89E-85
3	23.291	18.525	2.72E-120	6.46E-77
4	25.720	19.591	3.53E-146	9.20E-86
5	19.070	22.637	2.24E-81	9.30E-114
6	19.497	23.382	5.82E-85	3.23E-121
7	25.362	19.706	3.31E-142	9.62E-87
8	19.843	24.785	6.29E-88	6.51E-136
9	19.744	24.551	4.51E-87	2.12E-133
10	25.313	19.685	1.15E-141	1.45E-86
11	19.493	23.277	6.31E-85	3.81E-120
12	18.814	21.913	2.91E-79	9.68E-107
13	23.096	18.389	2.52E-118	8.07E-76
14	19.572	24.675	1.33E-85	9.92E-135
15	19.644	24.709	3.27E-86	4.23E-135
16	23.078	18.312	3.83E-118	3.33E-75
17	18.856	21.834	1.32E-79	5.52E-106
18	25.362	19.706	3.31E-142	9.62E-87
19	19.497	23.382	5.82E-85	3.23E-121
20	19.744	24.551	4.51E-87	2.12E-133
21	19.843	24.785	6.29E-88	6.51E-136
22	19.493	23.277	6.31E-85	3.81E-120
23	25.313	19.685	1.15E-141	1.45E-86
24	**18.102**	20.259	**1.54E-73**	1.47E-91
25	18.808	21.223	3.26E-79	2.94E-100
26	18.151	20.249	6.32E-74	1.82E-91

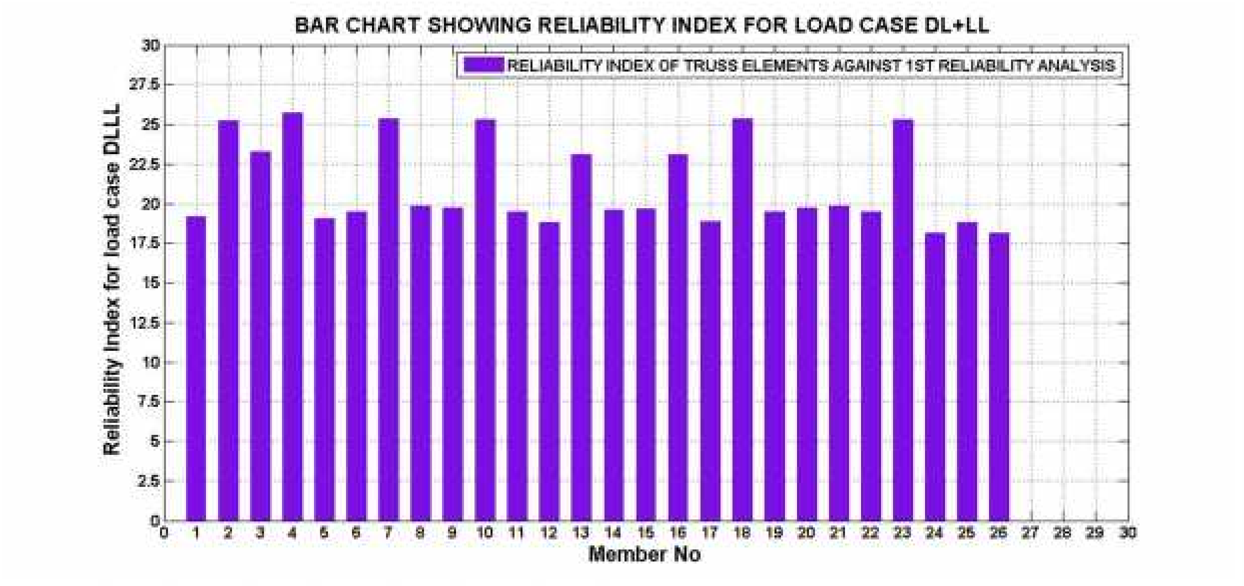


Fig: 5.27 Component Level Reliability Indices of 26-bar truss for (DL+LL) condition

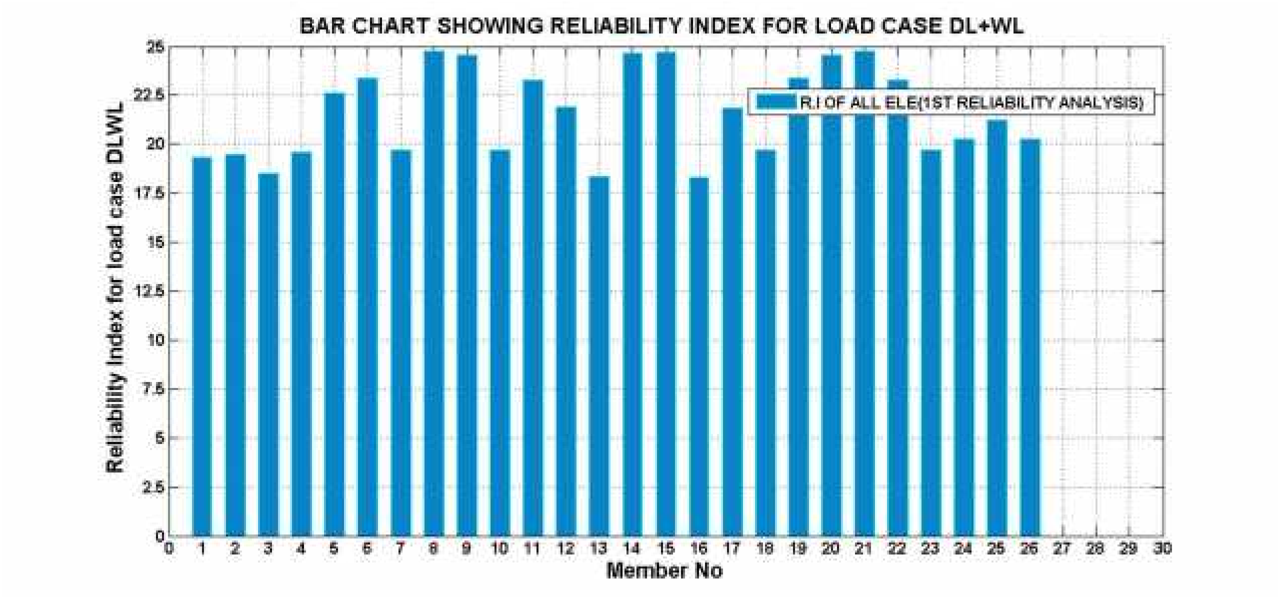


Fig:5.28 Component Level Reliability Indices of 26-bar truss for (DL+WL) condition

From the above result, it has been observed that element no 24 has minimum reliability index having value 18.102 and corresponding probability of failure is 1.54E-73.

Therefore considering first failure member is element no: 24

After detecting the first failure element, the member connectivity of the failure element has been removed and global stiffness matrix of the whole structure has been reconstructed. The modified structure has been reanalysed and component level reliability indices of the remaining elements is evaluated.

Table 5.43 Component Level Reliability Indices of the remaining truss elements after failure of element 24.

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL	Probability of failure FOR DL+LL	Probability of failure FOR DL+WL
1	17.563	14.922	2.37E-69	1.191E-50
2	5.544	19.481	1.48E-08	7.890E-85
3	15.202	14.918	1.73E-52	1.260E-50
4	17.593	16.940	1.39E-69	1.149E-64
5	17.919	14.782	4.20E-72	9.523E-50
6	19.497	23.382	5.82E-85	3.231E-121
7	25.362	19.706	3.31E-142	9.624E-87
8	15.136	14.425	4.68E-52	1.789E-47
9	15.029	14.506	2.36E-51	5.591E-48
10	18.444	18.931	2.93E-76	3.143E-80
11	19.497	17.571	5.84E-85	2.068E-69
12	18.173	20.112	4.19E-74	2.920E-90
13	3.765	18.389	8.33E-05	8.074E-76
14	**3.742**	24.675	**9.11E-05**	9.923E-135
15	19.389	18.288	4.81E-84	5.186E-75
16	19.406	14.647	3.45E-84	7.066E-49
17	18.216	20.060	1.92E-74	8.247E-90
18	25.362	19.706	3.31E-142	9.624E-87
19	19.497	23.382	5.82E-85	3.231E-121
20	15.029	14.506	2.36E-51	5.591E-48
21	15.136	14.425	4.68E-52	1.789E-47
22	19.497	17.571	5.84E-85	2.068E-69
23	18.444	19.685	2.93E-76	1.453E-86
25	21.725	17.560	5.90E-105	2.492E-69
26	16.292	19.556	5.58E-60	1.847E-85

From the above result, it has been observed that next element no 14 having minimum reliability index having value 3.742 and corresponding probability of failure is 9.11E-05.

Therefore considering second failure member is element no: 14

After detecting the second failure element, the member connectivity of the failure element has been removed and global stiffness matrix of the whole structure has been further reconstructed. The modified structure has been reanalysed and component level reliability indices of the remaining elements is evaluated.

Table: 5.44 Component Level Reliability Indices of the remaining truss elements after failure of element 24 & 14.

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL	Probability of failure FOR DL+LL	Probability of failure FOR DL+WL
1	17.56289	18.143026	2.370E-69	7.29E-74
2	16.22348	11.149631	1.721E-59	3.60E-29
3	14.68988	16.100174	3.742E-49	1.27E-58
4	19.16448	16.500181	3.665E-82	1.83E-61
5	16.45278	18.407193	4.005E-61	5.75E-76
6	16.57605	16.139471	5.191E-62	6.73E-59
7	17.43697	17.387925	2.162E-68	5.09E-68
8	15.29505	11.513356	4.125E-53	5.65E-31
9	15.38828	11.577747	9.809E-54	2.67E-31
10	19.06046	20.469938	2.690E-81	2.00E-93
11	18.26059	18.985081	8.521E-75	1.13E-80
12	18.17343	20.111611	4.190E-74	2.92E-90
13	15.46521	**9.859618**	2.979E-54	3.11E-23
15	14.09046	15.609904	2.174E-45	3.12E-55
16	18.20229	14.918193	2.475E-74	1.25E-50
17	18.00149	20.227542	9.482E-73	2.80E-91
18	16.81685	17.713532	9.184E-64	1.65E-70
19	16.57605	16.139471	5.191E-62	6.73E-59
20	15.15475	12.420232	3.524E-52	1.01E-35
21	15.29505	11.513356	4.125E-53	5.65E-31
22	18.04204	19.235504	4.556E-73	9.34E-83
23	19.06046	20.469938	2.690E-81	2.00E-93
25	17.82069	17.83091	2.442E-71	2.03E-71
26	17.32232	18.95204	1.596E-67	2.12E-80

From the above result, it has been observed that next element no is 13 having minimum reliability index having value 9.859 and corresponding probability of failure is 3.112E-23.

As per above observation it may be stated that probabilistic procedure of critical failure path is given in the following sequence:

1st failure member is element no: 24 (having Reliability Index=18.102)

2nd failure member is element no: 14 (Reliability Index=3.742)

Followed by 3rd failure element is 13(Reliability Index=9.85)

4th failure element is 20 (Reliability Index=11.008)

Note: subsequent failure of member 24, 14, 13 & 20 makes the structure statically determinate and failure of any member results total failure of structure.

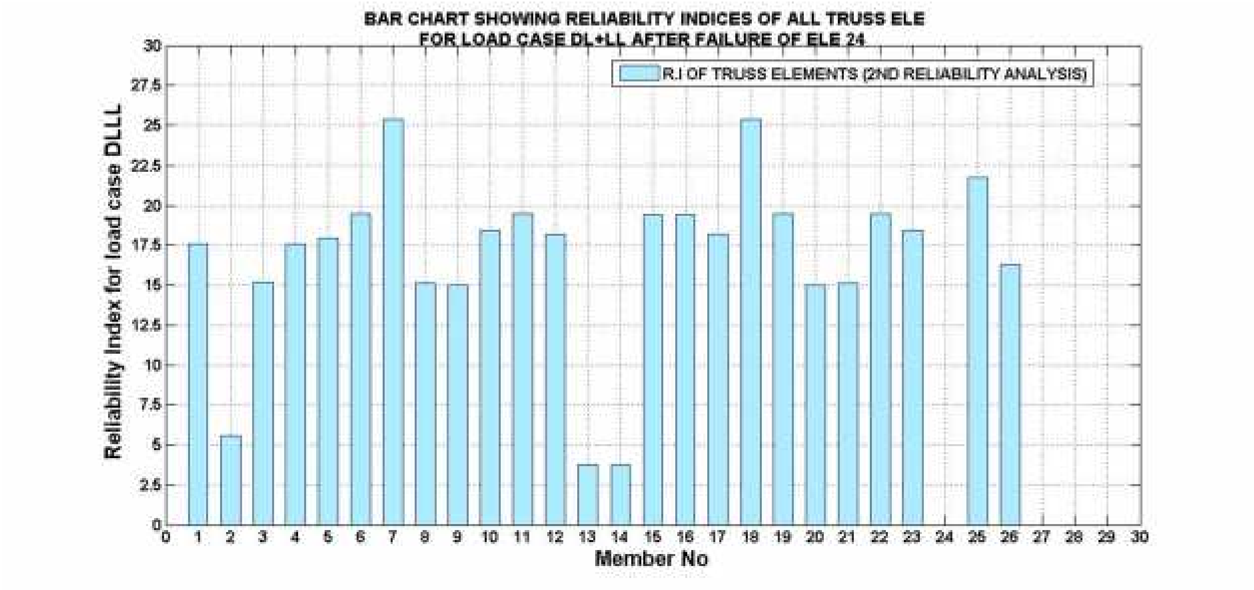


Fig:5.29 Component Level Reliability Indices of all truss element after failure of element 24 against (DL+LL) condition

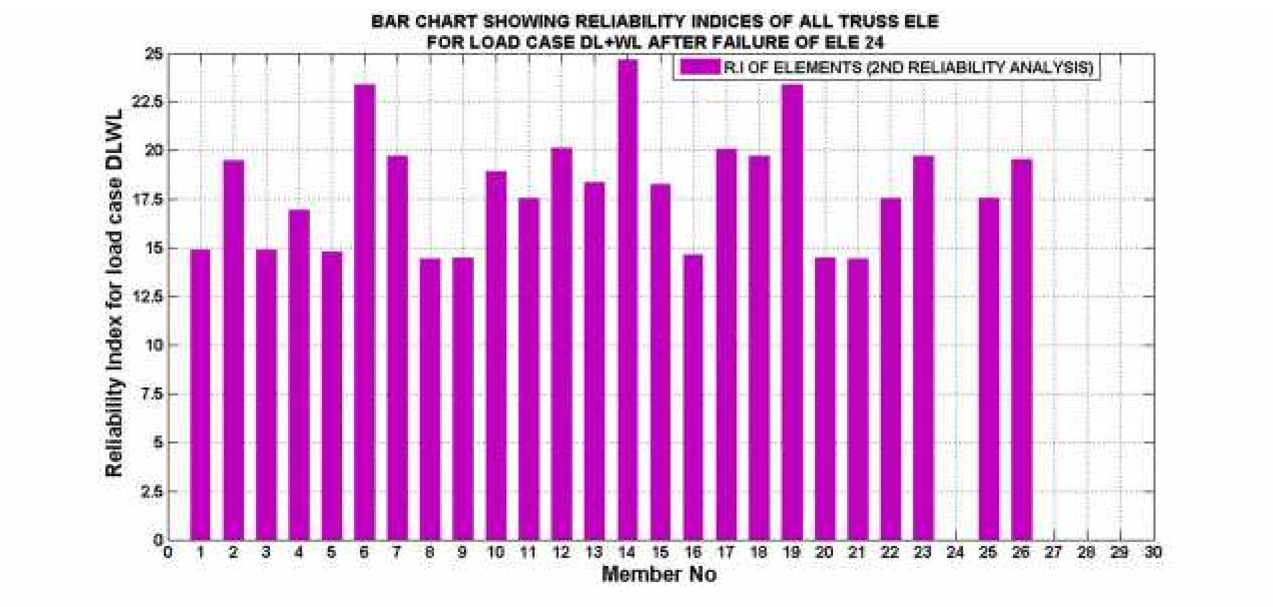


Fig:5.30 Component Level Reliability Indices of all truss elements after failure of element 24 against (DL+WL) condition

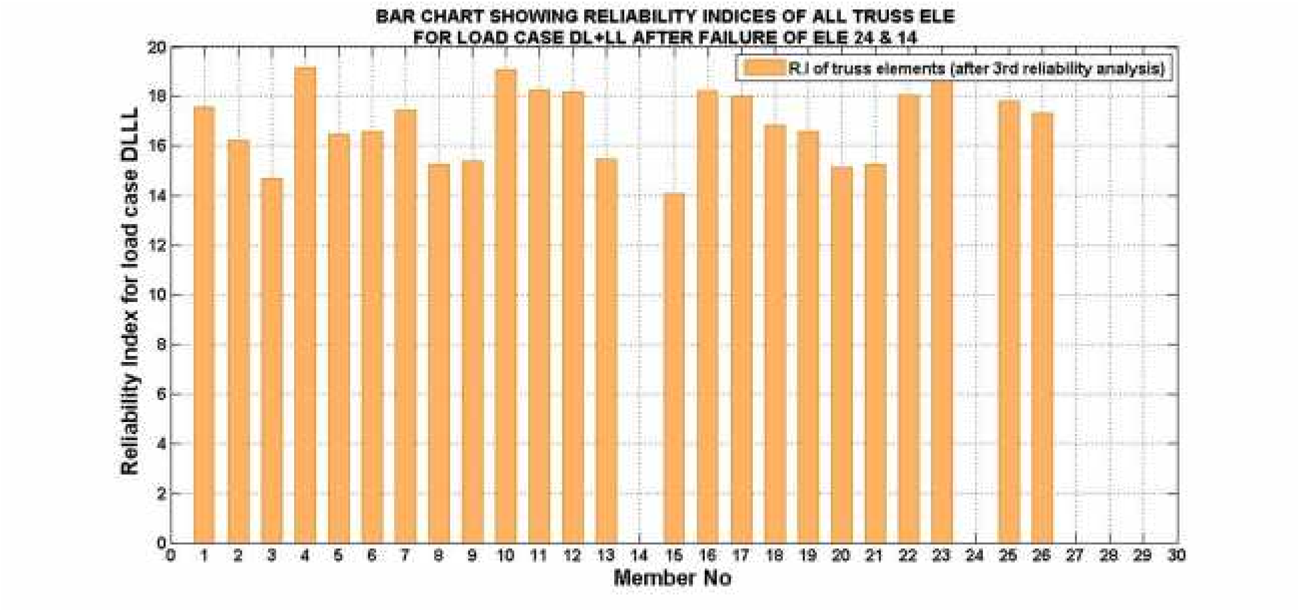


Fig:5.31 Component Level Reliability Indices of all truss elements after failure of elements no 24 and 14 against (DL+LL) condition

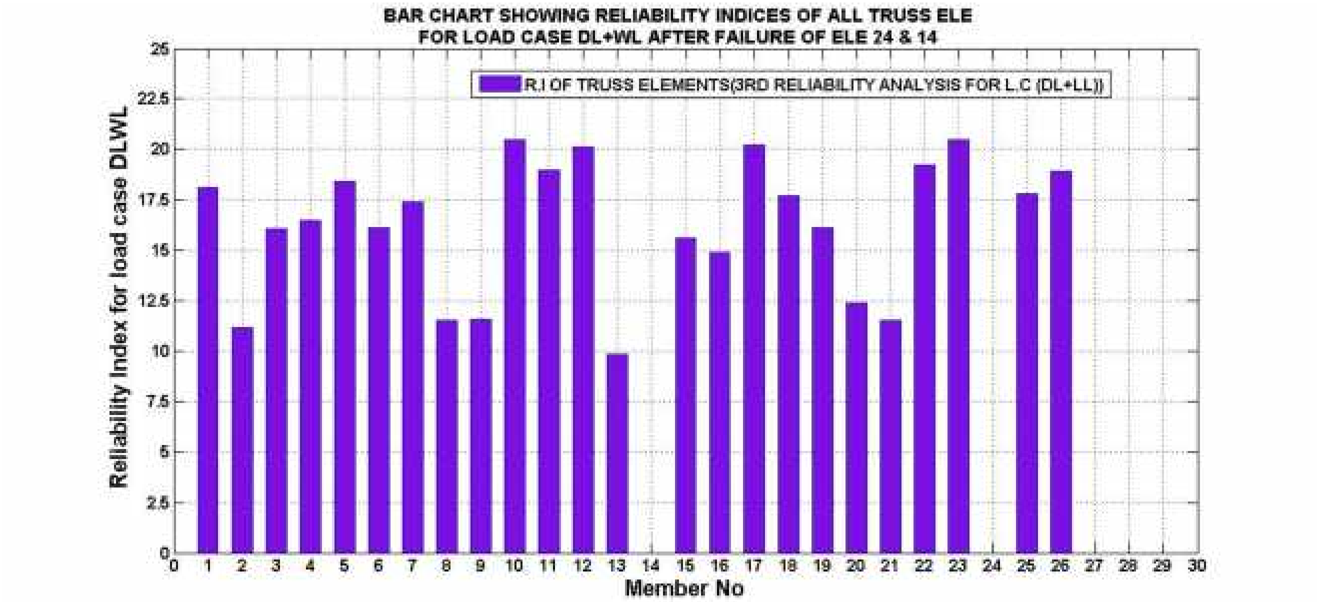


Fig:5.32 Component Level Reliability Indices of all truss elements after failure of elements no 24 and 14 against (DL+WL) condition

Table:5.45 Component Level Reliability Indices of the remaining truss elements after failure of element 24,14 & 13.

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL	Probability of failure FOR DL+LL	Probability of failure FOR DL+WL
1	16.735	12.223	3.64E-63	1.178E-34
2	16.652	11.985	1.47E-62	2.128E-33
3	19.107	16.810	1.10E-81	1.032E-63
4	13.260	14.922	1.98E-40	1.180E-50
5	13.691	15.351	5.75E-43	1.749E-53
6	18.871	19.428	9.96E-80	2.246E-84
7	18.258	18.601	8.90E-75	1.580E-77
8	18.255	15.347	9.39E-75	1.854E-53
9	14.668	15.990	5.16E-49	7.494E-58
10	19.095	18.687	1.40E-81	3.178E-78
11	20.493	19.660	1.24E-93	2.357E-86
12	18.891	21.124	6.73E-80	2.379E-99
15	19.426	19.199	2.34E-84	1.896E-82
16	18.429	14.842	3.83E-76	3.891E-50
17	21.384	17.828	9.51E-102	2.131E-71
18	21.365	17.258	1.43E-101	4.887E-67
19	18.781	20.734	5.41E-79	8.542E-96
20	15.380	**11.008**	1.11E-53	1.754E-28
21	16.924	16.673	1.49E-64	1.035E-62
22	17.459	16.266	1.48E-68	8.665E-60
23	18.405	19.369	5.97E-76	7.060E-84
25	21.080	19.099	6.02E-99	1.286E-81
26	19.156	17.855	4.32E-82	1.315E-71

Table:5.46 Component Level Reliability Indices of the remaining truss elements after failure of element 24,14 ,13 & 20.

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL
1	7.512	8.976
2	3.318	6.330
3	1.004	failed
4	19.039	failed
5	9.028	1.901
6	11.244	15.863
7	10.762	4.940
8	9.193	failed
9	failed	failed
10	0.235	0.665
11	3.742	3.165
12	0.703	2.140
15	10.842	16.671
16	4.434	1.811
17	failed	failed
18	2.062	failed
19	failed	failed
21	failed	failed
22	5.053	14.776

MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLWL
23	failed	1.350
25	failed	failed
26	failed	1.509

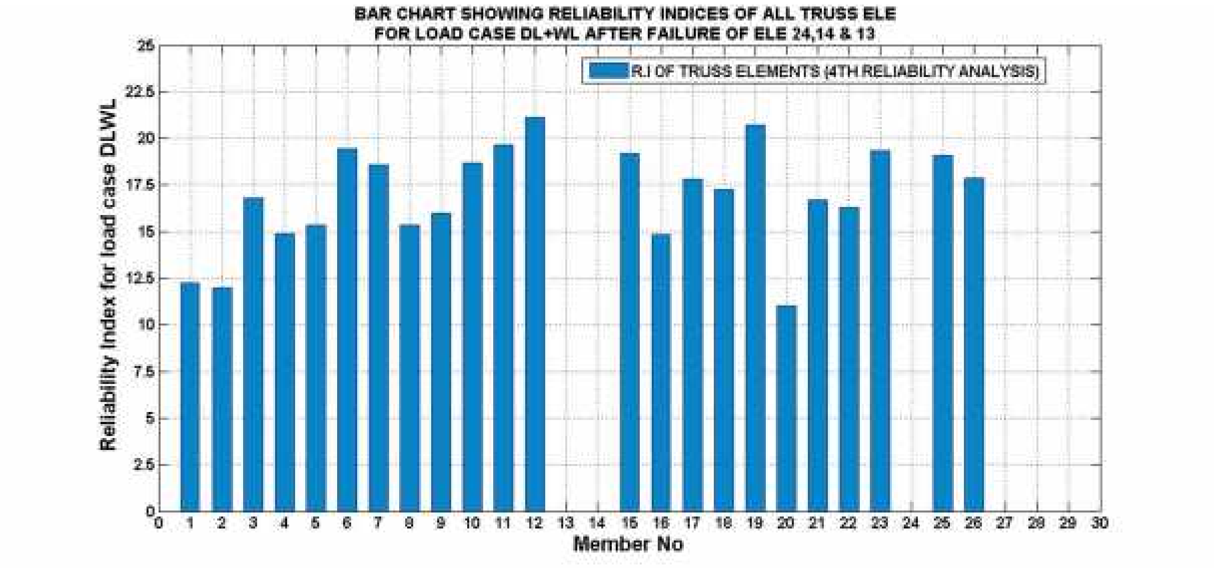


Fig: 5.33 Component Level Reliability Indices of all truss elements after failure of elements no 24, 14 and element 13 against (DL+WL) condition

Table: 5.47 Reliability Indices of truss elements for each successive failure

	1ST RA	2nd RA	3rd RA	4th RA	5th RA	
MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	FAILURE MEMBER
1	19.195	17.563	17.56289	16.735	7.512	
2	25.275	5.544	16.22348	16.652	3.318	
3	23.291	15.202	14.68988	19.107	1.004	
4	25.720	17.593	19.16448	13.260	19.039	
5	19.070	17.919	16.45278	13.691	9.028	
6	19.497	19.497	16.57605	18.871	11.244	
7	25.362	25.362	17.43697	18.258	10.762	
8	19.843	15.136	15.29505	18.255	9.193	
9	19.744	15.029	15.38828	14.668	failed	
10	25.313	18.444	19.06046	19.095	0.235	
11	19.493	19.497	18.26059	20.493	3.742	
12	18.814	18.173	18.17343	18.891	0.703	
13	23.096	3.765	15.46521			**13(3RD)**
14	19.572	3.742				**14(2ND)**
15	19.644	19.389	14.09046	19.426	10.842	
16	23.078	19.406	18.20229	18.429	4.434	

	1ST RA	2nd RA	3rd RA	4th RA	5th RA	
MEMBER NO	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	RELIABILITY INDEX FOR DLLL	FAILURE MEMBER
17	18.856	18.216	18.00149	21.384	failed	
18	25.362	25.362	16.81685	21.365	2.062	
19	19.497	19.497	16.57605	18.781	failed	
20	19.744	15.029	15.15475	15.380		**20(4TH)**
21	19.843	15.136	15.29505	16.924	failed	
22	19.493	19.497	18.04204	17.459	5.053	
23	25.313	18.444	19.06046	18.405	failed	
24	18.102					**24(1ST)**
25	18.808	21.725	17.82069	21.080	failed	
26	18.151	16.292	17.32232	19.156	failed	

	1ST RA	2nd RA	3rd RA	4th RA	5th RA	
MEMBER NO	RELIABILITY INDEX FOR DLWL	RELIABILITY INDEX FOR DLWL	RELIABILITY INDEX FOR DLWL	RELIABILITY INDEX FOR DLWL	RELIABILITY INDEX FOR DLWL	FAILURE MEMBER
1	19.369	14.922	18.143	12.223	8.976	
2	19.481	19.481	11.150	11.985	6.330	
3	18.525	14.918	16.100	16.810	failed	
4	19.591	16.940	16.500	14.922	failed	
5	22.637	14.782	18.407	15.351	1.901	
6	23.382	23.382	16.139	19.428	15.863	
7	19.706	19.706	17.388	18.601	4.940	
8	24.785	14.425	11.513	15.347	failed	
9	24.551	14.506	11.578	15.990	failed	
10	19.685	18.931	20.470	18.687	0.665	
11	23.277	17.571	18.985	19.660	3.165	
12	21.913	20.112	20.112	21.124	2.140	
13	18.389	18.389	9.860			**13**
14	24.675	24.675				**14**
15	24.709	18.288	15.610	19.199	16.671	
16	18.312	14.647	14.918	14.842	1.811	
17	21.834	20.060	20.228	17.828	failed	
18	19.706	19.706	17.714	17.258	failed	
19	23.382	23.382	16.139	20.734	failed	
20	24.551	14.506	12.420	11.008		**20**
21	24.785	14.425	11.513	16.673	failed	
22	23.277	17.571	19.236	16.266	14.776	
23	19.685	19.685	20.470	19.369	1.350	
24	20.259					**24**
25	21.223	17.560	17.831	19.099	failed	
26	20.249	19.556	18.952	17.855	1.509	

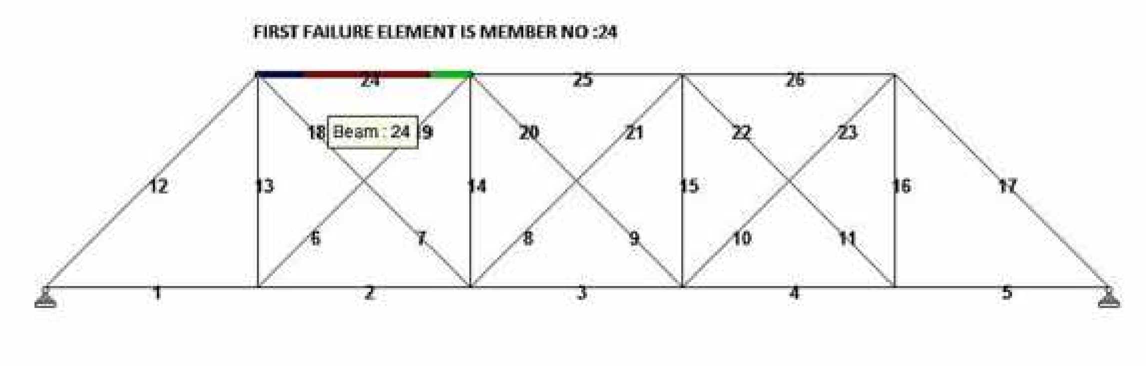


Fig:5.34 First failure elements having minimum reliability index.

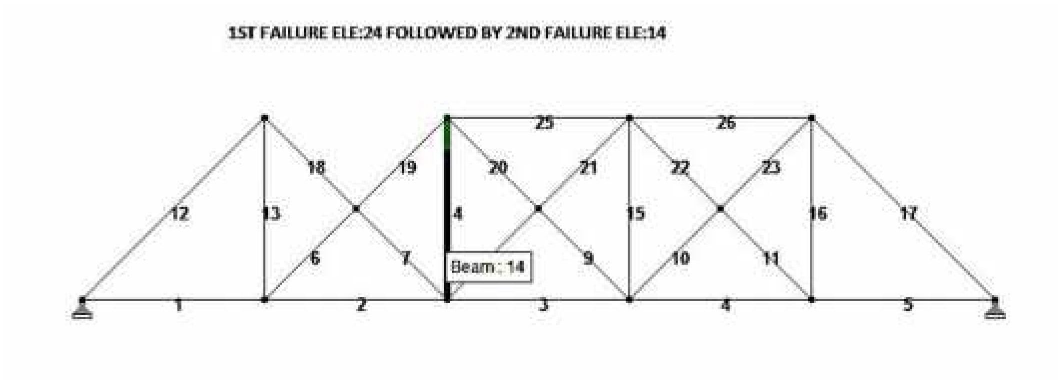


Fig:5.35 Geometrical configuration of the truss after failure of first element having minimum RI i.e element no 24

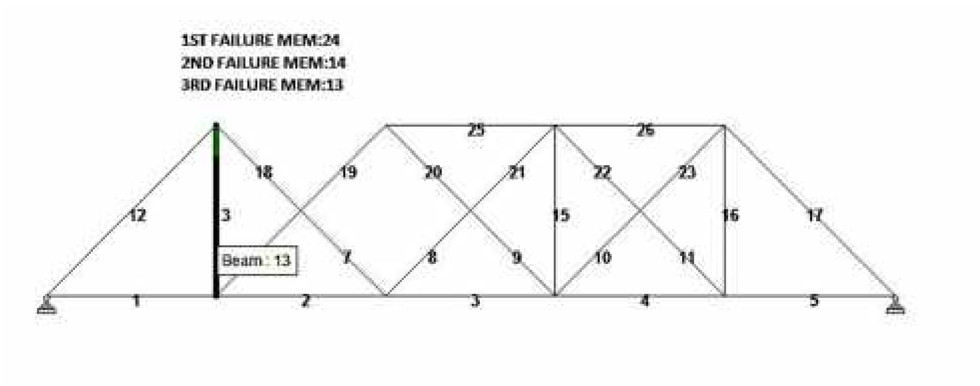


Fig:5.36 Geometrical configuration of the truss after failure of first two elements having minimum RI i.e element no 24 and 14.

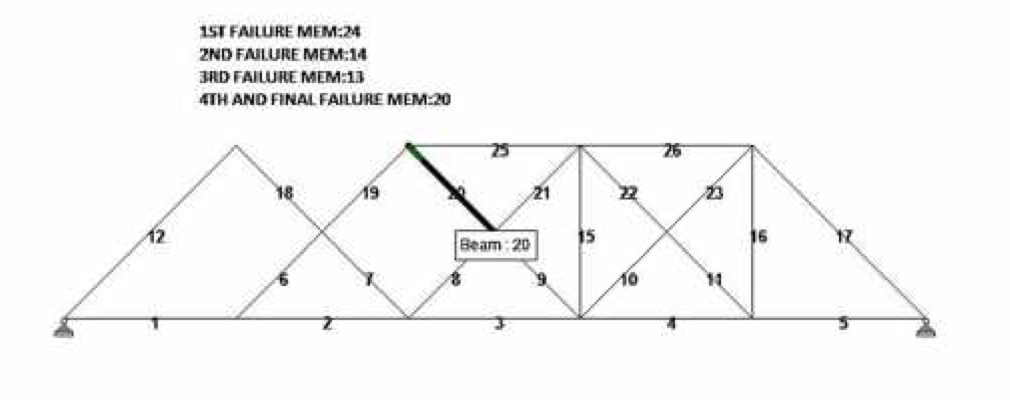


Fig:5.37 Geometrical configuration of the truss after failure of first three elements having minimum RI i.e element no 24 and 14 and 13.

5.2.3 System Reliability at level 1

For the analysis result, the system reliability of the said truss at level 1

The Ditlevsen bound for the system failure probability at level one are...:

The lower bound is:

The upper bound is: 1.5366e-73

Ditlevsen bounds for the system reliability at level one are:

The Upper RI Bound is: 18.102

The Lower RI Bound is:-

Here Δ =6.00

Critical failure elements are

1	5	6	8	9	11	12	14	15

17	19	20	21	22	24	25	26	

Table:5.48 List of elements with coefficient of influences and R.I which are considered in evaluation of system reliability at level 1

MEMBER NO	coefficient resistance against c/s area	Coefficient of influence for NODAL load (DL)when acting at AT NODE 10 IN KN in Y-dir	Coefficient of influence for NODAL load (DL)when acting at 11 IN KN in Y-dir	Coefficient of influence for NODAL load (DL)when acting at12 IN KN in Y-dir	Coefficient of influence for NODAL load (DL)when acting at 13 IN KN in Y-dir	Coefficient of influence for NODAL load (LL)when acting at10 IN KN in Y-dir	Coefficient of influence for NODAL load (LL)when acting at 11 IN KN in Y-dir	Coefficient of influence for NODAL load (LL)when acting at 12 IN KN in Y-dir	Coefficient of influence for NODAL load (LL)when acting at 13 IN KN in Y-dir	RELIABILITY INDEX FOR DLLL prior to failure
1	0.000	-0.2826	0.1273	0.3273	0.3200	-0.2826	0.1273	0.3273	0.3174	19.194
5	0.000	0.3174	0.3273	0.1273	-	0.3174	0.3273	0.1273	-	19.070
6	0.001	-0.0875	0.5166	0.3196	0.2000	-0.0875	0.5166	0.3196	0.1991	19.497
8	0.000	-0.1299	-0.2187	0.3470	0.1500	-0.1299	-0.2187	0.3470	0.1530	19.843
9	0.000	0.1530	0.3470	-0.2187	-	0.1530	0.3470	-0.2187	-	19.744
11	0.001	0.1991	0.3196	0.5166	-	0.1991	0.3196	0.5166	-	19.492
12	0.001	1.1314	0.8485	0.5657	0.2800	1.1314	0.8485	0.5657	0.2828	18.813
14	0.000	-0.0463	0.3894	-0.0714	-	-0.0463	0.3894	-0.0714	-	19.572
15	0.000	-0.0489	-0.0714	0.3894	-	-0.0489	-0.0714	0.3894	-	19.643
17	0.001	0.2828	0.5657	0.8485	1.1300	0.2828	0.5657	0.8485	1.1314	18.855
19	0.001	-0.0875	0.5166	0.3196	0.2000	-0.0875	0.5166	0.3196	0.1991	19.497
20	0.000	0.1530	0.3470	-0.2187	-	0.1530	0.3470	-0.2187	-	19.744
21	0.000	-0.1299	-0.2187	0.3470	0.1500	-0.1299	-0.2187	0.3470	0.1530	19.843
22	0.001	0.1991	0.3196	0.5166	-	0.1991	0.3196	0.5166	-	19.492
24	0.001	0.6619	0.8347	0.5740	0.2600	0.6619	0.8347	0.5740	0.2592	18.102
25	0.001	0.4918	0.9547	0.9547	0.4900	0.4918	0.9547	0.9547	0.4918	18.807
26	0.001	0.2592	0.5740	0.8347	0.6600	0.2592	0.5740	0.8347	0.6619	18.150

Here correlation coefficient $°_{ij}$ of the safety margin between any two failure element in very near to zero, for evaluation of system reliability upper bound value is taken

Upper Bound of Probability of failure:

$P_f \leq 1 - \sum_{i=1}^{n} [1 - P(F_i)]$ =18.102 and corresponding Reliability index is 1.5366e-73

5.2.4 Discussion on Result of Example 2

In the 2nd Example, a 26 bars statically indeterminate truss has been considered for reliability analysis as well as determination of critical failure path. Here COV for all nodal loads, member cross sectional area and yield stress of steel is considered as 0.05. As per result obtained after solving the related code, it has been found that 1st failure member is element no: 24 (having Reliability Index=18.102), 2nd failure member is element no: 14 (Reliability Index=3.742) followed by 3rd failure element is 13(Reliability Index=9.85). After failure of member 13 , reanalysis has done to detect next failure element and element 20 have the lowest reliability index having value 11.008. : Subsequent failure of members 24, 14, 13 and 20 makes the structure statically determinate and after that failure of any member results total failure of structure.

The system reliability at level 1 of the said structure is 18.102 and corresponding probability of failure is 1.5366e-73.

From the above study it has been found that reliability based approach towards detection of critical failure path of statically indeterminate truss indicating that subsequent failure of truss elements results gradual reduction of reliability indices of elements in survival. However, increase in reliability indices of few elements are also noticed may be due to redistribution of internal force.

While detecting the critical failure path of the structure, abrupt declination of reliability indices of truss elements in survival is also observed before failure of the structure as a whole.

5.3 Reliability estimation with variation of cross sectional area of one critical element (Example: 3)

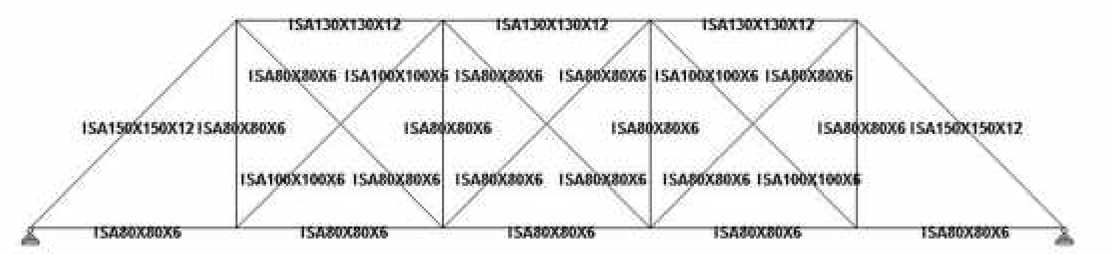


Fig:5.38 Member specification of Truss elements

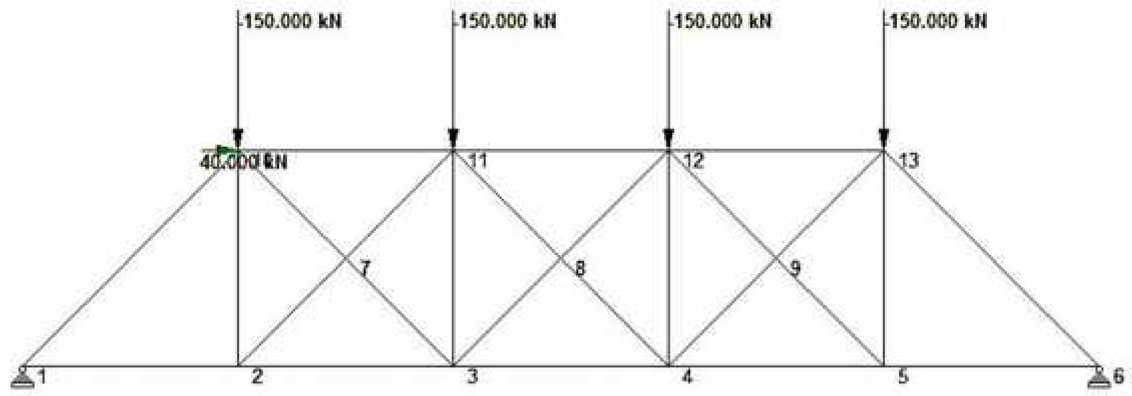


Fig: 5.39 Node no & applied nodal forces at joints

6.3.1 General

In this Example similar type geometrical configuration of truss has been selected as selected in example 2 with initial member specification and mean of nodal loads as shown in the above figure. In that case, c/s area of the element (critical element) having maximum probability of failure or minimum reliability index has been varied from (Mean c/s area-1.5*SD) to (Mean s/c area +1.5*SD) with increment of 0.50*SD and E value of the elements has been reduced to 0.20 times of initial Value when the element are in failure state. As per different values of c/s area of the member and reduced value of elastic modulus of the mostly critical element, the element stiffness matrix has been modified and linear elastic analysis has been performed for all cases and accordingly reliability indices of all elements has been evaluated and variation of Reliability Index for all cases has been examined against reduction of E-value of critical elements.

Table:5.49 Reliability Indices of Truss Elements against variation of C/S area of critical elements and reduction of E- value of critical element.

		Member 24	Area (mean +1.5xSD)	Area (mean+1.0xSD)	Area (mean+0.5xSD)	Area (mean)	Area (mean-0.5xSD)	Area (mean-1.0xSD)	Area (mean-1.5xSD)
		c/s area in m2	0.0028819	0.0027566	0.0026313	0.002506	0.0023807	0.0022554	0.0021301
			Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Member no	Initial Member designation	c/s area in m2	Reliability Index	Reliability Index	Reliability Index	Reliability Index	Reliability Index	Reliability Index	Reliability Index
1	ISA 80X80X6	0.000929	3.482	3.345	3.336	2.672	2.636	2.598	2.556
2	ISA 80X80X6	0.000929	9.718	9.453	9.411	6.523	6.387	6.241	6.083
3	ISA 80X80X6	0.000929	2.404	2.409	2.416	2.991	3.023	3.058	3.096
4	ISA 80X80X6	0.000929	9.161	8.987	8.978	8.230	8.188	8.143	8.094
5	ISA 80X80X6	0.000929	2.073	2.017	2.009	1.390	1.357	1.321	1.282
6	ISA 80X80X6	0.001167	3.905	3.846	3.803	0.815	0.670	0.513	0.343
7	ISA 80X80X6	0.000929	5.212	5.243	5.291	9.975	10.295	10.654	11.058
8	ISA 80X80X6	0.000929	2.215	2.186	2.189	2.492	2.508	2.526	2.546
9	ISA 80X80X6	0.000929	1.721	1.725	1.728	2.025	2.041	2.059	2.079
10	ISA 80X80X6	0.000929	4.914	4.893	4.895	5.012	5.019	5.026	5.033
11	ISA 80X80X6	0.001167	3.299	3.289	3.287	3.185	3.180	3.174	3.167
12	ISA 150X150X10	0.003459	2.095	2.092	2.092	2.092	2.092	2.092	2.092
13	ISA 80X80X6	0.000929	5.505	5.452	5.417	2.927	2.806	2.675	2.534
14	ISA 80X80X6	0.000929	8.789	8.693	8.646	5.553	5.410	5.257	5.093
15	ISA 80X80X6	0.000929	8.586	8.554	8.556	8.749	8.760	8.771	8.784
16	ISA 80X80X6	0.000929	5.000	4.989	4.988	4.903	4.899	4.894	4.888
17	ISA 150X150X10	0.003459	1.784	1.741	1.741	1.741	1.741	1.741	1.741
18	ISA 80X80X6	0.000929	5.212	5.243	5.291	9.975	10.295	10.654	11.058
19	ISA 80X80X6	0.001167	3.905	3.846	3.803	0.815	0.670	0.513	0.343
20	ISA 80X80X6	0.000929	1.721	1.725	1.728	2.025	2.041	2.059	2.079
21	ISA 80X80X6	0.000929	2.215	2.186	2.189	2.492	2.508	2.526	2.546
22	ISA 80X80X6	0.001167	3.299	3.289	3.287	3.185	3.180	3.174	3.167
23	ISA 80X80X6	0.000929	4.914	4.893	4.895	5.012	5.019	5.026	5.033
24	**ISA 130X130X8**	0.002506	2.060	1.802	**1.531**	2.214	1.972	1.715	1.443
25	ISA 130X130X8	0.002506	1.588	1.581	1.580	1.533	1.519	1.512	1.508
26	ISA 130X130X8	0.002506	1.592	1.590	1.588	1.586	1.584	1.527	1.529

Table: 5.50 MEF of truss element 13 due variations of c/s area of element24 and reduction of E-value of failure elements when nodal load at node 10 in +ve X-dir and –ve Y-dir.

MEMBER END FORCES IN TRUSS ELEMENT no 13 DUE TO REDUCTION OF C/S AREA OF MEMBER 24							
	WHEN LOAD AT NODE 10 IN X-DIR	WHEN LOAD AT NODE 10 IN X-DIR	WHEN LOAD AT NODE 10 IN X-DIR	WHEN LOAD AT NODE 10 IN X-DIR	WHEN LOAD AT NODE 10 IN X-DIR	WHEN LOAD AT NODE 10 IN X-DIR	WHEN LOAD AT NODE 10 IN X-DIR
c/s area in m2	Area (mean+1.5xSD)	Area (mean+1.0xSD)	Area (mean+0.5xSD)	Area (mean)	Area (mean-0.5xSD)	Area (mean-1.0xSD)	Area (mean-1.5xSD)
	0.0028819	0.0027566	0.0026313	0.002506	0.0023807	0.0022554	0.0021301
NODAL FORCE AT NODE 10 IN KN	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
28	-2.792	-2.757	-2.718	0.313	0.477	0.657	0.852
30	-2.991	-2.954	-2.912	0.335	0.511	0.704	0.913
32	-3.191	-3.150	-3.106	0.357	0.546	0.750	0.974
34	-3.390	-3.347	-3.301	0.380	0.580	0.797	1.035
36	-3.590	-3.544	-3.495	0.402	0.614	0.844	1.096
38	-3.789	-3.741	-3.689	0.424	0.648	0.891	1.157
40	-3.988	-3.938	-3.883	0.447	0.682	0.938	1.218
42	-4.188	-4.135	-4.077	0.469	0.716	0.985	1.279
44	-4.387	-4.332	-4.271	0.491	0.750	1.032	1.340
46	-4.587	-4.529	-4.466	0.514	0.784	1.079	1.400
48	-4.786	-4.726	-4.660	0.536	0.818	1.126	1.461
50	-4.985	-4.923	-4.854	0.558	0.852	1.173	1.522
52	-5.185	-5.119	-5.048	0.581	0.887	1.220	1.583

MEMBER END FORCES IN TRUSS ELEMENT no 13 DUE TO REDUCTION OF C/S AREA OF MEMBER 24							
	WHEN LOAD AT NODE 10 IN y-DIR	WHEN LOAD AT NODE 10 IN y-DIR	WHEN LOAD AT NODE 10 IN y-DIR	WHEN LOAD AT NODE 10 IN y-DIR	WHEN LOAD AT NODE 10 IN y-DIR	WHEN LOAD AT NODE 10 IN y-DIR	WHEN LOAD AT NODE 10 IN y-DIR
c/s area in m2	Area (mean+1.5xSD)	Area (mean+1.0xSD)	Area (mean+0.5xSD)	Area (mean)	Area (mean-0.5xSD)	Area (mean-1.0xSD)	Area (mean-1.5xSD)
	0.0028819	0.0027566	0.0026313	0.002506	0.002380	0.0022554	0.0021301
NODAL FORCE AT NODE 10-Y DIR IN KN	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
105	-19.443	-19.198	-18.930	2.177	3.325	4.573	5.937
112.5	-18.696	-18.460	-18.202	2.093	3.197	4.397	5.708
120	-17.948	-17.721	-17.474	2.010	3.069	4.221	5.480
127.5	-17.200	-16.983	-16.746	1.926	2.941	4.046	5.252
135	-16.452	-16.244	-16.018	1.842	2.813	3.870	5.023
142.5	-15.704	-15.506	-15.290	1.758	2.685	3.694	4.795
150	-14.956	-14.768	-14.562	1.675	2.557	3.518	4.567
157.5	-14.209	-14.029	-13.834	1.591	2.430	3.342	4.338
165	-13.461	-13.291	-13.106	1.507	2.302	3.166	4.110
172.5	-12.713	-12.553	-12.377	1.424	2.174	2.990	3.882
180	-11.965	-11.814	-11.649	1.340	2.046	2.814	3.653

187.5	-11.217	-11.076	-10.921	1.256	1.918	2.638	3.425
195	-10.470	-10.337	-10.193	1.172	1.790	2.463	3.197

Table: 5.51 MEF of truss element 13 due variations of c/s area of element24 and reduction of E-value of failure elements when nodal load at node 11 and 12 in -ve Y-dir.

MEMBER END FORCES IN TRUSS ELEMENT NO 13 DUE TO REDUCTION OF C/S AREA OF MEMBER 24							
	WHEN LOAD AT NODE 11 IN y-DIR	WHEN LOAD AT NODE 11 IN y-DIR	WHEN LOAD AT NODE 11 IN y-DIR	WHEN LOAD AT NODE 11 IN y-DIR	WHEN LOAD AT NODE 11 IN y-DIR	WHEN LOAD AT NODE 11 IN y-DIR	WHEN LOAD AT NODE 11 IN y-DIR
c/s area in m2	Area (mean+1.5xSD)	Area (mean+1.0xSD)	Area (mean+0.5xSD)	Area (mean)	Area (mean-0.5xSD)	Area (mean-1.0xSD)	Area (mean-1.5xSD)
	0.0028819	0.0027566	0.0026313	0.002506	0.0023807	0.0022554	0.0021301
NODAL FORCE AT NODE 11-Y DIR	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
105	65.846	66.148	66.478	92.491	93.906	95.444	97.125
112.5	63.313	63.604	63.922	88.934	90.294	91.773	93.389
120	60.781	61.060	61.365	85.377	86.682	88.102	89.653
127.5	58.248	58.516	58.808	81.819	83.070	84.432	85.918
135	55.716	55.972	56.251	78.262	79.459	80.761	82.182
142.5	53.183	53.428	53.694	74.705	75.847	77.090	78.447
150	50.651	50.883	51.137	71.147	72.235	73.419	74.711
157.5	48.118	48.339	48.580	67.590	68.623	69.748	70.976
165	45.586	45.795	46.024	64.032	65.012	66.077	67.240
172.5	43.053	43.251	43.467	60.475	61.400	62.406	63.505
180	40.521	40.707	40.910	56.918	57.788	58.735	59.769
187.5	37.988	38.163	38.353	53.360	54.176	55.064	56.033
195	35.456	35.618	35.796	49.803	50.565	51.393	52.298

MEMBER END FORCES IN TRUSS ELEMENT no 13 DUE TO REDUCTION OF C/S AREA OF MEMBER 24							
	WHEN LOAD AT NODE 12 IN y-DIR	WHEN LOAD AT NODE 12 IN y-DIR	WHEN LOAD AT NODE 12 IN y-DIR	WHEN LOAD AT NODE 12 IN y-DIR	WHEN LOAD AT NODE 12 IN y-DIR	WHEN LOAD AT NODE 12 IN y-DIR	WHEN LOAD AT NODE 12 IN y-DIR
c/s area in m2	Area (mean+1.5 xSD)	Area (mean+1.0xSD)	Area (mean+0.5xSD)	Area (mean)	Area (mean-0.5xSD)	Area (mean-1.0xSD)	Area (mean-1.5xSD)
	0.0028819	0.0027566	0.0026313	0.002506	0.0023807	0.0022554	0.0021301
NODAL FORCE AT NODE 12-Y DIR IN KN	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
105	40.452	40.660	40.887	58.762	59.734	60.791	61.945
112.5	38.896	39.096	39.314	56.502	57.436	58.453	59.563
120	37.340	37.532	37.742	54.242	55.139	56.115	57.180
127.5	35.785	35.968	36.169	51.981	52.841	53.777	54.798
135	34.229	34.405	34.597	49.721	50.544	51.438	52.415
142.5	32.673	32.841	33.024	47.461	48.246	49.100	50.033
150	31.117	31.277	31.451	45.201	45.949	46.762	47.650
157.5	29.561	29.713	29.879	42.941	43.651	44.424	45.268

165	28.005	28.149	28.306	40.681	41.354	42.086	42.885
172.5	26.450	26.585	26.734	38.421	39.057	39.748	40.503
180	24.894	25.022	25.161	36.161	36.759	37.410	38.120
187.5	23.338	23.458	23.589	33.901	34.462	35.072	35.738
195	21.782	21.894	22.016	31.641	32.164	32.734	33.355

Table: 5.52 MEF of truss element 13 due variations of c/s area of element24 and reduction of E-value of failure elements when nodal load at node 13 in -ve Y-dir.

MEMBER END FORCES IN TRUSS ELEMENT no 13 DUE TO REDUCTION OF C/S AREA OF MEMBER 24							
	WHEN LOAD AT NODE 13 IN y-DIR	WHEN LOAD AT NODE 13 IN y-DIR	WHEN LOAD AT NODE 13 IN y-DIR	WHEN LOAD AT NODE 13 IN y-DIR	WHEN LOAD AT NODE 13 IN y-DIR	WHEN LOAD AT NODE 13 IN y-DIR	WHEN LOAD AT NODE 13 IN y-DIR
c/s area in m2	Area (mean+1.5xSD)	Area (mean+1.0xSD)	Area (mean+0.5xSD)	Area (mean)	Area (mean-0.5xSD)	Area (mean-1.0xSD)	Area (mean-1.5xSD)
	0.0028819	0.0027566	0.0026313	0.002506	0.0023807	0.0022554	0.0021301
NODAL FORCE AT NODE 13-Y DIR	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
105	23.899	23.996	24.102	32.472	32.927	33.422	33.962
112.5	22.980	23.073	23.175	31.223	31.660	32.136	32.656
120	22.060	22.150	22.248	29.974	30.394	30.851	31.350
127.5	21.141	21.227	21.321	28.725	29.127	29.565	30.043
135	20.222	20.304	20.394	27.476	27.861	28.280	28.737
142.5	19.303	19.381	19.467	26.227	26.595	26.994	27.431
150	18.384	18.459	18.540	24.978	25.328	25.709	26.125
157.5	17.464	17.536	17.613	23.729	24.062	24.423	24.819
165	16.545	16.613	16.686	22.480	22.795	23.138	23.512
172.5	15.626	15.690	15.759	21.231	21.529	21.853	22.206
180	14.707	14.767	14.832	19.982	20.263	20.567	20.900
187.5	13.788	13.844	13.905	18.734	18.996	19.282	19.594
195	12.869	12.921	12.978	17.485	17.730	17.996	18.287

Randomness of the Design variables:

Mean Yield Stress(f_y)	250 Mpa
COV of f_y	0.10
COV of C/S area of element (A_i)	0.10
COV of Nodal Load (P_i)	0.10

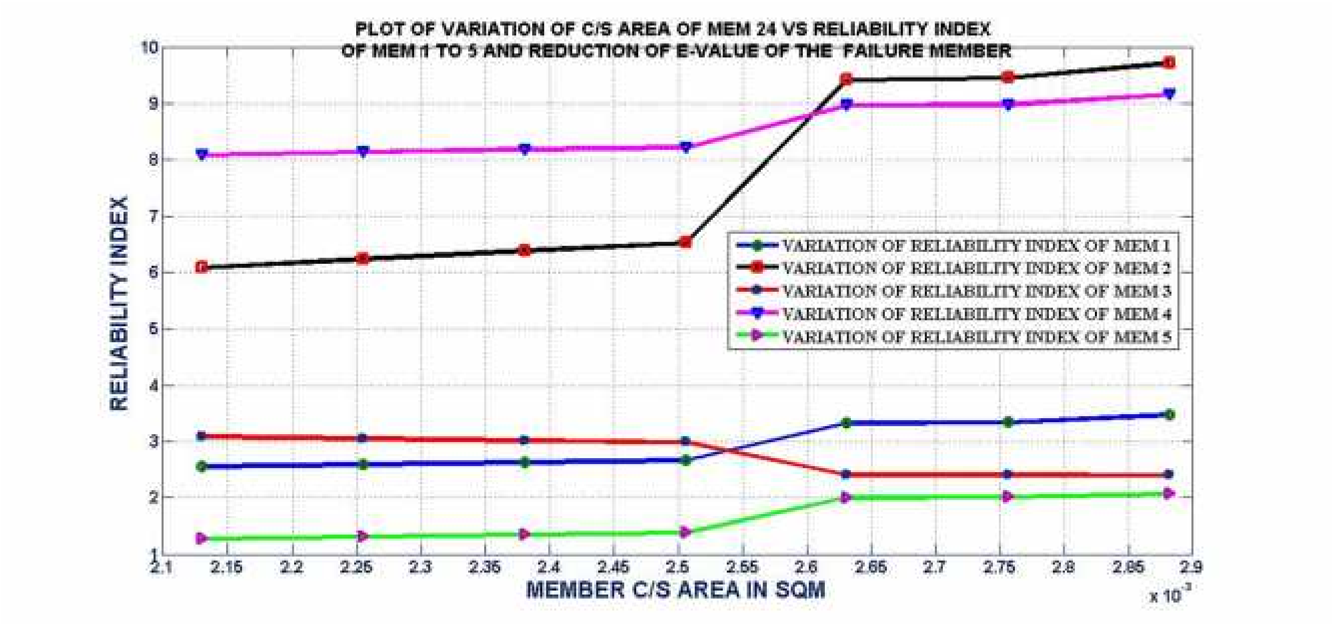


Fig:5.40 change in reliability indices of truss elements(1,2,3,4 & 5) due to variation of c/s area and reduction of E-value of failure element.

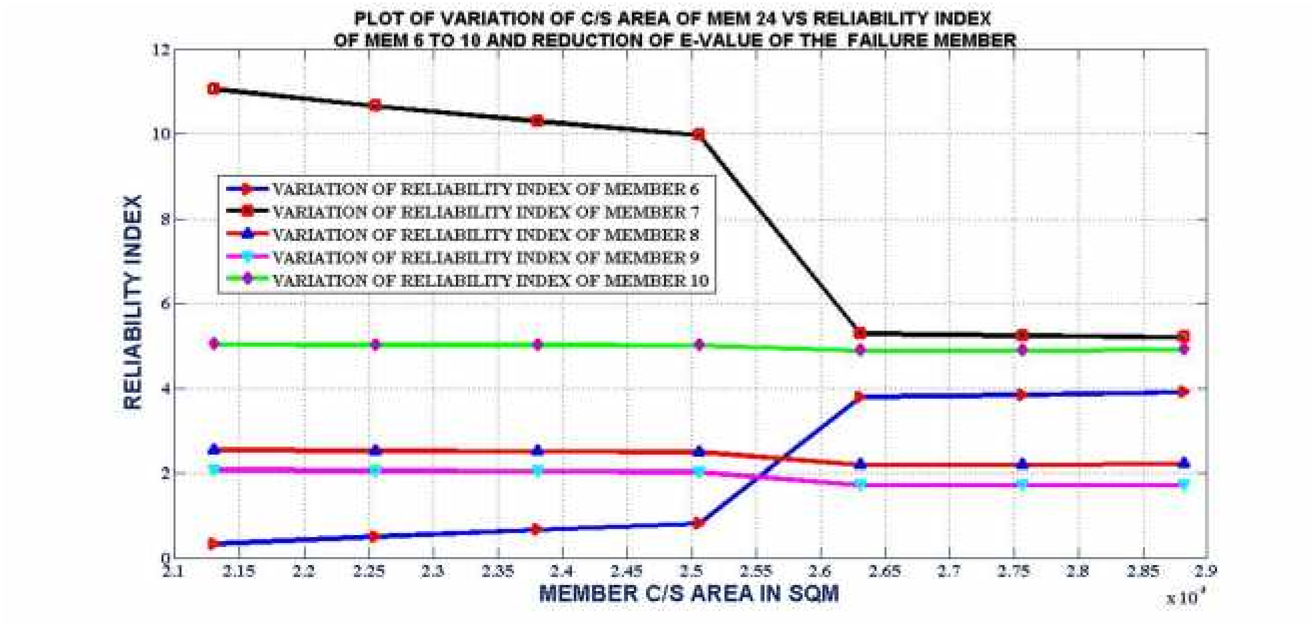


Fig:5.41 change in reliability indices of truss elements(6,7,8,9 & 10) due to variation of c/s area and rduction of E-value of failure element.

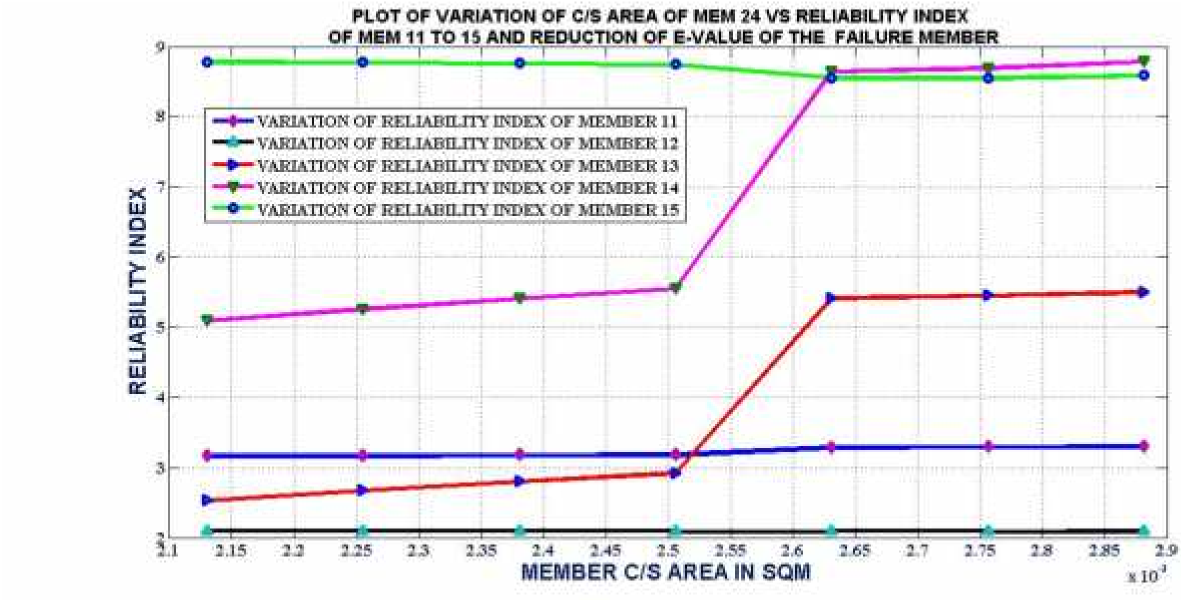


Fig:5.42 change in reliability indices of truss elements(11 to 16) due to variation of c/s area and reduction of E-value of failure element.

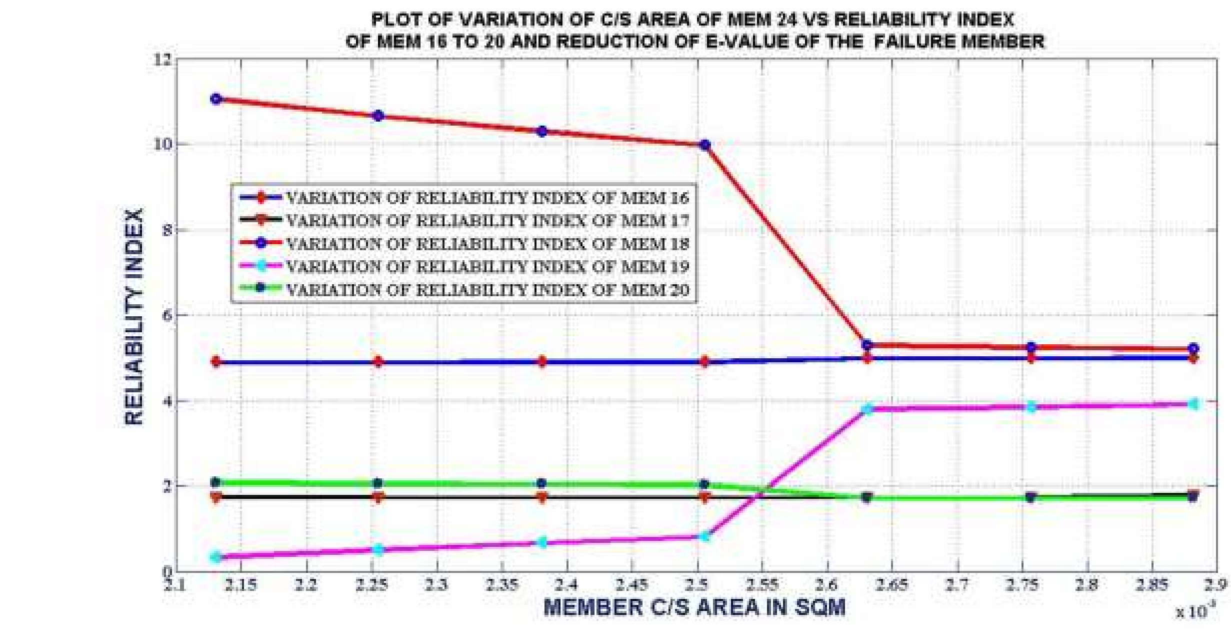


Fig:5.43 change in reliability indices of truss elements(16 to 20) due to variation of c/s area and reduction of E-value of failure element.

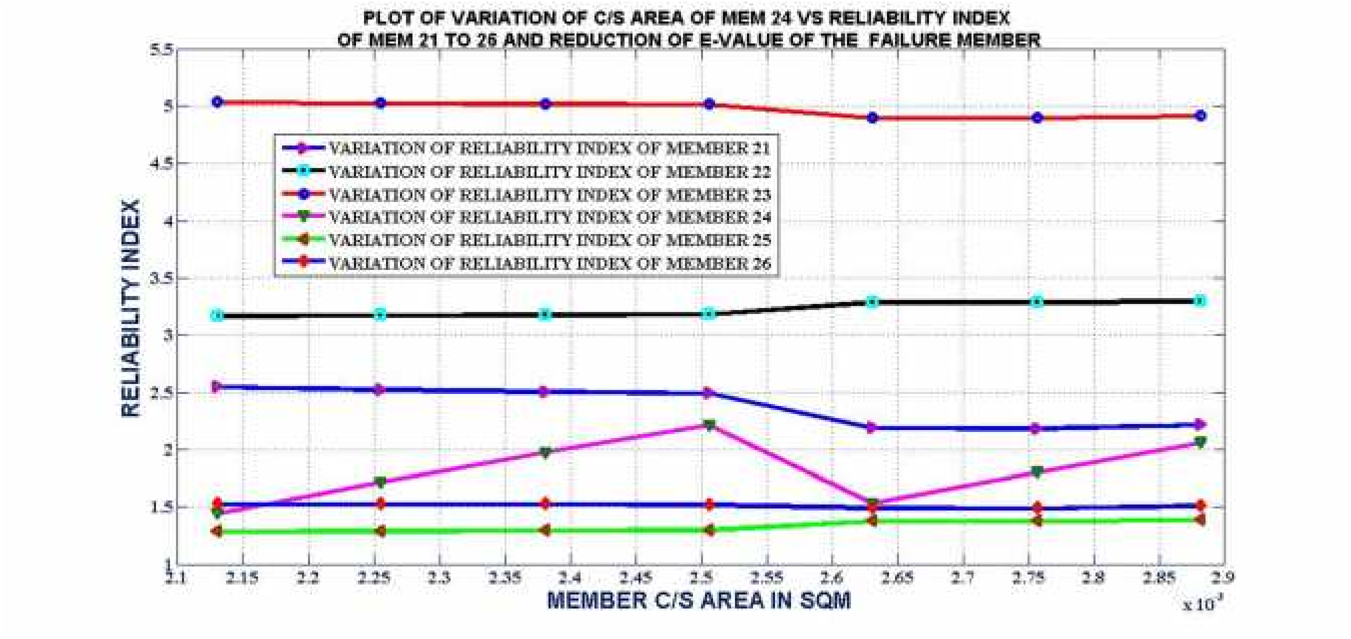


Fig:5.44 change in reliability indices of truss elements(21 to 26) due to variation of c/s area and reduction of E-value of failure element.

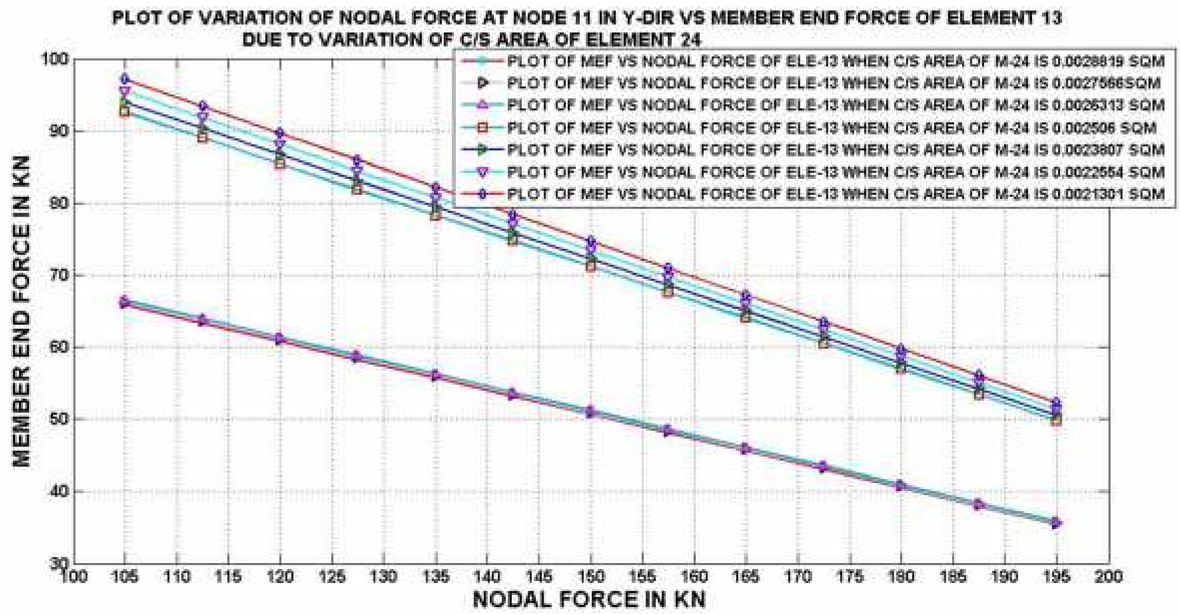


Fig:5.45 change in axial force due to variation of nodal force at 11 and variation of c/s area and reduction of E-value of failure element.

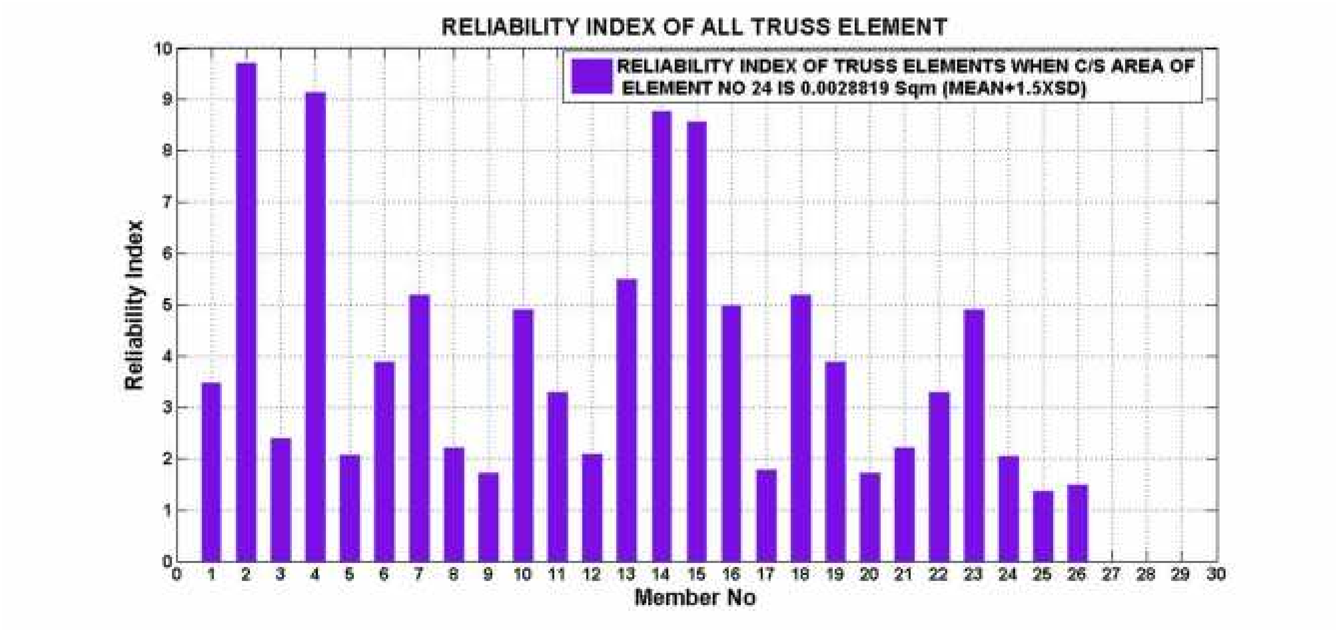


Fig:5.46 Bar chart of Reliability Indices of truss element for case 1

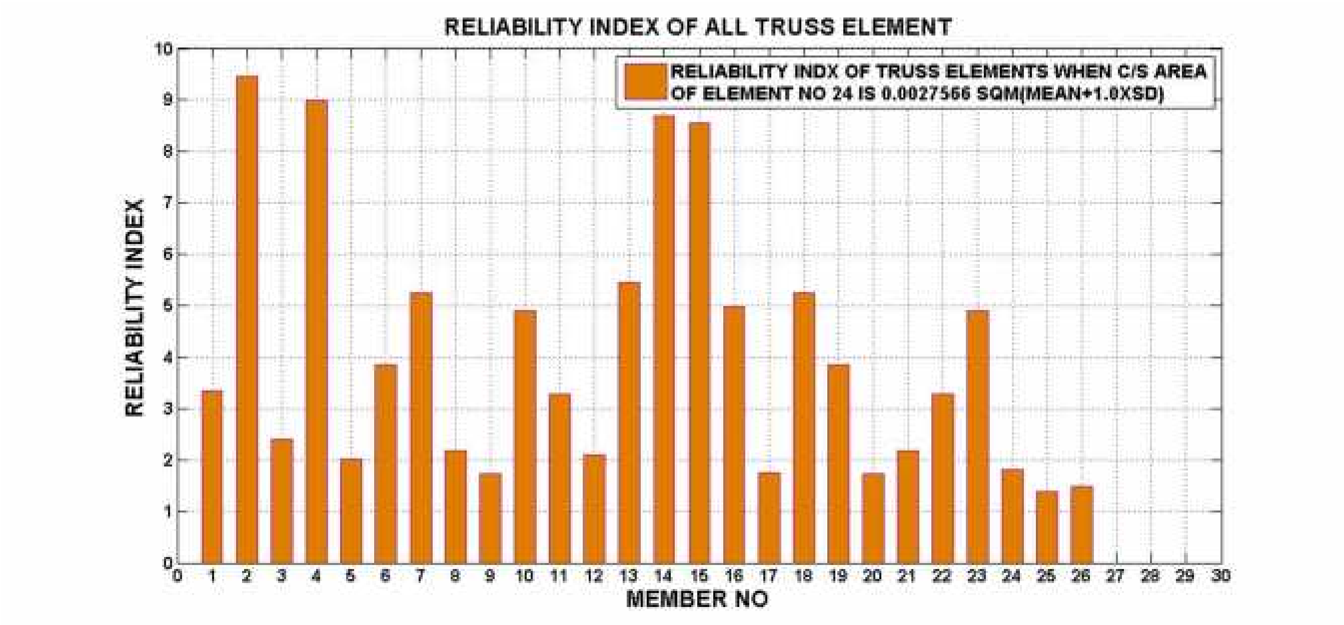


Fig: 5.47 Bar chart of Reliability Indices of truss element for case 2

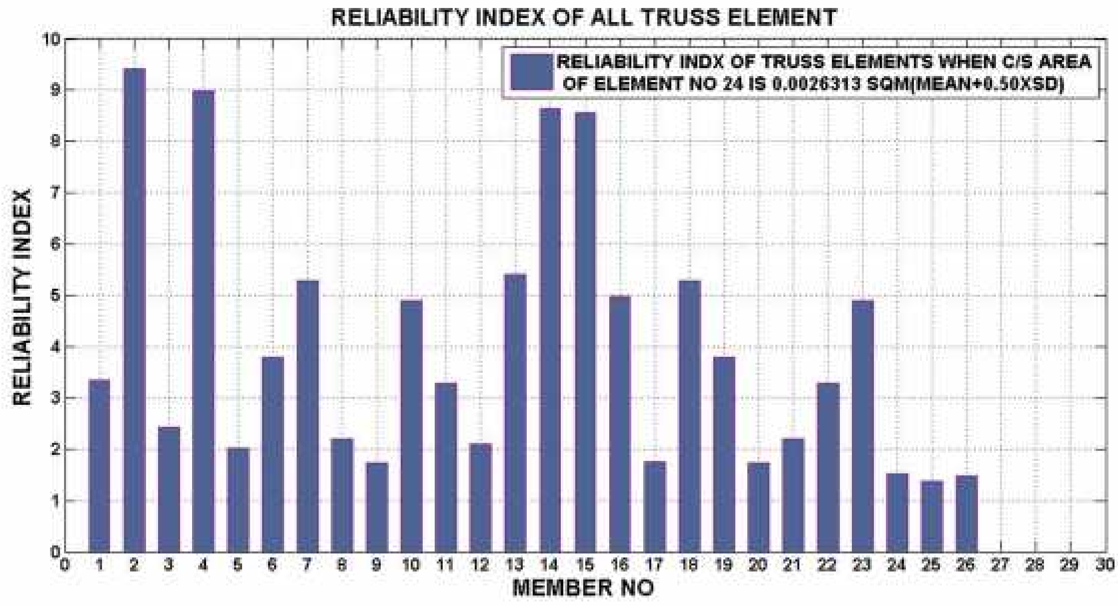


Fig: 5.48 Bar chart of Reliability Indices of truss element for case 3

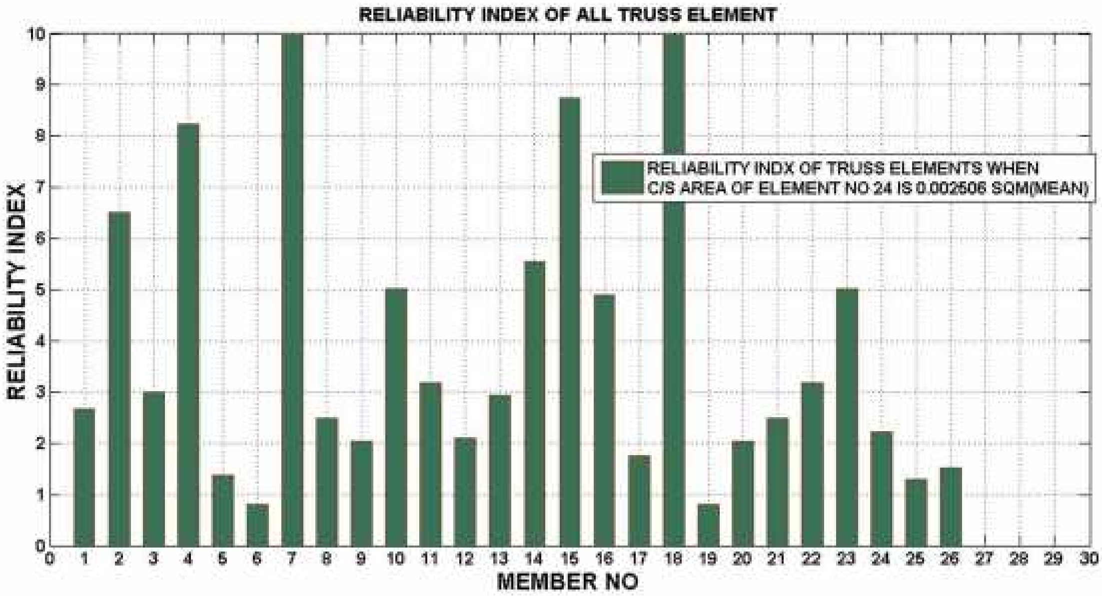


Fig: 5.49 Bar chart of Reliability Indices of truss element for case 4

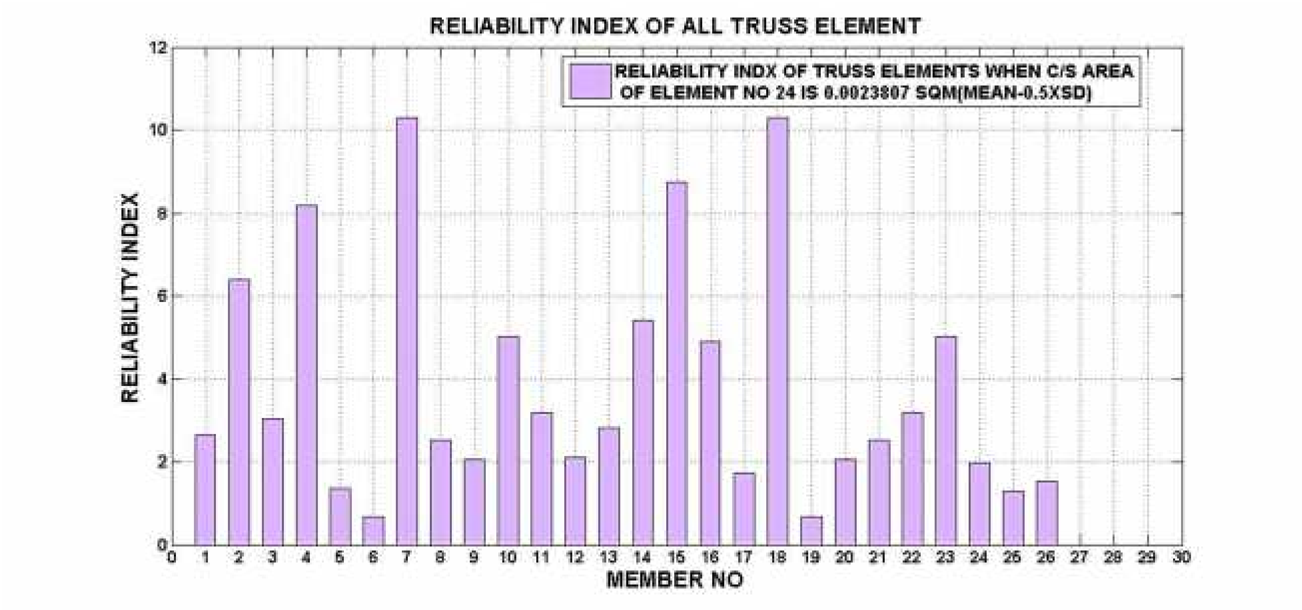


Fig: 5.50 Bar chart of Reliability Indices of truss element for case 4

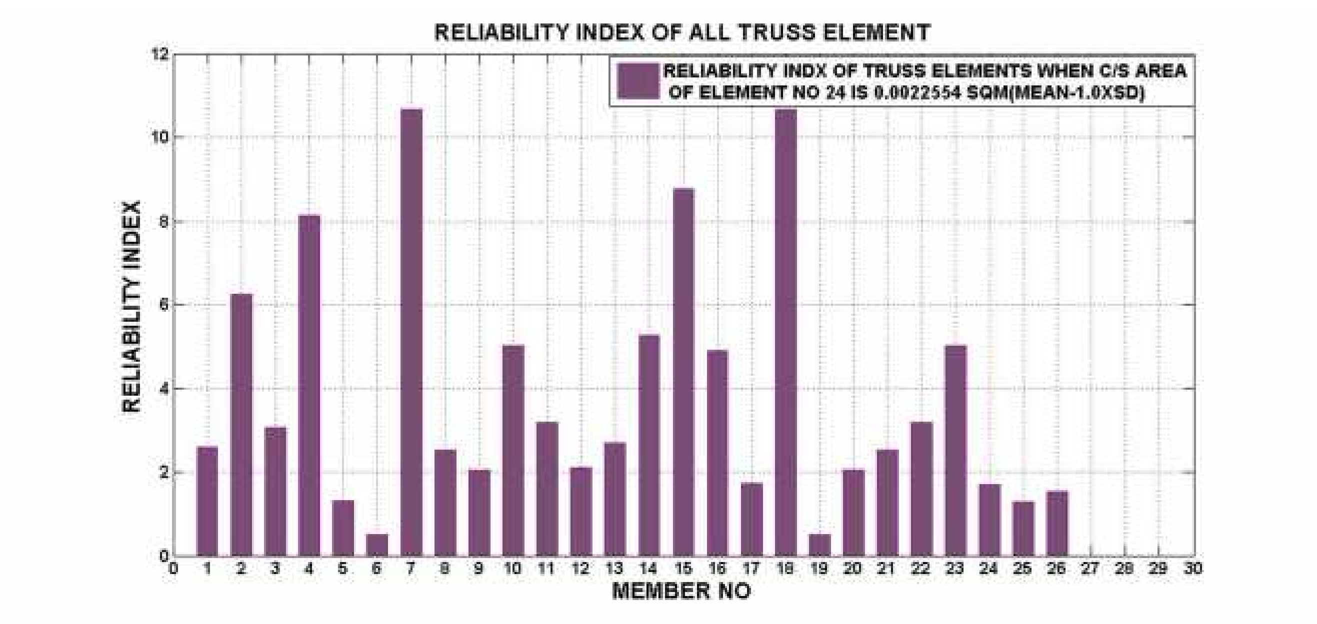


Fig: 5.51 Bar chart of Reliability Indices of truss element for case 6

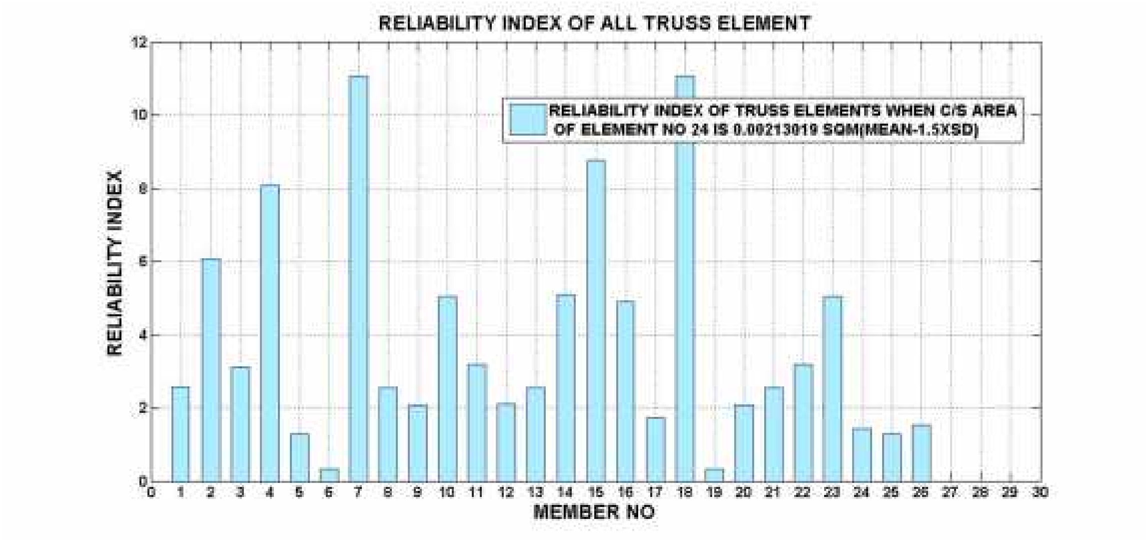


Fig: 5.52 Bar chart of Reliability Indices of truss element for case 7

5.3.2 Discussion on Result of Example 3

In the 3rd example, same truss geometry has considered as in case of example 2. In that case the cross sectional area of the most critical failure element is varied from (Mean-1.5xSD) to (Mean+1.5xSD) with increment c/s area of 0.50xSD. The modulus of elasticity of the critical elements is also reduced to 0.20 times initial E-value. Accordingly, the reliability analysis for the all seven cases has been made and variations of reliability index of the truss element are plotted with variation of cross sectional area and reduction of E-value of critical member. The result is indicating that abrupt reduction in reliability index of element no 2, 6, 14, 13 and 19. From that Example we can easily detect the elements which are more vulnerable to reduction of its reliability index due to variation of c/s area of any element and reduction of E-value of the critical failure element. This is also noted that increase in reliability index is observed in element no: 18, 7 & 3 for redistribution of forces. Since according to axial rigidity of the members, some elements attracts more force than other elements. Using this algorithmic code, it may possible to comment on which members are more vulnerable due to variation of cross sectional area of any element.

From the above study it has been found that, variation of cross sectional area of the critical element results gradual declination of reliability indices of the elements. However, reliability indices of few elements are increased to some extents may be due to redistribution of forces. Reliability indices of the elements are abruptly reduced when modulus elasticity of the failure element is nominally fixed to 20% of the initial “E” Value.

Chapter 6

CONCLUSION AND FUTURE SCOPE OF WORK

6.1 Concluding Remarks:

In the present study, reliability of statically determinate and indeterminate trusses has been estimated. The detection of critical failure path is also attempted for the indeterminate truss. An algorithm is developed for the truss structure in MATLAB platform to obtain the reliability index and subsequent critical failure path based on finite element formulation with due consideration of the randomness both in material, load and geometrical properties. The proposed model is demonstrated numerically using different statically determinate and indeterminate trusses. Based on the numerical studies of the truss structures, the following the conclusions may be drawn.

- Reliability estimation of truss elements depends on various random variables and objective function of limit state of collapse as considered.
- Parametric study on reliability index with the effect of gradual decrement of cross-sectional areas on the elemental reliability index has been studied. It is found that with the reduction of c/s area of critical element (min), the reliability indices reduced in most of the other elements of the truss.
- Reliability indices of the elements are abruptly reduced when modulus of elasticity of the critical failure element is drastically reduced to its 20% of the initial "E" value.
- Assuming the failure of the most critical element (significantly reduced E), change in (Reliability Index) for the other elements has been sequentially evaluated.
- The detection of critical path of the structure is significantly important for the overall safety consideration. Attempt has been made to identify the critical failure path based on the sequence of reliability index based degraded element.

6.2 Future Scope of Work:

- The methodology developed for reliability analysis of truss structure may be further extended to other structure such as moment resisting frame.

- System reliability analysis may be further extended to higher level on the basis of series system where elements are parallel system with multiple (2, 3, 4 …) failure elements.

- Reliability based System Identification may be performed for the structures

- Member Optimization based on the estimation of reliability of different elements may be performed for economic design.

- The limit state function for serviceability may be incorporated along with the considered limit state of collapse using the reliability of different elements of the structures.

- Development of retrofit strategy based on the system reliability of the structure.

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APPENDIX I

```
%% MATLAB CODE FOR LINEAR ELASTIC ANALYSIS OF TRUSS FOR VARIABLE LOADS
%% MATLAB CODE FOR RELIABILITY ANALYSIS OF TRUSS STRUCTURE

clear all
close all
%joint coordinate(node_no,X,Y,Z)(SIZE OF MATRIX:nos of node x 4)
joicoor = xlsread('truss_105_indt_AE','sheet1','a1:d13');
%member connectivity(Mem_no,staring node, ending node)....
% (SIZE OF MATRIX:nos of member X 3)
mem_con= xlsread('truss_105_indt_AE','sheet1','f1:h26');
%no_mem=nos of truss element
no_mem=size(mem_con,1);
%no_node=nos of joint/nodes
no_node=size(joicoor,1);
%nos_dof:total nos of degree of freedom
nos_dof=3*no_node;
%length of truss member(SIZE OF VECTOR: no_mem x 1)
%L_mem= length of each truss element
L_mem=zeros(no_mem,1);
for i=1:no_mem
L_mem(i)=sqrt((joicoor(mem_con(i,2),2)-joicoor(mem_con(i,3),2))^2....
+(joicoor(mem_con(i,2),3)-joicoor(mem_con(i,3),3))^2+...
(joicoor(mem_con(i,2),4)-joicoor(mem_con(i,3),4))^2);
end
for i=1:no_mem
a = mem_con(i,2:3);
b = joicoor(a(2),2:3);
c = joicoor(a(1),2:3);
delta = b'-c';
theta1(i) = atan(delta(2)/delta(1));
end
%Young Modulus of members_vector(E_ VECTOR SIZE: Nos of member  X 1)
% E_mem= Young modulus of truss elements
E_mem = xlsread('truss_105_indt_AE','sheet1','k32:q57');
% E_mem=zeros(no_mem,1);
%area_mem=area of the members(SIZE OF VECTOR: Nos of member X 1)
area_mem = xlsread('truss_105_indt_AE','sheet1','a32:h57');
No_row_Col_area_mat=size(area_mem)
No_col_area_mat=No_row_Col_area_mat(1,2)
No_row_area_mat=No_row_Col_area_mat(1,1)
area_mem =area_mem (1:No_row_area_mat,2:No_col_area_mat)
%cosines of members w.r.t globsl coordinate system
% (SIZE OF VECTOR: Nos of member x 1)
CX_mem=zeros(no_mem,1);
for i=1:no_mem
CX_mem(i)= (joicoor(mem_con(i,3),2)-joicoor(mem_con(i,2),2))/L_mem(i);
end
CY_mem=zeros(no_mem,1);
for i=1:no_mem
CY_mem(i)= (joicoor(mem_con(i,3),3)-joicoor(mem_con(i,2),3))/L_mem(i);
end
CZ_mem=zeros(no_mem,1);
for i=1:no_mem
CZ_mem(i)= (joicoor(mem_con(i,3),4)-joicoor(mem_con(i,2),4))/L_mem(i);
end
theta=zeros(no_mem,1);
for i=1:no_mem
thitax(i)=acos(CX_mem(i))*180/pi
```

```
thitay(i)=acos(CY_mem(i))*180/pi
thitaz(i)=acos(CZ_mem(i))*180/pi
end

%ELEMENTWISE STIFFNESS MATRIX W.R.T LOCAL COORDINATE SYSTEM
%k_ele:elemental stiffness matrix(size:6x6)
%degree of freedom of each node=3
K_ele=zeros(6,6);
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
K_ele(:,:,i,i2)=((area_mem(i,i2)*E_mem(i,2)/L_mem(i))*...
[CX_mem(i)^2,CX_mem(i)*CY_mem(i),CX_mem(i)*CZ_mem(i),...
-CX_mem(i)^2,-CX_mem(i)*CY_mem(i),-CX_mem(i)*CZ_mem(i);...
CY_mem(i)*CX_mem(i),CY_mem(i)^2,CY_mem(i)*CZ_mem(i),...
-CY_mem(i)*CX_mem(i),-CY_mem(i)^2,-CY_mem(i)*CZ_mem(i);...
CZ_mem(i)*CX_mem(i),CZ_mem(i)*CY_mem(i),CZ_mem(i)^2,...
-CZ_mem(i)*CX_mem(i),-CZ_mem(i)*CY_mem(i),-CZ_mem(i)^2;...
-CX_mem(i)^2,-CX_mem(i)*CY_mem(i),-CX_mem(i)*CZ_mem(i),...
CX_mem(i)^2,CX_mem(i)*CY_mem(i),CX_mem(i)*CZ_mem(i);...
-CY_mem(i)*CX_mem(i),-CY_mem(i)^2,-CY_mem(i)*CZ_mem(i),...
CY_mem(i)*CX_mem(i),CY_mem(i)^2,CY_mem(i)*CZ_mem(i);...
-CZ_mem(i)*CX_mem(i),-CZ_mem(i)*CY_mem(i),-CZ_mem(i)^2,...
CZ_mem(i)*CX_mem(i),CZ_mem(i)*CY_mem(i),CZ_mem(i)^2]);
end
end
% end
% GLOBAL STIFFNESS MATRIX w.r.t GLOBAL COORDINATE SYSTEM
%global stiffness matrix(nos of DOFxnos of DOF)
K_glbl=zeros(nos_dof,nos_dof,(No_col_area_mat-1));
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
n=mem_con(i,2);
m=mem_con(i,3);
h=1:3;
q=1:3;
r=1:3;
k=1:3;
l=4:6;
p=4:6;
K_glbl((3*(n-1)+h),(3*(n-1)+q),i2)=K_glbl((3*(n-1)+h),(3*(n-1)+q),i2)+...
K_ele(r,k,i,i2);
K_glbl((3*(n-1)+h),(3*(m-1)+q),i2)=K_glbl((3*(n-1)+h),(3*(m-1)+q),i2)+...
K_ele(r,l,i,i2);
K_glbl((3*(m-1)+h),(3*(n-1)+q),i2)=K_glbl((3*(m-1)+h),(3*(n-1)+q),i2)+...
K_ele(l,r,i,i2);
K_glbl((3*(m-1)+h),(3*(m-1)+q),i2)=K_glbl((3*(m-1)+h),(3*(m-1)+q),i2)+...
K_ele(l,p,i,i2);
end
end
% Nodal forces DEAD LOAD MATRIX (node_no,force in X,force in Y, force in Z)
% (SIZE: Nos_of_node X 4)
nodal_force_matrix_DL=xlsread('truss_105_indt_AE','sheet1','r1:u13');
nodal_force_matrix1_DL=nodal_force_matrix_DL(1:no_node,2:4)';
nodal_for_vec_DL=nodal_force_matrix1_DL(:);
redandent_for_vec_DL=zeros((no_node),1);
for i=1:(no_node);
redandent_for_vec_DL(i)=nodal_for_vec_DL(3*i);
end
% RESTRAINED NODES: WHERE SUPPORTS ARE PROVIDED
restrained_nodes=xlsread('truss_105_indt_AE','sheet1','p1:p2');
%nos_rest: NOS OF NODE WHERE SUPPORTS ARE PROVIDED
```

```
nos_rest=size(restrained_nodes,1);
%rest_dir:RESTRAINED DIRECTION
rest_dir=zeros(nos_rest,3);
for i=1:nos_rest;
j=1:3;
rest_dir(i,j)=3*(restrained_nodes(i,1)-1)+j;
end
%restrained_direction of support nodes MATRIX(support_no,direction X,Y,Z)
rest_dir_trans=rest_dir';
rest_dir_vector=rest_dir_trans(:);
%rest_dir_vector1:VECTOR OF RESTRAINED DIRECTION
rest_dir_vector1=rest_dir_vector(:);
%act_dof=ACTIVE DEGREE OF FREEDOM WHERE TRANSLATION IS POSSIBLE
act_dof=setdiff([1:nos_dof]',rest_dir_vector1);
%Z_dir_res:DIPLACEMENT DIRECTION ALONG Z-AXIS
Z_dir_res=zeros((size(act_dof,1)/3),1);
for i=1:(size(act_dof,1)/3);
Z_dir_res(i)=act_dof(3*i);
end
% rest_dir_vector2=[act_dof;Z_dir_res]
%activeDoF:DIRECTION OF THE UNKNOWN DEGREE OF FREEDOM
activeDof=setdiff(act_dof,Z_dir_res);
% Nodal forces DEAD LOAD MATRIX (node_no,force in X,force in Y, force in Z)
% (SIZE: Nos_of_node X 4)
nodal_force_matrix_DL=xlsread('truss_105_indt_AE','sheet1','r1:u13');
nodal_force_matrix1_DL=nodal_force_matrix_DL(1:no_node,2:4)';
nodal_for_vec_DL=nodal_force_matrix1_DL(:);
nodal_for_vec_DL=nodal_for_vec_DL(activeDof);
%INITIAL EXTERNAL FORCE IN ACTIVE NODES( SIZE: ACTIVE DOF X 3)
externalforceinitial_DL=zeros(numel(activeDof),no_node);
for i=1:no_node;
for j=1:numel(activeDof);
externalforceinitial_DL(:,i)=nodal_for_vec_DL(:,:);
end
end
unit_diag_DL=eye(numel(activeDof),numel(activeDof));
for i=1:numel(activeDof);
for j=1:numel(activeDof);
externalforceinitial_DL1(i,j)=externalforceinitial_DL(j,1)...
*unit_diag_DL(j,i);
end
end
%FINAL STIFFNESS MATRIX OBTAINED AFTER DELETING ROWS AND COLS OF KNOWN
%DOF DIRECTIONS
for i2=1:(No_col_area_mat-1)
finalstiffness(:,:,i2)=K_glbl(activeDof,activeDof,i2);
end
% aa=inv(finalstiffness);
%U=DISPLACEMENT IN ACTIVE DOF DIRECTION
disp('Displacemets IN ACTIVE DEGREE OF FREEDOM DIRECTIONS')
for i=1:numel(activeDof);
for i2=1:(No_col_area_mat-1)
U_DL_f(:,i,i2)=inv(finalstiffness(:,:,i2))*externalforceinitial_DL1(:,i);
end
end
% STANDARD DEVIATION of DEAD LOAD
SD_DEADLOAD=xlsread('truss_105_indt_AE','sheet1','w1:z13');
SD_DEADLOAD_matrix1_DL=SD_DEADLOAD(1:no_node,2:4)';
SD_DEADLOAD_DL=SD_DEADLOAD_matrix1_DL(:);
SD_DEADLOADinitial_1=SD_DEADLOAD_DL(activeDof);
SD_DEADLOADinitial=zeros(numel(activeDof),no_node);
```

```
for i=1:no_node;
for j=1:numel(activeDof);
SD_DEADLOADinitial(:,i)=SD_DEADLOADinitial_1(:,:);
end
end
unit_diag_DLSD=eye(numel(activeDof),numel(activeDof));
for i=1:numel(activeDof);
for j=1:numel(activeDof);
SD_DEADLOADinitial_1(i,j)=SD_DEADLOADinitial(j,1)*unit_diag_DLSD(j,i);
end
end
% i DENOTING NOS OF VALUES OF EXTERNAL FORCE=12
% j DENOTING INCREMENT OF FORCE=+0.5 FOR EACH STEP
for i=1:1:13;
j=-3:0.5:3;
for k=1:numel(activeDof);
for   i2=1:(No_col_area_mat-1)
externalforce_DL(:,k,i)=externalforceinitial_DL1(:,k)+j(i)*...
SD_DEADLOADinitial_1(:,k);
% DISPLACEMTA AT  ACTIVE DOF FOR EACH SET OF INCREMENT OF FORCE
U_DL_f1(:,k,i,i2)=inv(finalstiffness(:,:,i2))*externalforce_DL(:,k,i);
end
end
end
% end
% disp dir vs displacement value for DEAD LOAD
dir_disp_DL=zeros(size(activeDof,1),numel(activeDof),(No_col_area_mat-1));
for i=1:13;
for k=1:numel(activeDof);
for    i2=1:(No_col_area_mat-1)
dir_disp_DL(:,k,i,i2)=[U_DL_f1(:,k,i,i2)];
end
end
end
dir_disp1=[(1:nos_dof)',zeros(nos_dof,no_node)];
dir_disp2_DL=zeros(nos_dof,numel(activeDof),13,(No_col_area_mat-1));
disp('Displacemet_direction.......Displacement')
for i=1:size(activeDof,1);
for j=1:13;
for k=1:numel(activeDof);
for i2=1:(No_col_area_mat-1)
dir_disp2_DL(activeDof(i),k,j,i2)=dir_disp2_DL(activeDof(i),k,j,i2)+...
dir_disp_DL(i,k,j,i2);
end
end
end
end
%%%
%DISPLACEMENT DIRECTION OF EACH NODES(disp_in_X,Disp_in_Y,Disp_in_Z)
disp_dir=zeros(no_node,3);
for i=1:no_node;
for j=1:3;
disp_dir(i,j)=3*(joicoor(i,1)-1)+j;
end
end
% node_vs_disp_dir( Node_No, disp_dir_X,disp_dir_Y,disp_dir_Z)
node_disp_dir=[joicoor(:,1),disp_dir];
% F1_DL:Member_Forces OF THE TRUSS ELEMENTS due to DEAD LOAD
F1_DL=zeros(13,numel(activeDof),no_mem,(No_col_area_mat-1));
for i=1:no_mem;
for j=1:13;
```

```
for k=1:numel(activeDof);
for i2=1:(No_col_area_mat-1)
%F1_DL(j,i)=MEMBER FORCES OF MEMBER i FOR j TYPE FORCE PATTERN
disp('F1_DL(j,k,i')
F1_DL(j,k,i,i2)=(E_mem(i,2)*area_mem(i,i2)/L_mem(i))*[-CX_mem(i),...
    -CY_mem(i),-CZ_mem(i),CX_mem(i),CY_mem(i),CZ_mem(i)]...
*[dir_disp2_DL((node_disp_dir(mem_con(i,2),2)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,2),3)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,2),4)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,3),2)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,3),3)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,3),4)),k,j,i2)]';
end
end
end
end
%  GRAPHICAL REPRESENTATION OF THE STRUCTURE
for i=1:no_mem
X_mem(i,:)=[joicoor(mem_con(i,2),2),joicoor(mem_con(i,3),2)];
Y_mem(i,:)=[joicoor(mem_con(i,2),3),joicoor(mem_con(i,3),3)];
Z_mem(i,:)=[joicoor(mem_con(i,2),4),joicoor(mem_con(i,3),4)];
plot3(X_mem(i,:),Z_mem(i,:),Y_mem(i,:),'r-')
hold on
end
xlabel('X-AXIS')
ylabel('Z-AXIS')
zlabel('Y-AXIS')
%MEMBER END FORCES DUE TO PRIMARY LOADS
F1_DL_member_1=F1_DL(1:13,1:numel(activeDof),1,1:(No_col_area_mat-1));
F1_DL_member_2=F1_DL(1:13,1:numel(activeDof),2,1:(No_col_area_mat-1));
F1_DL_member_3=F1_DL(1:13,1:numel(activeDof),3,1:(No_col_area_mat-1));
F1_DL_member_4=F1_DL(1:13,1:numel(activeDof),4,1:(No_col_area_mat-1));
F1_DL_member_5=F1_DL(1:13,1:numel(activeDof),5,1:(No_col_area_mat-1));
%%%%%
% load combination Dl+LL
%Member end forces due to Dl+LL combination for applied single nodal load
%at a particular node point
Force_DL_member=zeros(13,no_node,no_mem,(No_col_area_mat-1));
for i=1:no_mem;
for j=1:13;
for i2=1:(No_col_area_mat-1)
for k=1:numel(activeDof);
Force_DL_member(j,k,i,i2)=F1_DL(j,k,i,i2);
end
end
end
end
Force_DL_member_1=Force_DL_member(1:13,1:numel(activeDof),...
    1,1:(No_col_area_mat-1));
Force_DL_member_2=Force_DL_member(1:13,1:numel(activeDof),2,...
    1:(No_col_area_mat-1));
Force_DL_member_24=Force_DL_member(1:13,1:numel(activeDof),24,...
    1:(No_col_area_mat-1));
Force_DL_member_25=Force_DL_member(1:13,1:numel(activeDof),25,...
    1:(No_col_area_mat-1));
Force_DL_member_26=Force_DL_member(1:13,1:numel(activeDof),26,...
    1:(No_col_area_mat-1));
%%%%%%%
% load combination DL+LL
%Member end forces due to Dl+LL combination for applied  nodal load
%at  selected node points
```

```
Force_DL_whole=zeros(13,1,no_mem,(No_col_area_mat-1));
for i=1:no_mem;
for k=1: no_node;
for j=1:13;
for i2=1:(No_col_area_mat-1)
Force_DL_whole(j,:,i,i2)=sum(Force_DL_member(j,:,i,i2));
end
end
end
end
Force_DL_total=zeros(13,1,no_mem,(No_col_area_mat-1));
for i=1:no_mem;
for j=1:13;
for i2=1:(No_col_area_mat-1)
Force_DL_total(j,:,i,i2)=sum(Force_DL_whole(j,:,i,i2));
end
end
end
disp('calculate tensile and compressive capacity of all truss element')
%determinstic tensile resistance of truss menmbers
%compute tension resisntance of each tross element
for i=1:no_mem;
SIG_Y(i)=250000;
end
R_tension=zeros(no_mem,1,(No_col_area_mat-1));
for i=1: no_mem;
for i2=1:(No_col_area_mat-1)
R_tension(i,:,i2)=area_mem(i,i2)*SIG_Y(i);
end
end
%compute compression resisntance of each tross element
for i=1:no_mem;
for i2=1:(No_col_area_mat-1)
SIG_Y(i,i2)=250000;
end
end
%factor_to be change as per code
factor_1 = xlsread('truss_105_indt_AE','sheet7','ab6:ab31');
for i=1:no_mem;
for i2=1:(No_col_area_mat-1)
% factor(i,i2)=0.7;
factor(i,i2)=factor_1(i);
end
end
% Iuu_mem = xlsread('truss_1_indt_e3','sheet1','ac1:ad5');
R_comp=zeros(no_mem,1,(No_col_area_mat-1));
for i=1:no_mem;
for i2=1:(No_col_area_mat-1)
R_comp(i,:,i2)=area_mem(i,i2)*factor(i,i2)*SIG_Y(i,i2);
% R_comp(i,:,i2)=((pi()^2*E_mem(i,2)*Iuu_mem(i,2)/(L_mem(i)^2)));
end
end
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)<0;
typ(i,i2)={'compression'}
else
typ(i,i2)={'tension'}
end
end
end
```

```
for i=1: no_mem
for i2=1:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)<0;
mode(i,i2)=0
else
mode(i,i2)=1
end
end
end
for i=1: no_mem
for i2=1:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)<0;
capacity(i,:,i2)=R_comp(i,:,i2)
else
capacity(i,:,i2)=R_tension(i,:,i2)
end
end
end
for i=1: no_mem
for i2=1:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)<0
if abs(min(Force_DL_total(:,:,i,i2)))>capacity(i,:,i2);
% if abs((Force_DL_total(7,:,i,i2)))>capacity(i,:,i2);
% E_mem(i,i2)=0.3*E_mem(i,i2)
E_mem(i,i2)=0.20*E_mem(i,i2);
end
end
end
end
for i=1: no_mem
for i2=2:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)<0
if E_mem(i,i2)>E_mem(i,(i2-1));
E_mem(i,i2)=E_mem(i,i2)
end
end
end
end

for i=1: no_mem
for i2=1:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)>0
if abs(max(Force_DL_total(:,:,i,i2)))>capacity(i,:,i2);
% if abs((Force_DL_total(7,:,i,i2)))>capacity(i,:,i2);
% E_mem(i,i2)=0.3*E_mem(i,i2)
E_mem(i,i2)=0.20*E_mem(i,i2)
end
end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%REPEAT
%repeate fem
%ELEMENTWISE STIFFNESS MATRIX W.R.T LOCAL COORDINATE SYSTEM
%k_ele:elemental stiffness matrix(size:6x6)
%degree of freedom of each node=3
K_ele=zeros(6,6);
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
K_ele(:,:,i,i2)=((area_mem(i,i2)*E_mem(i,i2)/L_mem(i))*...
[CX_mem(i)^2,CX_mem(i)*CY_mem(i),CX_mem(i)*CZ_mem(i),...
```

```
-CX_mem(i)^2,-CX_mem(i)*CY_mem(i),-CX_mem(i)*CZ_mem(i);...
CY_mem(i)*CX_mem(i),CY_mem(i)^2,CY_mem(i)*CZ_mem(i),...
-CY_mem(i)*CX_mem(i),-CY_mem(i)^2,-CY_mem(i)*CZ_mem(i);...
CZ_mem(i)*CX_mem(i),CZ_mem(i)*CY_mem(i),CZ_mem(i)^2,...
-CZ_mem(i)*CX_mem(i),-CZ_mem(i)*CY_mem(i),-CZ_mem(i)^2;...
-CX_mem(i)^2,-CX_mem(i)*CY_mem(i),-CX_mem(i)*CZ_mem(i),...
CX_mem(i)^2,CX_mem(i)*CY_mem(i),CX_mem(i)*CZ_mem(i);...
-CY_mem(i)*CX_mem(i),-CY_mem(i)^2,-CY_mem(i)*CZ_mem(i),...
CY_mem(i)*CX_mem(i),CY_mem(i)^2,CY_mem(i)*CZ_mem(i);...
-CZ_mem(i)*CX_mem(i),-CZ_mem(i)*CY_mem(i),-CZ_mem(i)^2,...
CZ_mem(i)*CX_mem(i),CZ_mem(i)*CY_mem(i),CZ_mem(i)^2]);
end
end
% end
% GLOBAL STIFFNESS MATRIX w.r.t GLOBAL COORDINATE SYSTEM
%global stiffness matrix(nos of DOFxnos of DOF)
K_glbl=zeros(nos_dof,nos_dof,(No_col_area_mat-1));
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
n=mem_con(i,2);
m=mem_con(i,3);
h=1:3;
q=1:3;
r=1:3;
k=1:3;
l=4:6;
p=4:6;
K_glbl((3*(n-1)+h),(3*(n-1)+q),i2)=K_glbl((3*(n-1)+h),(3*(n-1)+q),i2)+...
K_ele(r,k,i,i2);
K_glbl((3*(n-1)+h),(3*(m-1)+q),i2)=K_glbl((3*(n-1)+h),(3*(m-1)+q),i2)+...
K_ele(r,l,i,i2);
K_glbl((3*(m-1)+h),(3*(n-1)+q),i2)=K_glbl((3*(m-1)+h),(3*(n-1)+q),i2)+...
K_ele(l,r,i,i2);
K_glbl((3*(m-1)+h),(3*(m-1)+q),i2)=K_glbl((3*(m-1)+h),(3*(m-1)+q),i2)+...
K_ele(l,p,i,i2);

end
end
% Nodal forces DEAD LOAD MATRIX (node_no,force in X,force in Y, force in Z)
% (SIZE: Nos_of_node X 4)
nodal_force_matrix_DL=xlsread('truss_105_indt_AE','sheet1','r1:u13');
nodal_force_matrix1_DL=nodal_force_matrix_DL(1:no_node,2:4)';
nodal_for_vec_DL=nodal_force_matrix1_DL(:);
redandent_for_vec_DL=zeros((no_node),1);
for i=1:(no_node);
redandent_for_vec_DL(i)=nodal_for_vec_DL(3*i);
end
% RESTRAINED NODES: WHERE SUPPORTS ARE PROVIDED
restrained_nodes=xlsread('truss_105_indt_AE','sheet1','p1:p2');
%nos_rest: NOS OF NODE WHERE SUPPORTS ARE PROVIDED
nos_rest=size(restrained_nodes,1);
%rest_dir:RESTRAINED DIRECTION
rest_dir=zeros(nos_rest,3);
for i=1:nos_rest;
j=1:3;
rest_dir(i,j)=3*(restrained_nodes(i,1)-1)+j;
end
%restrained_direction of support nodes MATRIX(support_no,direction X,Y,Z)
rest_dir_trans=rest_dir';
rest_dir_vector=rest_dir_trans(:);
%rest_dir_vector1:VECTOR OF RESTRAINED DIRECTION
```

```
rest_dir_vector1=rest_dir_vector(:);
%act_dof=ACTIVE DEGREE OF FREEDOM WHERE TRANSLATION IS POSSIBLE
act_dof=setdiff([1:nos_dof]',rest_dir_vector1);
%Z_dir_res:DIPLACEMENT DIRECTION ALONG Z-AXIS
Z_dir_res=zeros((size(act_dof,1)/3),1);
for i=1:(size(act_dof,1)/3);
Z_dir_res(i)=act_dof(3*i);
end
% rest_dir_vector2=[act_dof;Z_dir_res]
%activeDoF:DIRECTION OF THE UNKNOWN DEGREE OF FREEDOM
activeDof=setdiff(act_dof,Z_dir_res);
% Nodal forces DEAD LOAD MATRIX (node_no,force in X,force in Y, force in Z)
% (SIZE: Nos_of_node X 4)
nodal_force_matrix_DL=xlsread('truss_105_indt_AE','sheet1','r1:u13');
nodal_force_matrix1_DL=nodal_force_matrix_DL(1:no_node,2:4)';
nodal_for_vec_DL=nodal_force_matrix1_DL(:);
nodal_for_vec_DL=nodal_for_vec_DL(activeDof);
%INITIAL EXTERNAL FORCE IN ACTIVE NODES( SIZE: ACTIVE DOF X 3)
externalforceinitial_DL=zeros(numel(activeDof),no_node);
for i=1:no_node;
for j=1:numel(activeDof);
externalforceinitial_DL(:,i)=nodal_for_vec_DL(:,:);
end
end
unit_diag_DL=eye(numel(activeDof),numel(activeDof));
for i=1:numel(activeDof);
for j=1:numel(activeDof);
externalforceinitial_DL1(i,j)=externalforceinitial_DL(j,1)...
*unit_diag_DL(j,i);
end
end
%FINAL STIFFNESS MATRIX OBTAINED AFTER DELETING ROWS AND COLS OF KNOWN
%DOF DIRECTIONS
for i2=1:(No_col_area_mat-1)
finalstiffness(:,:,i2)=K_glbl(activeDof,activeDof,i2);
end
% aa=inv(finalstiffness);
%U=DISPLACEMENT IN ACTIVE DOF DIRECTION
disp('Displacemets IN ACTIVE DEGREE OF FREEDOM DIRECTIONS')
for i=1:numel(activeDof);
for i2=1:(No_col_area_mat-1)
U_DL_f(:,i,i2)=inv(finalstiffness(:,:,i2))*externalforceinitial_DL1(:,i);
end
end
% STANDARD DEVIATION of DEAD LOAD
SD_DEADLOAD=xlsread('truss_105_indt_AE','sheet1','w1:z13');
SD_DEADLOAD_matrix1_DL=SD_DEADLOAD(1:no_node,2:4)';
SD_DEADLOAD_DL=SD_DEADLOAD_matrix1_DL(:);
SD_DEADLOADinitial_1=SD_DEADLOAD_DL(activeDof);
SD_DEADLOADinitial=zeros(numel(activeDof),no_node);
for i=1:no_node;
for j=1:numel(activeDof);
SD_DEADLOADinitial(:,i)=SD_DEADLOADinitial_1(:,:);
end
end
unit_diag_DLSD=eye(numel(activeDof),numel(activeDof));
for i=1:numel(activeDof);
for j=1:numel(activeDof);
SD_DEADLOADinitial_1(i,j)=SD_DEADLOADinitial(j,1)*unit_diag_DLSD(j,i);
end
end
```

```
% i DENOTING NOS OF VALUES OF EXTERNAL FORCE=12
% j DENOTING INCREMENT OF FORCE=+0.5 FOR EACH STEP
for i=1:1:13;
j=-3:0.5:3;
for k=1:numel(activeDof);
for   i2=1:(No_col_area_mat-1)
externalforce_DL(:,k,i)=externalforceinitial_DL1(:,k)+j(i)*...
SD_DEADLOADinitial_1(:,k);
% DISPLACEMTA AT  ACTIVE DOF FOR EACH SET OF INCREMENT OF FORCE
U_DL_f1(:,k,i,i2)=inv(finalstiffness(:,:,i2))*externalforce_DL(:,k,i);
end
end
end
% end
% disp dir vs displacement value for DEAD LOAD
dir_disp_DL=zeros(size(activeDof,1),numel(activeDof),(No_col_area_mat-1));
for i=1:13;
for k=1:numel(activeDof);
for    i2=1:(No_col_area_mat-1)
dir_disp_DL(:,k,i,i2)=[U_DL_f1(:,k,i,i2)];
end
end
end
dir_disp1=[(1:nos_dof)',zeros(nos_dof,no_node)];
dir_disp2_DL=zeros(nos_dof,numel(activeDof),13,(No_col_area_mat-1));
disp('Displacemet_direction.......Displacement')
for i=1:size(activeDof,1);
for j=1:13;
for k=1:numel(activeDof);
for i2=1:(No_col_area_mat-1)
dir_disp2_DL(activeDof(i),k,j,i2)=dir_disp2_DL(activeDof(i),k,j,i2)+...
dir_disp_DL(i,k,j,i2);
end
end
end
end
%%%
%DISPLACEMENT DIRECTION OF EACH NODES(disp_in_X,Disp_in_Y,Disp_in_Z)
disp_dir=zeros(no_node,3);
for i=1:no_node;
for j=1:3;
disp_dir(i,j)=3*(joicoor(i,1)-1)+j;
end
end
% node_vs_disp_dir( Node_No, disp_dir_X,disp_dir_Y,disp_dir_Z)
node_disp_dir=[joicoor(:,1),disp_dir];
% F1_DL:Member_Forces OF THE TRUSS ELEMENTS due to DEAD LOAD
F1_DL=zeros(13,numel(activeDof),no_mem,(No_col_area_mat-1));
for i=1:no_mem;
for j=1:13;
for k=1:numel(activeDof);
for i2=1:(No_col_area_mat-1)
%F1_DL(j,i)=MEMBER FORCES OF MEMBER i FOR j TYPE FORCE PATTERN
disp('F1_DL(j,k,i')
F1_DL(j,k,i,i2)=(E_mem(i,i2)*area_mem(i,i2)/L_mem(i))*[-CX_mem(i),...
    -CY_mem(i),-CZ_mem(i),CX_mem(i),CY_mem(i),CZ_mem(i)]...
*[dir_disp2_DL((node_disp_dir(mem_con(i,2),2)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,2),3)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,2),4)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,3),2)),k,j,i2),...
dir_disp2_DL((node_disp_dir(mem_con(i,3),3)),k,j,i2),...
```

```
dir_disp2_DL((node_disp_dir(mem_con(i,3),4)),k,j,i2)]';
end
end
end
end
%coefficient of Resistance
coeff_resistance=zeros(no_mem,1,(No_col_area_mat-1));
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
if Force_DL_total(:,:,i,i2)<0;
coeff_resistance(i,i2)=factor(i,i2);
else coeff_resistance(i,i2)=1.000;
end
end
end
coeff_resistance_area=zeros(no_mem,1,(No_col_area_mat-1));
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
coeff_resistance_area(i,i2)=coeff_resistance(i,i2)*area_mem(i,i2);
end
end
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
% if max(Force_DL_total(7,:,i,i2))>0 && max(Force_DL_total(7,:,i,i2))>...
%          R_tension(i,i2)
if max(Force_DL_total(:,:,i,i2))>0 && max(Force_DL_total(:,:,i,i2))>...
R_tension(i,i2)
condition(i,i2)={'fail'};
% elseif  min(Force_DL_total(7,:,i,i2))<0 && ...
%          abs(min(Force_DL_total(7,:,i,i2)))>R_comp(i,i2);
elseif  min(Force_DL_total(:,:,i,i2))<0 && ...
abs(min(Force_DL_total(:,:,i,i2)))>R_comp(i,i2);
condition(i,i2)={'fail'};
else
condition(i,i2)={'ok'};
end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%co-relation between 2 random variables NODAL LOAD VS MEM END FORCES
% Y=a+bX+cX2+dX3+eX4+...........
%using method of least square
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
mem_force_mat_DL(:,:,i,i2) = F1_DL(:,:,i,i2);
end
end
%n= number of corelation coefficient
n=2
% N matrix of size nxnx nos of truss member
N=zeros(n,n,no_mem);
for i=1:n
for j= 1:n
for k=1:no_mem
N(i,j,k)=(i-1)+(j-1);
end
end
end
for i=1:no_mem;
N(1,1,i)=0;
end
```

```
%variable X
% MEAN AND STANDARD DEVIATION OF NODAL LOADS(DL ONLY)
U_DL = xlsread('truss_105_indt_AE','sheet4','A1:A39');
SD_DL= xlsread('truss_105_indt_AE','sheet4','b1:b39');
U_DL=U_DL(activeDof);
SD_DL=SD_DL(activeDof);
DL_MAT=zeros(size(mem_force_mat_DL,1),numel(U_DL),no_mem,...
    (No_col_area_mat-1))
for i=1:size(mem_force_mat_DL,1);
for i2=1:(No_col_area_mat-1)
j=-3:0.5:3;
for k=1:numel(U_DL);
for m=1: no_mem;
DL_MAT(i,k,m,i2)=U_DL(k)+j(i)*SD_DL(k);
end
end
end
end
% A1 matrix of size nxn
A1_DL=zeros(n,n,numel(U_DL),no_mem,(No_col_area_mat-1));
for i=1:n
for j=1:n
for k=1:numel(U_DL);
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
A1_DL(i,j,k,m,i2)=sum(DL_MAT(:,k,m,i2).^N(i,j,m));
end
end
end
end
end
%A11 is the inverse matrix of A1
for i=1:numel(U_DL);
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
A11_DL(:,:,i,m,i2)=inv(A1_DL(:,:,i,m,i2));
end
end
end
b=numel(activeDof)
sum_DL=zeros(n,b,no_mem,(No_col_area_mat-1));
for k=1:n;
for l=1:b ;
a=numel(mem_force_mat_DL(:,1));
for j=1:a;
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
sum_DL(k,l,m,i2)=sum_DL(k,l,m,i2)+(mem_force_mat_DL(j,l,m,i2)*...
DL_MAT(j,l,m,i2).^N(1,k,m));
end
end
end
end
end
b=numel(activeDof)
coefficients_DL=zeros(n,b,no_mem,(No_col_area_mat-1));
for i=1:n;
for j=1:b;
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
coefficients_DL(:,activeDof(j),m,i2)=(A11_DL(:,:,j,m,i2))*sum_DL(:,j,m,i2);
```

```
end
end
end
end

% COMPONENT LEVEL RELIABILITY ANALYSIS OF TRUSS STRUCTURE
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Y is the linear fuction of Random variable X1,X2,X3....Xn
%Y=a0+a1X1+a2X2+a3X3+......+anXn
%MEAN OF Y=MU_Y=a0+a1.Mu_X1+a2.Mu_X2+a3.Mu_X3+......+an.Mu_Xn
% A=coefficent vector of random variable Y
% A_DL=zeros(no_mem,numel(U_DL));
MU_DL_act=[activeDof,U_DL]
b=numel(U_DL)
for j=1:b;
if MU_DL_act(j,2)==0
MU_DL_act_dir(j)=activeDof(j);
end
end
MU_DL_act_dir_1=setdiff(activeDof,MU_DL_act_dir)
A_DL=coefficients_DL(:,MU_DL_act_dir_1,1:no_mem,1:(No_col_area_mat-1));
for i=1:no_mem;
for i2=1:(No_col_area_mat-1)
A_DL1(i,:,i2)=A_DL(2,:,i,i2);
A_DL2(i,:,i2)=A_DL(1,:,i,i2);
end
end
%MEAN VECTOR OF RANDOM VARIABLES X...here nodal DL,LL,WL
Mu_X_DL = xlsread('truss_105_indt_AE','sheet5','A1:A5');
SD_X_DL= xlsread('truss_105_indt_AE','sheet5','B1:B5');
Mu_Y_DL=zeros(no_mem,1);
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
Mu_Y_DL(m,i2)=A_DL1(m,:,i2)*Mu_X_DL(:)+sum(A_DL2(m,1:numel(Mu_X_DL),i2));
end
end
%SD VECTOR  OF VARABLE X...here for nodal load DL,LL,WL
SQ_SD_Y_DL=zeros(no_mem,1);
for i=1:numel(SD_X_DL)
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
SQ_SD_Y_DL(m,i2)=((A_DL1(m,i,i2)*(SD_X_DL(i))))^2+SQ_SD_Y_DL(m);
end
end
end
%mean and standard daviations
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
SD_Y_DL(m,i2)=sqrt(SQ_SD_Y_DL(m,i2));
Mu_Y_DLLL(m,i2)=Mu_Y_DL(m,i2);
SD_Y_DLLL(m,i2)=sqrt((SD_Y_DL(m,i2)^2));
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i=1:no_mem
for i2=1:(No_col_area_mat-1)
MEAN_AREA_MEM(i,i2)=area_mem(i,i2);
SD_AREA_MEM(i,i2)=0.1*area_mem(i,i2);
SIG_Y(i,i2)=250000
SD_SIG_Y(i,i2)=25000
end
```

```
end
p=1
n=1
%limit state function/safety margin against tension failure[R(i)+ -S(i)]
%limit state function/safety margin against comp failure[R(i)- +S(i)]
%R(i)+ indicates tensile capacity of truss member
%R(i)+ indicates compressive capacity of truss member
%X1* vector original random variable in actual form
X1_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
X2_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
X3_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
for i=1:no_mem;
% CONSIDERING PERMISSIBLE COMPRESSION STRESS=FACTOR*YIELD STRESS
% factor(i)=0.7;
factor(i)=factor_1(i);
end
for i=1:p
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
X1_DLLL(i,m,i2)=MEAN_AREA_MEM(m,i2);
if Mu_Y_DLLL(m)>0 ;
X2_DLLL(i,m,i2)=SIG_Y(m,i2);
else X2_DLLL(i,m,i2)=factor(m)*SIG_Y(m,i2);
end
if Mu_Y_DLLL(m)>0
X3_DLLL(i,m,i2)=MEAN_AREA_MEM(m,i2)*SIG_Y(m,i2);
else X3_DLLL(i,m,i2)=-MEAN_AREA_MEM(m,i2)*SIG_Y(m,i2)*factor(m);
end
end
end
% random variables in reduced form
Z1_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
Z2_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
Z3_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
Z1_DLLL(i,m,i2)=(X1_DLLL(i,m,i2)-MEAN_AREA_MEM(m,i2))/SD_AREA_MEM(m,i2);
if Mu_Y_DLLL(m)>0
Z2_DLLL(i,m,i2)=(X2_DLLL(i,m,i2)-SIG_Y(m,i2))/SD_SIG_Y(m,i2);
else Z2(i,m,i2)=(X2_DLLL(i,m,i2)-factor(m)*SIG_Y(m,i2))/...
        (factor(m)*SD_SIG_Y(m,i2)) ;
end
Z3_DLLL(i,m,i2)=(X3_DLLL(i,m,i2)-Mu_Y_DLLL(m,i2))/SD_Y_DLLL(m,i2);
end
end
end
end
%PARTIAL DERIVATIVES
G1_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
G2_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
G3_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
G1_DLLL(i,m,i2)=-SIG_Y(m,i2)*SD_AREA_MEM(m,i2)
G2_DLL(i,m,i2)=-MEAN_AREA_MEM(m,i2)*SD_SIG_Y(m,i2)
if Mu_Y_DLLL(m)>0
G3_DLLL(i,m,i2)=SD_Y_DLLL(m,i2)
else G3_DLLL(i,m,i2)=-SD_Y_DLLL(m,i2)
end
```

```
end
end
end
%elementwise partial deivative of limit state function w.r.t ...
% reduced variate
G_DLLL=zeros(3,1,no_mem,(No_col_area_mat-1));
for i=1:p;
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
G_DLLL(:,i,m,i2)=[G1_DLLL(i,m,i2);G2_DLLL(i,m,i2);G3_DLLL(i,m,i2)];
end
end
end
Z_DLLL=zeros(3,1,no_mem,(No_col_area_mat-1));
for i=1:p
for m=1:no_mem;
Z_DLLL(:,i,m,i2)=[Z1_DLLL(i,m,i2);Z2_DLLL(i,m,i2);Z3_DLLL(i,m,i2)];
end
end
% component reliability index initial values
BITA_DLLL=zeros(p,1,no_mem,(No_col_area_mat-1))
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
BITA_DLLL(i,m,i2)=(G_DLLL(:,i,m,i2)'*Z_DLLL(:,i,m,i2))/...
    sqrt(G_DLLL(:,i,m,i2)'...
*G_DLLL(:,i,m,i2));
end
end
end
% sesitivity factors
ALPHA_DLLL=zeros(3,1,no_mem,(No_col_area_mat-1));
for i=1:p;
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
ALPHA_DLLL(:,:,i,m,i2)=G_DLLL(:,i,m,i2)/(sqrt(G_DLLL(:,i,m,i2)'*...
    G_DLLL(:,i,m,i2)));
end
end
end
n1=1
BITA_initial_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
BITA_initial_DLLL(i,m,i2)=BITA_DLLL(i,m,i2);
end
end
end
X1_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
X2_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
X3_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
Z1_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
Z2_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
Z3_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
G1_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
G2_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
G3_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
G_changed_DLLL=zeros(3,no_mem,(No_col_area_mat-1));
ALPHA_changed_DLLL=zeros(3,no_mem,(No_col_area_mat-1));
BITA_changed_DLLL=zeros(p,no_mem,(No_col_area_mat-1));
```

```
for i=1:p
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
Z1_changed_DLLL(i,m,i2)=ALPHA_DLLL(1,i,m,i2)*BITA_initial_DLLL(i,m,i2);
Z2_changed_DLLL(i,m,i2)=ALPHA_DLLL(2,i,m,i2)*BITA_initial_DLLL(i,m,i2);
end
end
end
for i=1:p;
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
X1_changed_DLLL(i,m,i2)=MEAN_AREA_MEM(m,i2)+Z1_changed_DLLL(i,m,i2)*...
    SD_AREA_MEM(m,i2);
if Mu_Y_DLLL(m)>0
X2_changed_DLLL(i,m,i2)=SIG_Y(m)+Z2_changed_DLLL(i,m,i2)*SD_SIG_Y(m,i2);
else X2_changed_DLLL(i,m,i2)=factor(m)*SIG_Y(m,i2)+...
        Z2_changed_DLLL(i,m,i2)*SD_SIG_Y(m,i2)*factor(m);
end
end
end
end
for i=i:p
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
if Mu_Y_DLLL(m)>0
X3_changed_DLLL(i,m,i2)=X1_changed_DLLL(i,m,i2)*X2_changed_DLLL(i,m,i2)
else X3_changed_DLLL(i,m,i2)=-X1_changed_DLLL(i,m,i2)*...
        X2_changed_DLLL(i,m,i2)
end
end
end
end
for i=1:p;
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
Z3_changed_DLLL(i,m,i2)=(X3_changed_DLLL(i,m,i2)-Mu_Y_DLLL(m,i2))/...
    SD_Y_DLLL(m,i2);
end
end
end

for i=1:p
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
Z_changed_DLLL(:,i,m,i2)=[Z1_changed_DLLL(i,m,i2);...
    Z2_changed_DLLL(i,m,i2);Z3_changed_DLLL(i,m,i2)];
end
end
end
for i=1:p
for m=1:no_mem;
for i2=1:(No_col_area_mat-1)
G1_changed_DLLL(i,m,i2)=-X2_changed_DLLL(i,m,i2)*SD_AREA_MEM(m,i2);
G2_changed_DLLL(i,m,i2)=-X1_changed_DLLL(i,m,i2)*SD_SIG_Y(m,i2);
if Mu_Y_DLLL(m)>0
G3_changed_DLLL(i,m,i2)=SD_Y_DLLL(m,i2)
else G3_changed_DLLL(i,m,i2)=-SD_Y_DLLL(m,i2)
end
end
end
end
```

```
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
G_changed_DLLL(:,i,m,i2)=[G1_changed_DLLL(i,m,i2);...
    G2_changed_DLLL(i,m,i2);G3_changed_DLLL(i,m,i2)];
end
end
end
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
ALPHA_changed_DLLL(:,i,m,i2)=G_changed_DLLL(:,i,m,i2)/...
(sqrt(G_changed_DLLL(:,i,m,i2)'*...
G_changed_DLLL(:,i,m,i2)));
end
end
end
for i=1:p
for m=1:no_mem
for i2=1:(No_col_area_mat-1)
BITA_changed_DLLL(i,m,i2)=(G_changed_DLLL(:,i,m,i2)'*...
    Z_changed_DLLL(:,i,m,i2))/sqrt(G_changed_DLLL(:,i,m,i2)'*...
    G_changed_DLLL(:,i,m,i2));
end
end
end
for m=1:26
for i2=1:(No_col_area_mat-1)
Z1_changed_DLLL(n1,m,i2)=Z1_changed_DLLL(i,m,i2);
Z2_changed_DLLL(n1,m,i2)=Z2_changed_DLLL(i,m,i2);
X1_changed_DLLL(n1,m,i2)=X1_changed_DLLL(i,m,i2);
X2_changed_DLLL(n1,m,i2)=X2_changed_DLLL(i,m,i2);
X3_changed_DLLL(n1,m,i2)=X3_changed_DLLL(i,m,i2);
Z3_changed_DLLL(n1,m,i2)=Z3_changed_DLLL(i,m,i2);
Z_changed_DLLL(:,n1,m,i2)=[Z1_changed_DLLL(n1,m,i2);...
Z2_changed_DLLL(n1,m,i2);Z3_changed_DLLL(n1,m,i2)];
G1_changed_DLLL(n1,m,i2)=G1_changed_DLLL(i,m,i2);
G2_changed_DLLL(n1,m,i2)=G2_changed_DLLL(i,m,i2);
G3_changed_DLLL(n1,m,i2)=G3_changed_DLLL(i,m,i2);
G_changed_DLLL(:,n1,m,i2)=[G1_changed_DLLL(n1,m,i2);...
G2_changed_DLLL(n1,m,i2);G3_changed_DLLL(n1,m,i2)];
ALPHA_changed_DLLL(:,n1,m,i2)=G_changed_DLLL(:,n1,m,i2)/...
(sqrt(G_changed_DLLL(:,n1,m,i2)'*...
G_changed_DLLL(:,n1,m,i2)));
BITA_changed_DLLL(n1,m,i2)= (G_changed_DLLL(:,n1,m,i2)'*...
Z_changed_DLLL(:,n1,m,i2))/sqrt(G_changed_DLLL(:,n1,m,i2)'*...
G_changed_DLLL(:,n1,m,i2));
k=true
while k
Z1_changed_DLLL((n1+1),m,i2)=ALPHA_changed_DLLL(1,n1,m,i2)*...
BITA_changed_DLLL(n1,m,i2);
Z2_changed_DLLL((n1+1),m,i2)=ALPHA_changed_DLLL(2,n1,m,i2)*...
BITA_changed_DLLL(n1,m,i2);
X1_changed_DLLL((n1+1),m,i2)=MEAN_AREA_MEM(m,i2)+...
    Z1_changed_DLLL((n1+1),m,i2)*SD_AREA_MEM(m,i2);
if Mu_Y_DLLL(m)>0
X2_changed_DLLL((n1+1),m,i2)=SIG_Y(m,i2)+Z2_changed_DLLL((n1+1),m,i2)*...
    SD_SIG_Y(m,i2);
else X2_changed_DLLL((n1+1),m,i2)=factor(m)*SIG_Y(m,i2)+...
Z2_changed_DLLL((n1+1),m,i2)*...
SD_SIG_Y(m,i2)*factor(m);
```

```
end
if Mu_Y_DLLL(m)>0
X3_changed_DLLL((n1+1),m,i2)=X1_changed_DLLL((n1+1),m,i2)*...
X2_changed_DLLL((n1+1),m,i2);
else X3_changed_DLLL((n1+1),m,i2)=-X1_changed_DLLL((n1+1),m,i2)*...
X2_changed_DLLL((n1+1),m,i2);
end
Z3_changed_DLLL((n1+1),m,i2)=(X3_changed_DLLL((n1+1),m,i2)-...
Mu_Y_DLLL(m,i2))/SD_Y_DLLL(m,i2);
Z_changed_DLLL(:,(n1+1),m,i2)=[Z1_changed_DLLL((n1+1),m,i2);...
Z2_changed_DLLL((n1+1),m,i2);...
Z3_changed_DLLL((n1+1),m,i2)];

G1_changed_DLLL((n1+1),m,i2)=-X2_changed_DLLL((n1+1),m,i2)*...
    SD_AREA_MEM(m,i2);
G2_changed_DLLL((n1+1),m,i2)=-X1_changed_DLLL((n1+1),m,i2)*...
    SD_SIG_Y(m,i2);
if Mu_Y_DLLL(m)>0
G3_changed_DLLL((n1+1),m,i2)=SD_Y_DLLL(m,i2);
else G3_changed_DLLL((n1+1),m,i2)=-SD_Y_DLLL(m,i2);
end
G_changed_DLLL(:,(n1+1),m,i2)=[G1_changed_DLLL((n1+1),m,i2);...
G2_changed_DLLL((n1+1),m,i2);...
G3_changed_DLLL((n1+1),m,i2)];
ALPHA_changed_DLLL(:,(n1+1),m,i2)=G_changed_DLLL(:,(n1+1),m,i2)/...
(sqrt(G_changed_DLLL(:,(n1+1),m,i2)'*G_changed_DLLL(:,(n1+1),m,i2)));
BITA_changed_DLLL((n1+1),m,i2)= (G_changed_DLLL(:,(n1+1),m,i2)'*...
Z_changed_DLLL(:,(n1+1),m,i2)/...
sqrt(G_changed_DLLL(:,(n1+1),m,i2)'*G_changed_DLLL(:,(n1+1),m,i2)));
if abs(BITA_changed_DLLL((n1+1),m,i2)-BITA_changed_DLLL(n1,m,i2))<0.1;
if    abs(X1_changed_DLLL((n1+1),m,i2)-X1_changed_DLLL(n1,m,i2))<0.1;
if   abs(X2_changed_DLLL((n1+1),m,i2)-X2_changed_DLLL(n1,m,i2))<0.1;
if  abs(X3_changed_DLLL((n1+1),m,i2)-X3_changed_DLLL(n1,m,i2))<0.1;
k=false;
end
end
end
end
n1=n1+1;
end
end
end
```