A Study of Fragility Analysis of Transmission Tower Subjected To Specified Ground Motion

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***Abstract**-In this paper, the fragility analysis and concept of critical collapse curve for transmission tower sub-jected to wind and rain loads are presented to ac-quire the collapse equivalent basic wind speed and most unfavorable combinations of wind and rain loads corresponding to collapse status. The calcu-lating method for wind and rain loads is simplified and the error analysis is performed to validate its effectiveness. The concept of equivalent basic wind speed is used to conduct the fragility analysis of transmission tower subjected to wind and rain loads which avoid the complex formula of rain load and the choice of different combinations of basic wind speed and rain intensity, and then the concept of critical collapse curve is proposed to evaluate the collapse status of transmission tower. At last the influence of wind attack angle and wind spectrum on the fragility and critical collapse curves is discussed, and results show that the wind attack angle and wind spectrum have a great influ-ence on fragility and critical collapse curves. In this study, it can be seen that the use of equivalent basic wind speed make it possible to conduct the fragility analysis under wind and rain loads and the pro-posed concept of critical collapse curve is very con-venient to evaluate the collapse status for struc-tures subjected to wind and rain loads. In addition, the rain load has a great contribution to the tower collapse and should be paid more attention during severe gales and thunderstorms.*

Keywords-Steel Tower, Staad-pro

I. INTRODUCTION

1.1 Introduction

The seismic risk analysis includes three contents: seismic hazard analysis, fragility analysis and earthquake-induced loss estimation. Among them, the fragility analysis is to study the probability of structural failure for a given ground motion level, and can predict probabilities of the occurrence of different damage states induced by different magnitudes of earthquakes. The seismic capacity of transmission tower is evaluated by using nonlinear buckling analysis method and nonlinear dynamic analysis, considering the inherent uncertainty of the structure and ground motion. And the performance limits of different damage states induced by earthquake are determined. The objective of this literature is to evaluate the fragility curve of transmission towers based on seismic performance analysis considering the inelastic structural behaviour and the uncertainties.

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In order to determine the fragility curve of the transmission tower, it’s necessary to determine seismic responses of the tower induced by different magnitude of earthquakes. Due to the randomness of the ground motion, the seismic performance of the building will respond with uncertainty as well. The randomness of the ground motion is realized by building a package of various ground motions covering a wide range of peak intensity, time-varying amplitude, strong-motion duration and frequency content.

The inelastic behaviour of the transmission towers subjected to the extreme earthquakes has been investigated extensively. The towers might collapse or be damaged when shaken by intensive earthquakes. However, the information relating the nonlinear inelastic responses of such towers under extreme seismic loading with the damage severity is lacking, and the damage state of the tower remains unclear. Therefore, one of the objectives is to define the damage states of such structures under earthquake loading based on the performance analysis.

1.2 Aim

To perform seismic fragility analysis of transmission tower in seismic zone 4 and 5.

1.2.1 Objectives

1. To analyse and design transmission tower for zone 4 and 5 in accordance with IS1893:2002.
2. Numerical modelling of transmission tower for non-linear buckling.
3. To perform seismic fragility analysis of transmission tower and checked its damage serviceability condition.
4. To validate results of FEM model by joint method.
5. To calculate natural frequency and mode shape.

II. LITERATURE REVIEW

Liyu XIE, Jue TANG, Hesheng TANG & Qiang XIE "Seismic Fragility Assessment of Transmission Towers via Performance-based Analysis"

Overhead transmission lines play an important role in the operation of a reliable electric power system. Transmission towers are the vital components providing the supporters of high-voltage power lines. Many intensive earthquakes have happened in China recently, such as Jiji earthquake in 1999 and Wenchuan earthquake in 2008, which caused a great loss of electric power system. Failure of transmission tower under extremely intense earthquake has been reported in the literature. Therefore, it's very imperative to evaluate the seismic risk of these towers for seismic retrofit and seismic mitigation planning. The accurate prediction of tower failure is very important for the reliability and safety evaluation of the power transmission system (Li, 2009).

In this paper, the seismic capacity of transmission tower is evaluated by using nonlinear buckling analysis method and nonlinear dynamic analysis, considering the inherent uncertainty of the structure and ground motion. And the performance limits of different damage states induced by earthquake are determined. The objective of this literature is to evaluate the fragility curve of transmission towers based on seismic performance analysis considering the inelastic structural behaviour and the uncertainties.

The inelastic behaviour of the transmission towers subjected to the extreme earthquakes has been investigated extensively. The nonlinear static pushover analysis and incremental dynamic analysis (IDA) method (Vamvatsikos and Cornell, 2002) have been widely used in earthquake engineering for evaluating the structural capacity curves considering seismic excitations. The towers might collapse or be damaged when shaken by intensive earthquakes. However, the information relating the nonlinear inelastic responses of such towers under extreme seismic loading with the damage severity is lacking, and the damage state of the tower remains unclear. Therefore, one of the objectives in this paper is to define the damage states of such structures under earthquake loading based on the performance analysis.

W.M. Wang, H.N. Li and L. Tian "Progressive Collapse Analysis of Transmission Tower-Line System Under Earthquake"

Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian, PR China said that, High-voltage electric transmission tower may collapse under the strong earthquake and studies on the collapse mechanism, routine and capacity of transmission tower-line system are important for the structural design of tower. In this paper, a progressive collapse analytical procedure for the system is proposed based on the finite element method (FEM). During this procedure, the mass of the elements is still retained rather than removal after elements lose the load-bearing capacity. The proposed procedure is coded using the user subroutine VUMAT and then implemented in the advanced finite element program ABAQUS. A three-dimensional finite element model for the system of three towers and four-span lines is created. By using the coded subroutine, the collapse analysis of the tower-line system under the strong earthquake is performed. Collapse processes along longitudinal and lateral direction are studied, respectively. Furthermore, the influences of ultimate strain and strain rate effect of materials on the collapse mode and capacity are studied. The results indicate that the collapse analysis of the tower-line system by using the proposed procedure can provide collapse mode and vulnerable points for use in seismic performance and retrofit evaluation of structure. It is found from the numerical modeling that the influences of ground motion and ultimate strain on the collapse modes are apparent. The collapse-resistant capacity of system increases remarkably with the increase of ultimate strain and influences of strain rate on collapse routine and capacity are tiny in analytical results.
Current civil engineering practice prefers to use the FEM for structural analysis. During the collapse process under earthquake, some elements lose load-bearing capacity, which is problem for the FEM. Commonly, the method removing these elements is used, which is called the birth-death element method. With the method, some elements are removed during the simulation process, which is not agree with realistic situation. The method retaining the mass of these elements rather than removal is proposed.

Sumit Pahwa, Vivek Tiwari, Harsha Jatwa "Analytical Study of Transmission Tower Subjected to Wind and Seismic Loads Using Optimization Technique"

Shri. G.S. Institute of Technology & Science Indore M.P., India

This paper describes about an analytical comparative study on 1S2 transmission tower under wind and earthquake loads considering optimization technique. The optimization of wind and earthquake load is carried out by plotting graphs between earthquake forces with height, wind forces with height and tower with X and K bracing under wind and seismic load. All the calculation and analysis is carried out using STAAD PRO software and EXCEL spreadsheet.

Seismic Coefficient Method This is the simplest of the available methods and is applicable to structures which are simple, symmetric and regular. In this method, the seismic load is idealized as a system of equivalent static loads, which is applied to the structure, and an elastic analysis is performed to ensure that the stresses are within allowable limits. The sum of the equivalent static loads is proportional to the total weight of the structure and the constant of proportionality, known as the seismic coefficient, is taken as the product of various factors which influence the design and are specified in the codes.

Mr. T. Raghavendra "**COMPUTER AIDED ANALYSIS AND STRUCTURAL OPTIMIZATION OF TRANSMISSION LINE TOWER**"

Assistant Professor Department of Civil Engineering, R.V.College of Engineering, Bangalore The Transmission-line tower is highly indeterminate structure. In present study, a typical 132-KV double circuit transmission-line tower is considered, for optimizing the structure with respect to configuration and different materials as variable parameters. The tower is modeled and analyzed using STAAD-PRO and ANSYS software's. The basic model of the tower considered is analyzed in STAAD-PRO and the results with respect to the member axial forces are validated in ANSYS. A number of experimental configurations of the tower are obtained by increasing the base width of the tower and also by decreasing the bracing patterns below the waist of the tower.

M.Selvaraj, S.M.Kulkarni, R.Ramesh Babu, "Behavioral Analysis of built up transmission line tower from fiber reinforced polymer (FRP) pultruded sections".

For technical, aesthetic and economic reasons, future power transmission line towers will have to be built with new design concepts using new materials, reduction in construction costs and optimizing power delivery with restricted right of way. This paper discusses experimental studies carried out on X-braced panel of transmission line tower made from FRP pultruded sections. Mathematical model of individual members and members in the X-braced panel are generated using FEM software to study the analytical correlation with the experiments. The member stresses are monitored using strain gauges during full scale testing. Conclusions are drawn based on these studies.

The analysis is limited to linear-elastic response including buckling considerations. The experimental study discussed in this paper predicts that the deflections and strains are in close agreement with the experimental results and finite element analysis. The buckling mode of individual members and full scale panel are in close agreement with experiment and FE analysis.

III. METHODOLOGY

The basis of the finite element method is the representation of a body or a structure by an assemblage of subdivisions called finite elements. The Finite Element Method translates partial differential equation problems into a set of linear algebraic equations. The finite element method is a numerical technique of solving differential equations describing a physical phenomenon. It is a convenient way to find displacements and stresses of structures at definite physical coordinates called nodes. The structure to be analyzed is discredited into finite elements connected to each other at their nodes. Elements are defined and equations are formed to express nodal forces in terms of the unknown nodal displacements, based on known material constitutive laws. Forces and initial displacements are prescribed as initial conditions and boundary conditions. A global matrix system is assembled by summing up all individual element stiffness matrices and the global vector of unknown nodal displacement values is solved for using current numerical techniques. Many software programs are available in the market for the analysis of structures by this method. In the present study, the computer program Staad is used for the analyses performed.

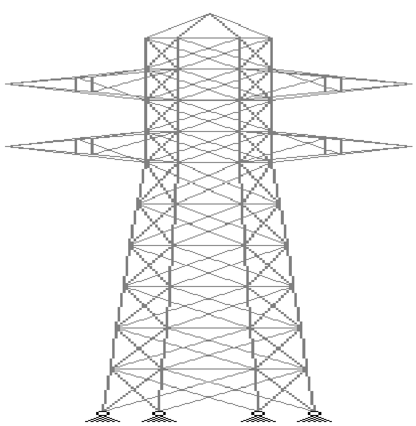
The software tool used in the design and analysis of the tower is STAAD.ProV8i. In today's world analysis tools allow engineers to refine designs to an unprecedented degree, and as a result, many utilities feel testing is not warranted. However, while great strides have been made in the analysis and design of latticed steel transmission towers, differences between analysis results and full-scale tests still occur.

Manual calculations is important for the recommendations of IS codes but the validation of these results and study of effects of these loads on the structure is also an important part to do. Analysis of the performed task is the key to success for the safe and durable serviceability of the structure under various load combinations.

Now based on the validation of results through STAAD.ProV8i, the important conclusions are made.

In modeling tower are modeled in which base width and bracing system are different, for base width and X, XBX and K type of bracing system are incorporated. In modeling firstly base width points are plotted and height of tower up to waist of towers is plotted with square shape of on either directions. Tower cage is modeled in which tower peak of tower is plotted then width and lengths of wings are plotted. All nodes are joined by using beam cursor. Now we have towers complete height with base width and tower cage we have to divide tower body into different number of panels. In above fig combination for XBX bracing shown in above fig panels system are only shown to base width also likewise models are made for one bracing system. Similarly another towers are prepared for K and X bracing system. Supports, sections and load are assigned.
The step-by-step procedure in Staad Pro.V8i software is given below.

1. Modelling
2. Pre-processor
   2.1 Define element type
   2.2 Define material properties
   2.3 Define support condition
   2.4 Define load and load combination
3. Solution
   3.1 Perform analysis
   3.2 Run analysis
4. General postprocessor
   4.1 Reaction Summary
   4.2 Utility ratio
   4.3 Deflection
   4.4 Stresses



IV. PROBLEM STATEMENTS

Design a transmission tower for self-weight with point load and wind load ISA section by using IS801.

Dead Load on the Tower.

Vertical Loads:

a. Self-weight of tower structure up to the point/level under consideration.
b. Loads due to weight of conductors/ground wire based on design weight span, weight of insulator string and accessories. In computing the weight of conductor and earth wire, the weight span which is 1.5 times the normal span or wind span, is used.
   i. Weight of the conductor = (weight span × unit weight of conductor)
      = 450 x 0.01594
      = 7.173 KN
   ii. Weight of ground wire = (weight span × unit weight of ground wire)
      = 450 x 0.004218
      = 1.9 KN
   iii. Weight of ground wire attachment = 2 KN. [Assumed].
   iv. Vertical load due to String Insulator = 3 kN. [Assumed.]

2. Load of 3.5 KN considered acting at the tip of cross arms up to 220 kV and 5 kN for 400 kV and higher voltage for the design of cross arms. [cl no,-12.2.3….(iii)]

Erection loads at lifting points, for 400 kV and higher voltages. [cl no,-12.2.3….(iv)]

A load of 1.5 KN considered acting at each cross arm, as a provision of weight of lineman with tools. (Applied at each panel point also)

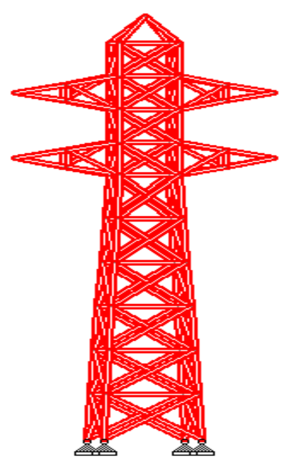


Figure 1.SELF WEIGHT

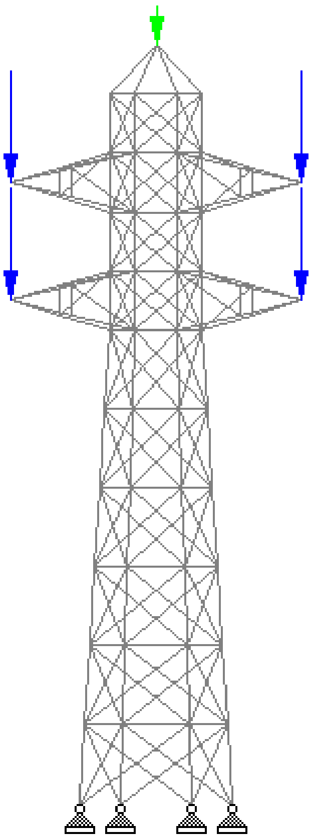


Figure 2.POINT LOAD

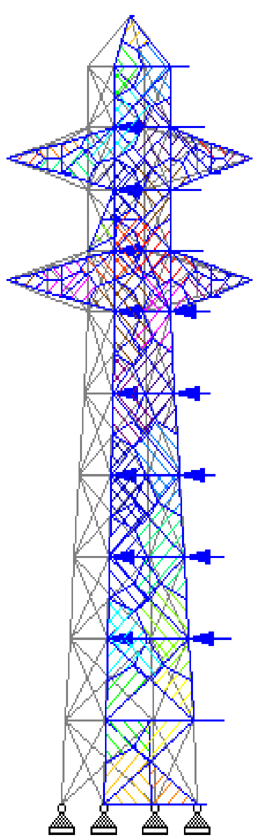
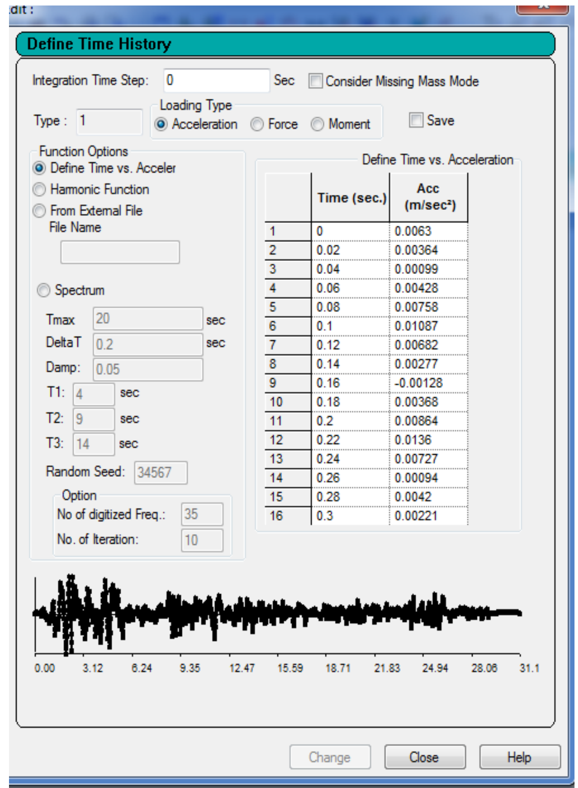


Figure 3.WIND LOAD

DYNAMIC LOAD

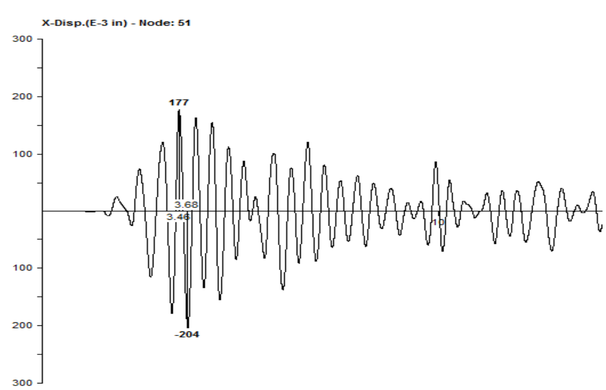
El-centro data inserted in Staad-Pro

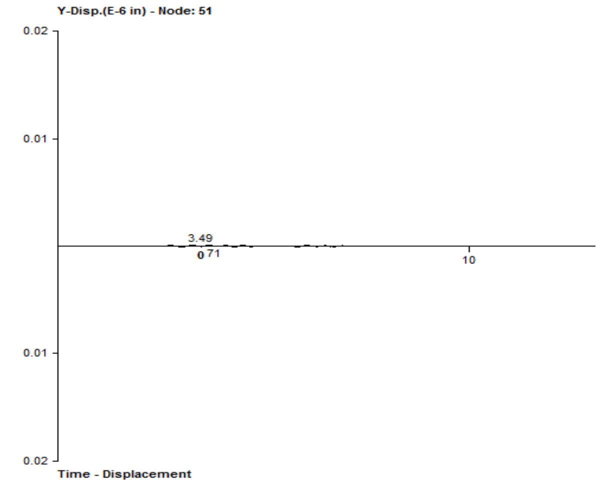


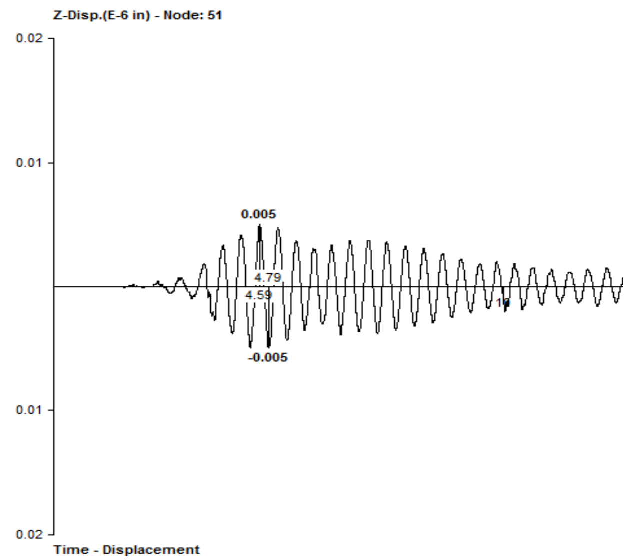
V. RESULTS AND DISCUSSION

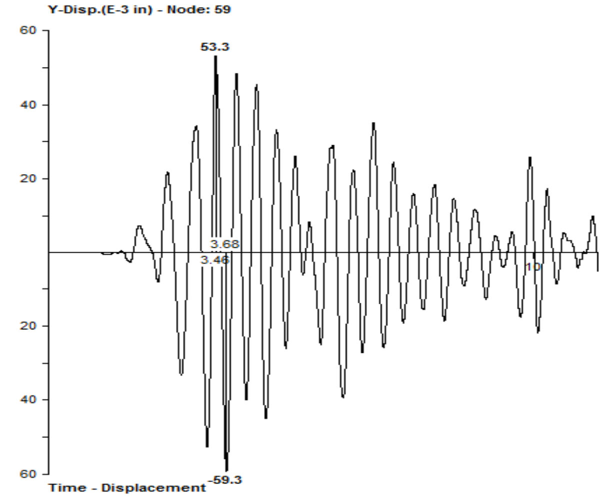
In the previous chapter transmission tower is analysed and designed as per IS-801 for wind zone-IV.After analysis and design ,time history analysis is done i.e.non linear dynamic analysis.For that previous earthquake information of El –centro ,New Zealend recorded by seismograph is taken for further analysis.Time step taken is 0.0002.Total time period was 31.3 sec.Results are compared at crowns and cross arms are taken for comparison

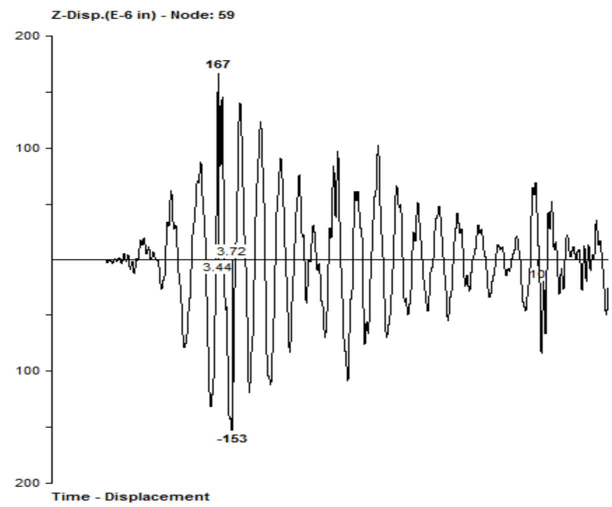
Time-Displacement at crown



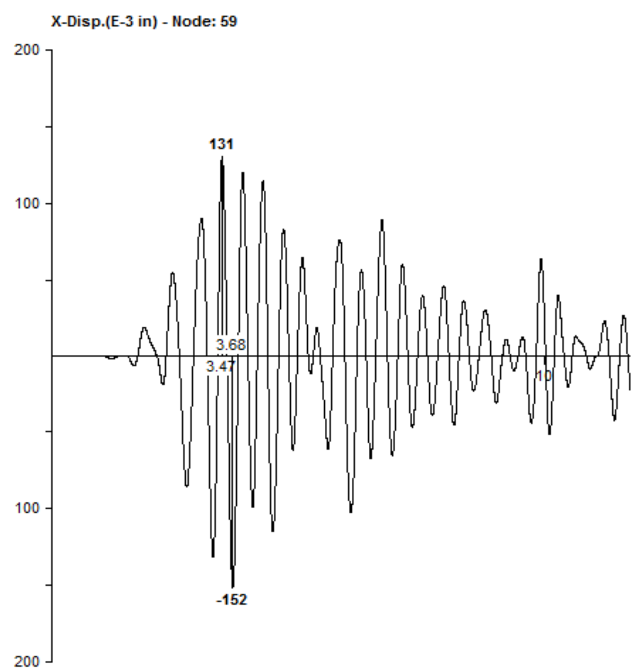




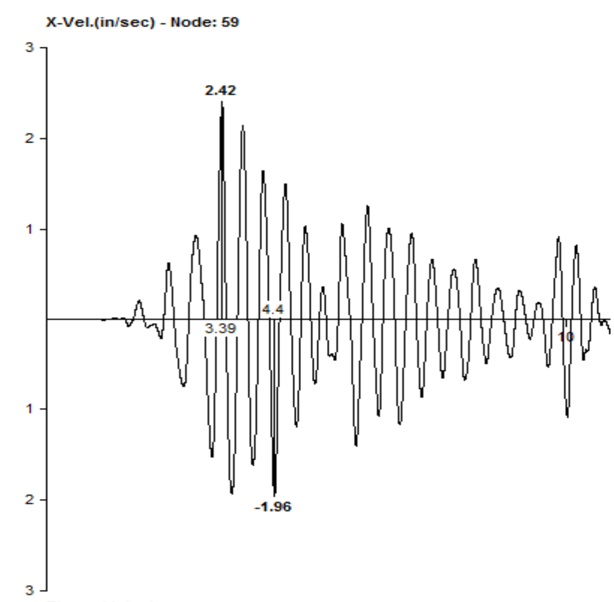


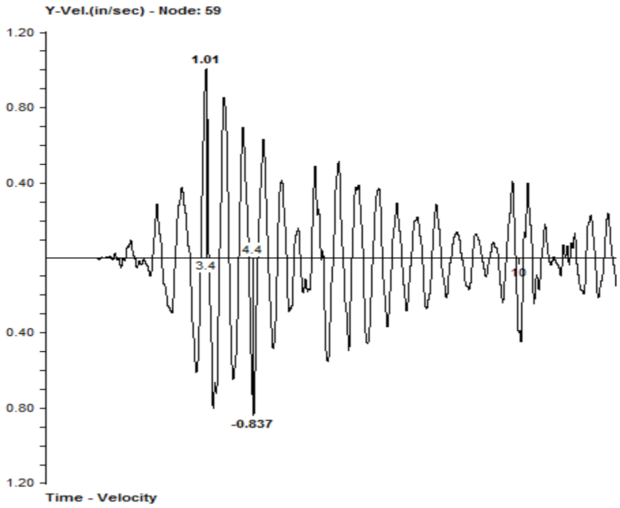


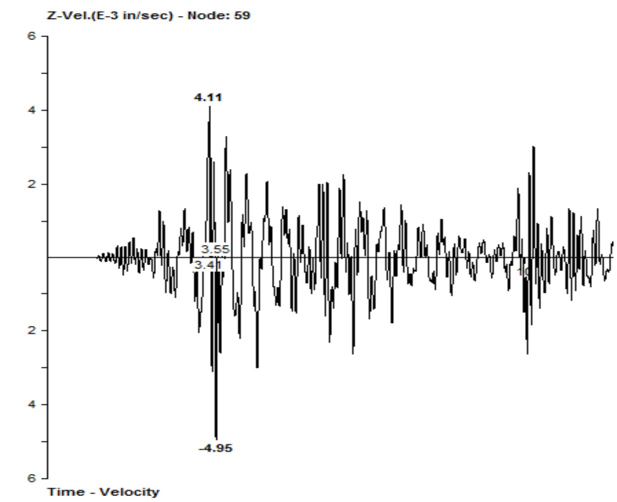
Time-Displacement at Cross-arm



Time-Velocity at Cross-arm







VI. CONCLUSION

In the first stage of study significance of fragility analysis is studied for post earthquake effect of transmission tower.Later a transmission tower is analysed and designed using IS 801and following conclusions can be drawn after applying El-centro data

- Displacement along X-direction is 127mm and 141 mm at crown and cross arms respectively,additional cross members and connections need to be provided
- Displacement along y-direction is 3.4 mm and 53.3 mm at crown and cross arms respectively,members need to change at cross arm,as there will be chance of collapse of cable
- Displacement along y-direction is 3.4 mm and 167 mm at crown and cross arms respectively

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