RESPONSE STUDY ON EARTH STATION ANTENNA SUPPORT STRUCTURE BY SIMULATING ACTUAL EARTHQUAKE SPECTRA

Dissertation

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CERTIFICATE

This is to certify that the Major Project entitled "**Response Study on Earth Station Antenna Support Structure By Simulating Actual Earthquake Spectra**" submitted by **Mr. Tushar V. Patel (03MCL11)**, towards the partial fulfillment of the requirements for the award of degree of **Master of Technology (CIVIL)** in field of **Computer Aided Structural Analysis and Design (CASAD)** of Nirma University of Science and Technology is the record of work carried out by him under my supervision and guidance. The work submitted has in my opinion reached a level required for being accepted for examination. The results embodied in this dissertation, to the best of my knowledge have not been submitted to any other university or institution for award of any degree or diploma.

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ABSTRACT

Complex real life structural analysis problems can now we handled easily using a galore of powerful computer hardware packed and zapped with the bewitching computer graphic facilities. Better insight into the behavior of the structural aspects can be now explored, up to the hilt. In addition to that, the engineering ingenuity helps in actually zeroing down on the keen issues related to design of complex structure with respect to the given design specifications.

With the advent of high speed digital computers and with the volcanic proliferation in the domain of computers, it is now possible to handle real life complex structures along with the soil mass. These type of studies are very important for the complex Radar antennas, High speed tracking type earth-station antennas, Microwave transmission towers and large sized telescopes for deep space missions; where the structures have strict and stringent displacement and rotational compliances to be met with.

In this piece of work, an attempt is made to study the given antenna support structure in its totality particularly in the Eigen value domain including the detailed studies of the structural response due to the Bhuj earthquake spectra. As per the standard literature and interaction with IIT- Roorkee, the fact dawned upon us that for antenna support structure with stringent rotational and displacement compliances, a more reliable theoretical as well as experimental approach has to be undertaken to generate the confidence level in the design before construction is taken up.

As per the instructions of IIT-R, the theoretical approach suggested was to study the elements of the structure in the component approach and then take all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario. This whole scenario of predicting the natural frequency of the entire system by incorporating the flexibility of a large volume of soil mass is

termed as holistic approach in determining the natural frequencies of the entire structural system. First few modes are the high-energy modes, which are having maximum amplitude and our study is particularly from the point of view of bending, compression and torsional modes, and their structural response due to the actual earthquake spectra of Bhuj.

In this piece of work, the case study has been picked up regarding the suitability of a building frame, vis-a-vis, the conventional robust conical massive concrete pedestal as an antenna support structure of high speed tracking antennae, under earthquake forces.

The approach synthesis for the final submission of the dissertation was decided as follows:

1. For the holistic analysis the scope of the present work is not to model the antenna system but consider the translational and rotational masses of the antenna structure on the RCC framework at the center of gravity locations using mass less beam concepts.
2. Consider the RCC staging as the standard SP-22 (S & T)-1982 problem in order to ratify the frequency results obtained in the theoretical study as given in the IS code using standard Stodola approach. Boundary conditions were exercised at the frame ends assuming that the base is of infinite stiffness as per the full fixity condition assumed by the code.
3. Consider the Finite Element Modeling of raft and soil mass and consider the effect of soil mass when it gets interacted with superstructure especially in the dynamic analysis domain. Parametric study was exercised in order to get suitable model of raft and soil mass for the holistic analysis.
4. Investigate the structural dynamic response of the frame w.r.t the actual earthquake spectra for Bhuj experienced in 26th January 2001.

Accordingly in the treatise, chapter-1 introduces the problem, and the objective of the study.

Chapter-2 gives the details of literature review.

Chapter-3 incorporates the theoretical aspects regarding analysis. Different methods for dynamic analysis and discussion about the response spectrum analysis

Chapter-4 deals with the basic theoretical aspects of Finite Element Modeling..

Chapter-5 deals with the Eigen value analysis of an antenna supporting structure
i in component approach as well as in holistic approach..

Chapter-6 deals with the study of response in both x-direction and z-direction in component approach for two different forcing functions.

Chapter-7 deals with the study of response in both x-direction and z-direction in holistic approach for two different forcing functions.

Chapter-8 summary and conclusions of the study are drawn.

Chapter-9 further development or future scope of the study is drawn.

For this submission, the scope of the work is to generate the finite element model of the RCC staging framework as per the topology given in the SP-22 problem. This model of staging is further to be integrated with the FE Model of raft and soil mass and objective is to study the structural response of the holistic model and compare w.r.t the pointing error specification of the antenna and suggest the suitable foundation.

On this model the translational mass of the antenna structure is modeled for considering the effect of antenna coming on the slab. The detailed holistic approach has been taken up as a part of the final dissertation including the response studies w.r.t IS: 1893 and Bhuj earthquake spectra.

The aim of study is to find out the suitability of the tall building frames for mounting the earth station antenna in the earthquake region. The structural responses are also studied as per the advice of IIIT-R in order to check the pointing error specification for the antenna structure. This study is also carried out to avoid semi resonance problem for high speed tracking antennas & radars mounted on the RCC frames / pedestals, during earthquake time.

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SCHEDULE OF NOTATIONS

Symbol	Description
$F(t)_I$	Vector of inertia force
$F(t)_D$	Vector of damping force
$F(t)_S$	Vector of internal forces
$F(t)$	Externally applied loads
$a(t)$	Acceleration
$a(t)$	Velocity
$a(t)$	Displacement
$[M]$	Mass matrix
$[K]$	Stiffness matrix
$[C]$	Damping matrix
$[\phi]$	Mode shape matrix
$A(t)_{ig}$	Free-field ground displacements
ω	Forcing frequency
ω_n	Natural frequency
t	Time
ζ	Damping ratio
K1	Lateral stiffness of first storey
K2	Lateral stiffness of second storey
P_i	Participation factor
λ	Eigen value
x_i,y_i,z_i	Coordinates
u_i,v_i,w_i	Displacement
$Y(t)_n$	Generalized coordinate

CHAPTER - 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Complex real life analysis problem can now we handled easily using galore of powerful computer hardware with the bewitching computer graphic facility. Better insist in to the behavior of the structural aspects can be explored. The engineering ingenuity helps in actually zeroing down on the keen issues related to design of complex structure with respect to the given design specification.

With the advent of high speed digital computer and with the volcanic proliferation in the domain of hardware and software it is now possible to handle real life complex structure along with the soil mass. This type of studies are very important for the complex earth-station antennas, microwave transmission towers and large sized telescopes for deep space missions; where the structures have strict and stringent displacements and rotation compliances to be met with.

Generally satellite earth station requires fully steer able dish shaped antenna for fixed satellite services. These antennas receive or radiate electromagnetic waves. High precision stability is required to perform its functions smoothly even under adverse atmospheric conditions. To ensure confidence on the durability of antenna performance, design of its supporting structure should be done with utmost care. So supporting structure design should consider various factors such as type of loads coming on structure, suitability of available materials for construction, site conditions and above all engineering skill to satisfy stringent requirements of supporting structure even under adverse environmental conditions. A response analysis of an antenna supporting structure on soil media should consider flexible characteristics of soil medium and foundation. In this peace of work, an attempt is made to study given structure in its totality particularly in domain of dynamic analysis including the response study at the crucial points with respect to the ground acceleration, g levels.

The response spectrum analysis with soil-structure interaction will give different results that may be computed from a fixed base building subjected to a free field ground motion. Certainly it is a simpler problem when one can separate the determination of the design ground motion from the dynamic analysis of the building, which is the case when one, performs a conventional dynamic analysis. This uncoupling of the soil system from the building system may, in general give a predicted response that could be conservative. For convenience sake, this may be a rational to use a fixed base model over a soil-structure interaction model. In critical structures, such as an antenna supporting system, some of the modes of the response such as deformation of the base of the structure or rocking of the structure may be just as important as the primary translation modes of vibration. The soil-structure interaction model subjected to dynamic loading can't be treated in the same way one would consider static loading. When analyzing a holistic system under static loading, it is sufficient to model the structure on the soil system, which will have fixed or semi-fixed boundaries at a sufficient distance from the structure where these boundary conditions do not affect the static response of the structure.

1.2 WHAT IS A RESPONSE SPECTRUM ANALYSIS OF THE STRUCTURE?

A spectrum analysis is one in which the results of a modal analysis are used with a known spectrum to calculate displacements and stresses in the model. It is mainly used in place of a time-history analysis to determine the response of structures to random or time-dependent loading conditions such as earthquakes, wind loads, ocean wave loads, jet engine thrust, rocket motor vibrations, and so on.

The curve showing the maximum response versus structural frequency relationship is called the response spectrum. Where the response might be displacement, velocity, acceleration, or force. There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member fasces in each mode using smooth design spectra that are the average of several earthquake motions.

1.3 PHOTOGRAPH SPEAKS

Some of the following images giving thought to an earth-station antenna supporting structure, though the size of the supporting structure is different and all are building frame. These real life photographs show that how important an antenna supporting structure is. These are not high speed tracking antennas but they are the earth-station antennas. These antennas vibrate with wind force generally.

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1.4 NEED OF PRESENT STUDY

For structures of prime importance viz., Radars, High speed tracking antennas, the need for such holistic analysis is felt beyond the shadow of doubt in general. Moreover in particular, the case study of a typical large size earth-station antenna greater than 7.5 m diameter is cited here, which is proposed to be designed for high transmit and receive frequencies [11-14 Hz] for an Indian sub-continent. It proves beyond the cloud of any suspicion that for meeting such stringent specifications, exact mathematical modeling of the entire system becomes the need of the hour both in domains of static and as well as dynamic analysis. Static analysis is carried out for equivalent wind speed and also for gravity loads for different orientations of the reflector dish for checking the pointing error specifications. Dynamic analysis is carried out for predicting natural frequencies of the system in order to cross-check with respect to the following important design data of the antenna system:

1. Servo motor frequencies
2. Lock rotor frequencies

It is important to decouple all the frequencies of the subsystems in order to avoid any resonance issues. The problem becomes more vulnerable when the earth-station antenna becomes a Radar or High speed-tracking antenna; where by dint of acceleration force/torque the entire system is subjected to quick stress reversals and the actual frequencies of the system get excited.

This study is important in gist, because of the points cited vide above.

1.5 OBJECTIVES OF DESSERTATION

The objective of study is to generate the finite element of the RCC staging framework as per the topology given in the SP-22 problem. This model of staging is further to be integrated with the FE model of raft and soil mass. Find out the suitability of the tall building frames for mounting the earth station antenna during the earthquake time. The structural responses are also to be studied as per the advice of IIT-R in component approach and then take all components together along with the soil mass gives the holistic approach and check the pointing error specification for the antenna structure. This study is important to avoid resonance problem for high speed tracking antennas & radars mounted as the RCC frames / pedestals, during earthquake time

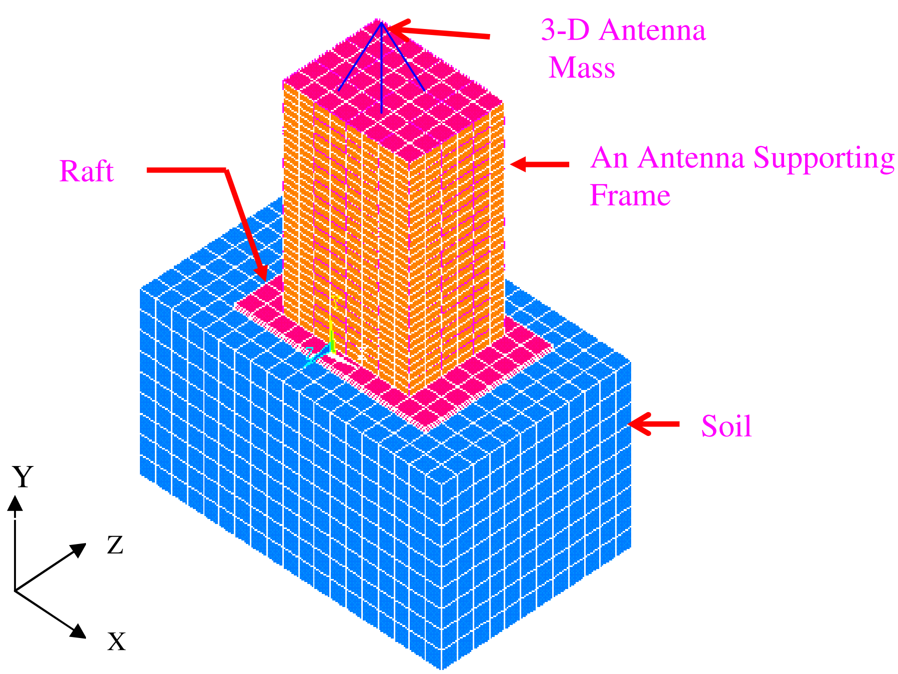

Figure 1.1 Model of Antenna Supporting Structure with Raft & Soil Mass

1.6 ORGANIZATION OF DISSERTATION

Dissertation is divided into nine chapters. The first chapter introduces the problem and the objective of the study.

Chapter-2 gives the details of literature review.

Chapter-3 incorporates the theoretical aspects regarding analysis. Different methods for dynamic analysis and discussion about the response spectrum analysis

Chapter-4 deals with the basic theoretical aspects of Finite Element Modeling..

Chapter-5 deals with the Eigen value analysis of an antenna supporting structure i in component approach as well as in holistic approach..

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Chapter-8 summary and conclusions of the study are drawn.

Chapter-9 further development or future scope of the study is drawn.

Appendix-A gives SP-22 and Is-1893 (2002) relevant few articles.

Appendix-B incorporates few articles on Antenna structures.

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CHAPTER 2

LITERATURE REVIEW

Some of the following papers giving thought to Finite Element Modeling of soil, the effect of soil-structure interaction on the different structures and the study of structural response due to actual earthquake are studied and abstract of the same are presented here,

Jennings P. C. et al (1973) presented soil modeling by a linear half space and the building structure by an N-degree of freedom oscillator. Both the earthquake response and steady state response to sinusoidal excitation is examined. By assuming that the interaction system possess n+2 significant resonate frequencies, the response of the system is reduced to the superposition of the responses of damped linear oscillators subjected to modified excitations the results are invalid even though interaction system do not possess classical normal modes. For the special case of the single storey systems and the 1^{st} mode of n-storey systems, simplified approximate formulas are developed for the modified natural frequency and damping ratio and for modified excitation. Example calculations are carried out by the approximate and more exact analysis for one storey, two storey and ten storey interaction systems. The results show that interaction tends to decrease all resonate frequencies, but that the effect are often significant only for the fundamental mode for many n-storey structures and are more pronounced for rocking than the translation. If the fixed base structure has damping the effect of interaction on the earthquake response are not always conservative, and an increase or decrease in the response can occur, depending on the parameters of the system.

Vaish A. K. et al (1974) elaborates the use of substructure method. The analysis of the earthquake response of structure-foundation systems, idealized as an assemblage of finite elements. Using a substructure approach, in which the foundation is first analyzed independently of the structure to obtain its dynamic compliance characteristic, carries out the same system. That effect is then incorporated in the equation of the motion. Author concludes that the substructure procedure allows the response of the structure to be evaluated with a higher degree of refinement, with far greater computational efficiency

Hamidzadeh-Eraghi H.R. et al (1981) has determined the response of rigid rectangular foundation block resting on a elastic half space, by considering first the displacement functions for any position on the surface of an unloaded half-space due to harmonic point force. The influence of the foundation has been taken into account by assuming a relaxed condition at the interface, i.e. the uniform displacement under the foundation and that the sum of the point forces must be equal to the total applied force. The three motions of vertical, horizontal and rocking have been considered and numerical values for the in-phase and the quadrature components of displacement function are presented for a Poisson's ratio of 0.25. the effect of mass and inertia of the foundation has allowed by an impedance matching technique. Author has given response curves and non-dimensional resonant frequency curves for a rectangular and square foundation for different mass and inertia ratios and several values of Poisson's ratio. These curves are useful for design purpose.

Novak M. et al (1983) has presents the effect of soil structure interaction on the damping of structure. Foundation flexibility affects the total damping of structure in two ways (1) the structure gains damping through energy dissipation in soil and (2) modifies the original structural damping, reducing it for most structures. These effects are evaluated using two approaches: an energy consideration, which is a simple but, approximate approach and the complex eigenvalue analysis which is mathematically accurate but uses damped, non-classical vibration modes.

Author concludes that the error of the more convenient energy approach increases as the foundation damping increases and may reach 50 percent or even more for the higher vibration modes, depending on foundation conditions. Frequency dependent foundation impedance functions complicate the analysis. In such a case, model damping can be evaluated by means of an interactive procedure or established from transfer functions of the system.

Ovunc B. A. (1986) has developed by considering the actual mass distribution and the effect to member axial force. The dynamic analysis of structures under the effect of soil-structure interaction and the effect of member axial force is based on the continuous mass matrix method, in which the equations of motion are satisfied at any arbitrary point of the structure not only at nodal points. For the members embedded in the soil, the soil reactions and the skin frictions are also considered as continuously varying over the members. The soil-structure interaction is taken into account as the deformation of the soil caused by the motion of the structure, which is in turn, modifies the response of the structures.

Fenves G. L. et al (1990) has presents the response given by a fourteen story reinforced concrete building to the 1st October, 1987 Whittier earthquake and 4th October, 1987 aftershock shows significant effects of soil-structure interaction. A mathematical model of the building foundation soil system provides response quantities not directly available from the records. The model is calibrated using dynamic properties of the building as determined from the processed strong motion records. Soil-structure interaction reduces the base shear force in the longitudinal direction of building compared with typical assumption in which the interaction is neglected. The reduction in base shear for this building and earthquake is approximately represented in proposed building code provisions for soil-structure interaction. Author concludes that soil-structure interaction modifies the response of typical multistory building in one moderate earthquake and aftershocks.

Noorzaei J. et al (1991) has studied the physical modeling of space frame raft and soil system by using isoperimetric beam bending element to represent beams and columns of the frame, plate-bending element for representing raft as well as slabs of the structure. The soil mass has been idealized by coupled finite-element brick elements. Furthermore, a detailed parametric study of the effect of variation in raft and slab thickness on the interactive behavior of space frame –raft-soil system has been carried out.

Phan L. T. et al (1994) has analyzed strong-motion and ambient vibration data from a 6-storey commercial office building in San Bruno, California. Comparison of dynamic characteristics revealed that the first mode response frequency deducted from the Loma Prieta earthquake records is significantly lower than deduced from ambient vibration data, and damping ratio for strong motion is higher than that obtained from ambient vibration. A computer model of the building was developed and analyzed using two boundary conditions. The fixed base condition was used to simulate the building response to ambient vibration and the spring – supported condition was used to incorporate soil-structure interaction and thus simulate realistic building response to the loom Primate earthquake. Results of analyses showed that the first mode response frequencies for the two cases differ by essentially the same factor observed from measurement. This suggests that the difference in the first mode response frequencies between ambient vibration and strong motion in this building was due largely to soil-structure interaction.

Wen – Hwa et al (1995) has presents an efficient methodology, which uses modal analysis implemented in the frequency domain to obtain the structural response of a system with soil-structure interaction. The interaction effects are represented using a free-field ground motion modification factor, derived for each mode of vibration and used in the determination of structural response. Applying this algorithm, the advantages of the modal superposition method are fully exploited, and the interaction problem can be solved easily and effectively within the framework of the conventional frequency domain analysis for a fixed-base structure.

AL-Homoud A. S. et al (1996) has presents the results of many free and forced vertical vibrations tests conducted on surface and embedded models for footings on dry and moist poorly graded sand. The effect of mass, area geometry, embedment, saturation, load amplitude and frequency were studied. For this purpose square, rectangular and circular models of concrete footing were chosen. Swedish sand was chosen as foundation soil. Results have been obtained for models having different mass, same base shape and area; models of different base shape geometry and about equal masses and base area. Forced vertical vibration tests results showed an increase in natural frequency and reduction in amplitude with the increase of model footing resulted in a decrease in the natural frequency while the dynamic response increased. Also, the results showed that the circular model footing give the values of dynamic response in comparison to other models. On other hand, results showed a decrease in damping ratio with increase in the base are of the model footing, depth of embedment and saturation of sand. On other hand, results showed a decrease in damping ratio with increase in the footing mass. Circular footing gives the highest value of damping ration among other footings.

Kulkarni S. S. et al (1997) has compared various methods of modeling the building structures. The two types building; symmetrical and unsymmetrical are considered for analysis is also carried out to investigate further in to the dynamic behavior of these structures. Author concludes that, time period result clearly shows that the stiffness of the structure steadily increases from neglecting the diaphragm to rigid diaphragm. Hence, when response spectrum analysis is employed neglecting the diaphragm, the seismic forces are underestimated. The same analysis overestimates the wind forces. This being consistent with the nature of the response spectra of both seismic and wind analysis.

Ganev T. et al (1997) has presented the result from forced vibration tests, micrometer observations and earthquake response analysis of a nuclear reactor containment model constructed on stiff soil in Hualien, Taiwan. The dynamic behavior of the soil-structure system is simulated successfully with two numerical models: a sway-rocking model, whose soil parameters are evaluated on the basis of continuum formulation method, and a finite element model, using a program SASSI with the flexible volume sub structuring approach. The dependencies of the soil parameters of both models on the amplitudes of the different dynamic excitations are investigated in detail. An original numerical simulation of micro tremor is performed. Comparison with results of a previous study involving a rigid tower on a soft soil in Chiba, Japan is also presented.

Aviles J. et al (1998) has given a numerical solution for evaluating the effects of foundation embedment on the effective period and damping and the response of soil-structure systems. A simple system similar to that used in practice to account for inertial interaction effects is investigated, with inclusion of kinematics interaction effects for the important special case of vertical incident waves. The effective period and damping are obtained by establishing equivalence between the interacting system excited by the foundation input motion and replacement oscillator excited by the free-field ground motion. In this way, the use of standard free-field response spectra applicable to the effective period and damping of the system is permitted. Also an approximate solution for total soil-structure interaction is presented, which indicates that the system period is insensitive to kinematics interaction and the system damping may be expressed as that for inertial interaction but modified by a factor due to kinematics interaction. Results involving both kinematics and inertial effects are compared with those obtained for no soil-structure interaction and inertial interaction only. The more important parameters involved are identified and their influences are examined over practical ranges of interest.

Stewart J. P. et al (1999) has described analysis procedures and system identification techniques for evaluating inertial SSI effects on the seismic structural response. The analysis procedures are similar to provisions in some building codes but incorporate more rationally the influence of site conditions and the foundation embedment, flexibility, and shape on foundation impedance. Implementation of analysis procedures and system identification techniques is illustrated using building shaken during the 1994 Northridge earthquake. The analysis procedure predicts the observed SSI effect using a variable strong motion data from a board range of sites and then develops general conclusions regarding SSI effects s on seismic structural excitation and response.

Inaba T. et al (2000) has pointed out the importance of investigating the relationship between the ground motion and structures damage. Strong seismic motion was observed at NTT (Nippon Telegraph and Telephone) building during the 1995 Kobe earthquake. The structural damage to this building was relatively slight. In order to evaluate the relationship between ground motion and structural damage, the seismic response of the building and of the surface soil were evaluated by means of a nonlinear soil-structure interaction analysis using FEM. In observation it was found that a large nonlinearity was recognized in the ground motion near NTT Kobe Ekimae building. The amplification characteristics of the soil varied according to the intensity of the ground motion. The ground motion decreased the shear modulus of the layers from G.L.-32 to 38 m, by less than one of the layer directly underneath, resulting in the rocking of the building; further, the rocking increased the shear strain near the building. The maximum displacement at the 8t" floor of the building, about 15% were due to the rocking of the building. Authors conclude that the soil-structure interaction had a large effect on the seismic response of the building.

Wen-Hwa Wu et al (2001) has developed an efficient methodology for applying modal analysis to assess symmetrically the combined soil-structure interaction and torsion coupling effects on asymmetric buildings. This method is implemented in the frequency domain to accurately incorporate the frequency-dependant foundation impedance functions. For extensively extracting the soil-structure interaction effects, a diagonal transfer matrix in the modal space is derived. A comprehensive investigation of asymmetric building-soil interaction can then be conveniently conducted by examining various types of response quantities. Results of parametric study show that the increasing height-to-base ratio of a structure generally amplifies its transnational and torsion responses. Moreover both the transnational and torsion responses are reduced for the case where the two resonant frequencies are well separated and this reduction is enhanced with the decreasing values of the relative soil stiffness and the height-to-base ratio. The most noteworthy phenomenon may be the fact that the SS1 effects can enlarge the translational response if the structure is slender and the two resonant frequencies are very close.

V.K Gupta & M.D Trifunac has deals with the knowledge of the higher order peak amplitudes becomes as essential input to the seismic design of building when the maximum stresses may repetitively exceed the elastic design limit. It is useful to understand how these higher order peak amplitudes depend on various governing parameters and what are their amplitudes in terms of the largest peak amplitudes. Higher order peaks in the earthquake response of multistoried building have been investigated by studying their amplitudes as fractions of the corresponding highest peak, for a parametric variation of the building and excitation characteristics. The longer is the duration, the greater are these amplitudes. The variation of the peak amplitudes along the building height for any response function is, however, influenced by the mode shapes, and by their relative participation for a building with fixed number of stories. This is largely depends on the distribution of floor masses and storey stiffness along the building height.

A.K. Jain & R.A Mir has presents the inelastic seismic response of 6-story and 10-story reinforced concrete frames designed using the latest specification. Theses frames were subjected to the EL Centro earthquake of May 1940 and 50 percent reduced Mexico earthquake of 1985. It is shown that the ductility requirements in columns were quite high and they were unsafe. The frames had strong girder-weak column proportions. Such frames are actually being built in seismic zone IV in the country. These frames were redesigned using the ACI specifications. The revised frames behaved much better. It is recommended that suitable modifications be made in Indian code specification so that frames may have weak-girder strong-column proportioning as well as certain minimum sagging moment capacity to resist reversible earthquake forces.

Kevin K. F. has deals with energy balance is used to characteristics the seismic energy in inelastic structures where energy input to the structure is decomposed into strain energy, damping energy, and plastic energy. The exact quantification of plastic energy is derived based on force analogy method for moment-resisting frames. A method of generation energy density spectra is then proposed based on yield displacement of a single degree of freedom system. The effects of different structural vibration characteristics are then studied on energy density spectra; these effects include variations of yield displacement level, earthquake scaling factor, and damping ratio, which proves to be useful in improving the basic understanding of energy characteristics in structural dynamic response. Finally, the use of energy density spectra is demonstrated on a multi-degree of freedom structure to show the practical application of these spectra.

Charles Menun & Armen Der Kiureghian has using the theory of random vibrations; a response-spectrum-based procedure for predicting the envelope of vector of seismic responses has been developed. The envelope is completely defined by quantities available in the conventional response spectrum method. When the orientation of the principal directions along which the ground motion components are uncorrelated are know, the envelope is an ellipsoid that is inscribed within the rectangular envelope defined by the peak values of the individual response components. The size and orientation of the ellipsoid depends on the correlation between the individual response components. For the case when the principal directions are unknown, a supreme envelope is defined that bounds the union of the elliptical for all directions. A simple analytical expression for this envelope, which is not elliptical in shape, has been derived.

Elemi A. Pavlou, Michael C. Constantinou has studied the effect of near-field and soft-soil ground motions on structures with viscous damping systems were examined. Damping modification factors for damping ratios up to 100% of critical were obtained for sets of near-field and soft-soil ground motions and compared to the values presented in 2000 NEHRP recommended provision. A study was carried out for the ductility demand in structures without and with damping systems, where the damped building were designed for a smaller base shear than conventional buildings in accordance with the 2000 NEHRP recommended provisions. Nonlinear response-history and simplified method of the 2000 NEHRP recommended provision were used to analyze single-degree-of-freedom systems and three-story moment frames with linear viscous and nonlinear viscous damping systems to acquire knowledge on the influence of near-field and soft-soil ground motions on the accuracy of simplified methods of analysis.

CHAPTER 3

THEORETICAL ASPECTS

3.1 DYNAMIC ANALYSSIS

3.1.1 INTRODUCTION

All the real physical structures behave dynamically when subjected to loads or displacements. The additional inertia forces, from Newton's Second law are equal to the mass times the acceleration. If the loads or displacements are applied very slowly, the inertia force can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis.

In addition, all real structures potentially have an infinite number of displacements. Therefore, the most critical phase of structural analysis is to create a computer model with a finite number of massless members and a finite number of node displacements that will simulate the behavior of real lumped at the nodes. Also, for linear elastic structures, the stiffness properties of the members can be approximated with a high degree of confidence with the aid of experimental data. However, the loading, energy dissipation properties and boundary conditions for many structures are difficult to estimate. This is always true for the cases of seismic input or wind loads.

To reduce the errors that may be caused by the approximations, it is necessary to conduct many different dynamic analyses using different computer models, loading and boundary conditions. Because if the large number of computer runs required for a typical dynamic analysis, it is very important that accurate and numerically efficient method be used within computer programs.

Dynamic analysis of structure includes (i) Solution of free vibration problem and (ii) Several forced excitation analysis types; Response spectrum analysis and linear times history analysis all utilizing modal superposition method. The dynamic response results are presented as structural deformation (displacements, velocities, or accelerations and as internal element loads and stresses.

3.2 FREE VIBRATION ANALYSIS

3.2.1 FREE VIBRATION ANALYSIS OF SINGLE DEGREE OF FREEDOM SYSTEM

3.2.1.1 INTRODUCTION TO FUNDAMENTAL CONCEPTS

The dynamic behavior of buildings is better understood with the help of certain basic concepts pertaining to dynamic response. Consider the simplest structure, namely a single storey building, the roof of which is supported on columns. Usually, in such structures, the mass of the roof is much larger than that of the columns. For the purpose of understanding their basic behavior it is sufficient to consider the former alone and neglect the latter. Further, the dynamic motion of this mass considered can be reasonably described by a single kinematic quantity, namely the horizontal displacement of the mass. This idealized structure is called a single degree of freedom (SDOF) system. When buildings are mildly shaken and let go, the amplitude of peak lateral displacement of the subsequent motion, called free vibration, keeps decreasing, in general, and eventually comes to rest.

3.2.1.2 DAMPING

Damping of physical system is resistance to motion; this implies that energy is dissipated in the building. Heat loss in friction, air resistance, cracking and yielding are some forms of damping. Damping is of several types.

1. **Viscous Damping** occurs in lubricated sliding surfaces with small clearance.
2. **Friction Damping** occurs when two machine parts rub against each other dry or unduplicated.
3. **Structural Damping** is due to the internal friction of molecules.
4. **Slip or Interfacial Damping** is due to microscopic slip on the interfaces of machine parts in contact under fluctuating loads.
5. **Radiation or Dispersion Damping** is due to the loss of energy by dissipation of energy by wave propagation of energy by wave propagation, radiating

away into soil mass negative damping occurs when a system draws energy from some source.

3.2.1.3 DYNAMIC EQUILIBRIUM

The force equilibrium of a multi-degree-of-freedom lumped mass system as a function of time can be expressed by the following relationship:

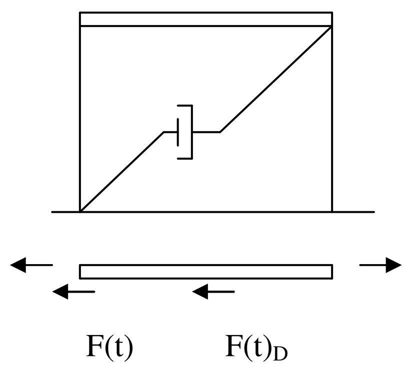


Fig. 3.1 Dynamic Equilibrium of Single Degree of Freedom System

$$F(t)_I + F(t)_D + F(t)_S = F(t) \qquad (3.1)$$

In which the force vectors at time t are :

$F(t)_I$ is a vector of inertia forces acting on the node masses

$F(t)_D$ is a vector of viscous damping, or energy dissipation, forces

$F(t)_S$ is a vector of internal forces carried by the structure

$F(t)$ is a vector of externally applied loads

Equation (3.1) is based on physical laws and is valid for both linear and nonlinear systems if equilibrium is formulated with respect to the deformed geometry of the structure.

For many structural systems, the approximation of linear structural behavior is made to convert the physical equilibrium statement, Equation (3.1), to the following set of second-order, linear, differential equation,

$$[M]\, a''(t)_a + [C]\, a'(t)_a + [K]\, a(t)_a = F(t). \qquad (3.2)$$

For seismic loading, the external loading F(t) is equal to zero. The basic seismic motions are the three components of free-field ground displacements $a(t)_{ig}$ that are known at some point below the foundation level of the structure. Therefore, Equation (3.2) can write in terms of the displacements a(t), velocities a'(t), and accelerations a"(t) that are relative to the three components of free-field ground displacements. Therefore, the absolute displacements, velocities and accelerations can be eliminated from Equation (1.2)by writing the following simple equations :

$$a(t)_a = a(t) + I_x\, a(t)_{xg} + I_y\, a(t)_{yg} + I_z\, a(t)_{zg}$$

$$a(t)_a = a(t) + I_x\, a(t)_{xg} + I_y\, a(t)_{yg} + I_z\, a(t)_{zg} \qquad (3.3)$$

$$a(t)_a = a(t) + I_x\, a(t)_{xg} + I_y\, a(t)_{yg} + I_z\, a(t)_{zg}$$

Where I_i is a vector with ones in the "i" directional degrees-of-freedom and zero in all other positions. The substitution of Equation (3.3) into Equation (3.2) allows the node point equilibrium equations to be rewritten as :

$$[M]\, a(t) + [C]\, a(t) + [K]\, a(t) = -[M]_x\, a(t)_{xg} - [M]_y\, a(t)_{yg} - [M]_z\, a(t)_{zg} \qquad (3.4)$$

Where, $[M]_i = [M]\, I_i$

The simplified form of Equation (1.4) is possible since the rigid body velocities and displacements associated with the base motions cause no additional damping or structural forces to be developed.

3.2.2 FREE VIBRATION ANALYSIS OF MULTI-DEGREE OF FREEDOM SYSTEM

The basic concepts of building dynamics have been developed in the previous topic on single degree of freedom systems (SDOF). A multi-storey building being a three-dimensional structure is free to move. In general, in all directions. Thus, each node of the building has six degrees of freedom. The vibration of such systems with six degrees of freedom per node, usually, tends to be computationally intensive even for buildings with small number of bays and storey. This literature is intended to discuss the methods to be employed in the dynamic analysis of systems with more than one degree of freedom, i.e. of multi-degree of freedom systems (MDOF). Hence, for the purposes of developing the basic concepts of multi-storey building dynamics, making the following simplifying assumptions reduces the problem size:

Assumptions:

1. The columns are axially rigid. This assumption is reasonable for low-rise buildings.
2. The lateral displacements of all points at a floor level are same. This assumption is valid for buildings with rigid floor diaphragms.
3. The rotational inertia of the floor masses in the vertical plane are negligible.
4. The mass of the building is mostly concentrated at the floor levels.

3.2.2.1 UNDAMPED FREE VIBRATION

For undamped free vibrations, equation of motion becomes

$$M\, a(t) + K\, a(t) = \{0\}. \qquad (3.5)$$

Just as in the free vibration of SDOF system, let the solution be harmonic and of the form

$$a(t) = v \sin \acute{\omega} t. \tag{3.6}$$

Substituting equation (3.6) in equation (3.5)

$$K v - \acute{\omega}^2 M v = \{0\}. \tag{3.7}$$

or

$$(k_1 + k_2 - \acute{\omega}^2) v_1 - k_2 v_2 = 0.$$

$$- k_2 v_1 + (k_2 - \acute{\omega}^2 m_2) v_2 = 0. \tag{3.8}$$

Clearly, equation (3.8) gives only the ratio v_1 / v_2, and not individual magnitude of v_1 and v_2. Further, v_1 and v_2 take non-zero values only if

$$\begin{vmatrix} k_1 + k_2 - \acute{\omega}^2 m_1 & -k_2 \\ -k_2 & k_2 - \acute{\omega}^2 m \end{vmatrix} = 0.$$

or $$(k_1 + k_2 - \acute{\omega}^2 m_1)(k_2 - \acute{\omega}^2 m_2) - (k_2)^2 = 0. \tag{3.9}$$

Equation (3.9) is called the characteristic equation of the two-storey building. It has two real roots say $\acute{\omega}_1$ and $\acute{\omega}_2$ ($\acute{\omega}_1 > \acute{\omega}_2$) called first and second natural frequencies. The lowest value $\acute{\omega}_1$ is called the fundamental natural frequency. For each of these two values, equation (3.8) provides a ratio of $v_{n1} / v_{n2.\ n=1,\ 2}$ If the displacement corresponding to the top storey is taken as unity, i.e. $v_{n2=1}$ then v_{n1} is known. Thus, the two displaced shapes $\{\Phi\}_1$ and $\{\Phi\}_2$ corresponding to the two frequencies $\acute{\omega}_1$ and $\acute{\omega}_2$ are obtained. These displaced shapes of building are graphically shown in Figure 3.2. These are called the mode shapes corresponding to the two natural frequencies. Clearly, $\{\Phi\}_1$ and $\{\Phi\}_2$ are not unique as far as their absolute values are concerned. Since only v_{n1} / v_{n2} are known, mode shapes obtained by multiplying $\{\Phi\}_1$ and $\{\Phi\}_2$ with any constant will still satisfy equation (3.7).`

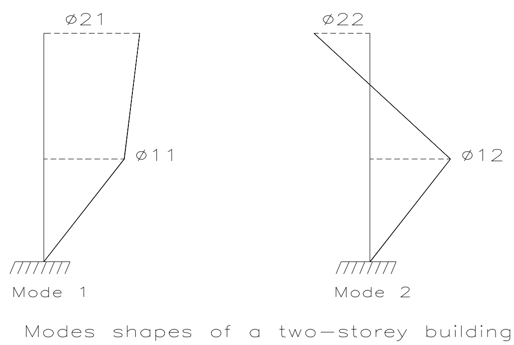


Figure 3.2 Mode-Shapes of a two storey building

At the two natural frequencies the floors of the building execute synchronous motion i.e. the floor displacements have the same time dependence and the overall shape of the displacement profile of the building does not change, though the amplitude does. These natural frequencies and mode shapes are (dynamic) characteristics of the building, and are dependant only on the building properties K and M. Denote the collection of all the mode shape vectors as [Φ], the mode shape matrix. Hence,

$$[\Phi] = [\{\Phi\}_1 \ \{\Phi\}_2] = \begin{pmatrix} \Phi_{11} & \Phi_{21} \\ \Phi_{12} & \Phi_{22} \end{pmatrix} \qquad (3.10)$$

It can be shown that,

$$\{\Phi\}_m^T M \{\Phi\}_n = \begin{cases} M_n & \text{if } m = n \\ 0 & \text{if } m \neq n \end{cases}$$

and

$$\{\Phi\}_m^T K \{\Phi\}_n = \begin{cases} Kn & \text{if } m = n \\ 0 & \text{if } m \neq n \end{cases} \qquad (3.11)$$

It can be shown that for a particular type of damping matrix, C called the classical Damping Matrix, the following identity also holds

$$\{\Phi\}_m^T C \{\Phi\}_n = \begin{cases} C_n & \text{if } m = n \\ 0 & \text{if } m \neq n \end{cases} \qquad (3.12)$$

Equations (3.11) and (3.12) indicate that two modal shape vectors, $\{\Phi\}_m$ and $\{\Phi\}_n$ are orthogonal with respect to mass, damping and stiffness matrices, is called the generalized mass of mode and is different from the floor mass m_i. It is dependant on the mode shape and hence it is also not unique. C_n and K_n are called generalized damping and generalized stiffness of mode n of the building.

Considering the non- uniqueness of the mode shapes, one may normalize the mode shapes in a number of ways. Two approaches are commonly adopted in normalization. In the first approach, the displacement at the top storey is taken as unity and the other floor displacement are calculated accordingly. Another approach is to choose $\{\Phi\}_n$ such that

$$\{\Phi\}_n^T M \{\Phi\}_n = 1. \qquad (3.13)$$

The power of these natural modes is evident in describing any arbitrary displacements a(t), of the floors of the building in terms of the derived mode shapes. The displacement profile of the two-storey building at any given time instant can be described by superimposing the mode shapes $\{\Phi\}_1$ and $\{\Phi\}_2$, with suitable multiplying factors. Hence,

$$a(t) = [\{\Phi\}_1 \ \{\Phi\}_2] \begin{pmatrix} y_{1(t)} \\ y_{2(t)} \end{pmatrix} = [\Phi]\, y \qquad (3.14)$$

[Φ] is called the Mode Shape Matrix. Graphically, equation (3.14) is depicted in Figure 3.3. In equation (3.11), y is called the generalized (or normal) coordinate vector. From equation (3.11) and (3.14)

$$y_n = \frac{\{\Phi\}_n^{T} M \; a}{\{\Phi\}_n M \; a} \qquad n = 1,2 \qquad (3.15)$$

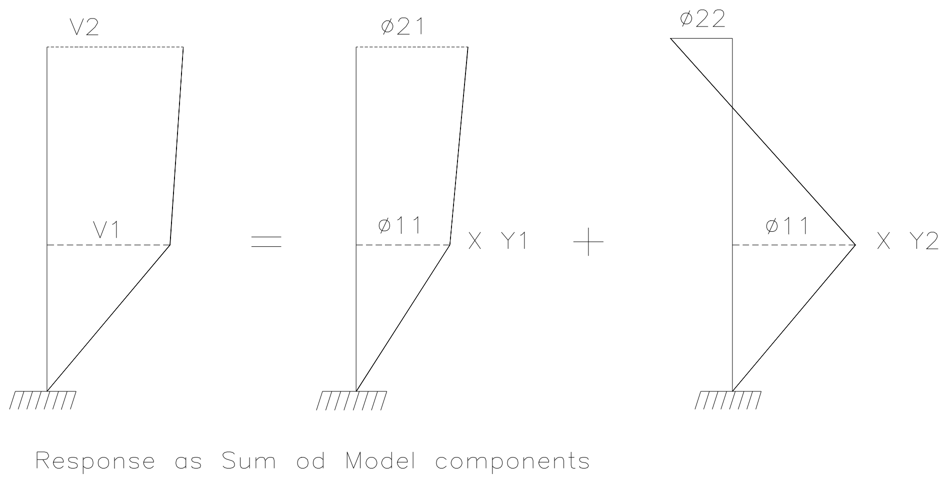


Figure 3.3 Response of sum of model components

3.3 FORCED VIBRATION ANALYSIS

3.3.1 DIFFERENT METHOD OF DYNAMIC ANALYSIS

3.3.1.1 STEP-BY-STEP SOLUTION METHOD

The most general solution method for dynamic analysis is an incremental method in which the equilibrium equations are solved at times Δt, 2Δt, 3Δt, etc. There are a large number of different incremental solution methods. In general, they involve a solution of the completed set of equilibrium equations at each time they involve a solution of the completed set of equilibrium equations at each time increment. In the case of nonlinear analysis, it may be necessary to reform the stiffness matrix for the complete structural system fro each time step. Also, iteration may be required within each time increment to satisfy equilibrium. As a result of the large computational requirements, it can take s significant amount of time to solve structural systems with just a few hundred degree-of-freedoms.

3.3.1.2 MODE SUPERPOSITION METHOD

The most common and effective approach for seismic analysis of linear structural systems is the mode superposition method. After sets of orthogonal vectors have been evaluated, this method reduces the large set of global equilibrium equations to a relatively small number of uncoupled second order differential equations. The numerical solution of those equations involves greatly reduced computational time. It has been shown that seismic motions excite only the lower frequencies of the structure. Typically, earthquake ground accelerations are recorded at increments of 200 points per second. Therefore the basic loading data does not contain information over 50 cycles per second. Hence, neglecting the higher frequencies and mode shapes of the system normally does not introduce errors.

3.3.1.3 RESPONSE SPECTRA ANALYSIS

The basic mode superposition method, which is restricted to linearly elastic analysis, produces the complete time history response of joint displacements and member forces because of specific ground motion loading. There are two major disadvantages of using this approach. First, the method produces a large amount of output information that can require an enormous amount of computational effort to conduct all possible design checks as a function of time. Second, the analysis must be repeated for several different earthquake motions to ensure that all the significant modes are significant modes are excited, because a response spectrum for one earthquake, in a specified direction, is not a smooth function.

There are significant computational advantages in using response spectra method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of displacements and member forces in each mode using smooth design spectra the average of several earthquake motions.

3.3.1.4 UNDAMPED HARMONIC RESPONSE

The most common and very simple type of dynamic loading is the application of steady-state harmonic loads of the following form

$$F(t) = f \sin(\omega t) \quad (3.16)$$

The node point distribution of all static load patterns, f, which are not a function of time, and the frequency of the applied ω, are user specified. Therefore the case of zero
Damping, the exact node point equilibrium equations for the structural system are

$$[M]\, a(t) + [K]\, a(t) = f \sin(\omega t) \quad (3.17)$$

The exact steady-state solution of this equation requires that the node point displacements and acceleration are given by :

$$a(t) = v \sin(\omega t)\ , \quad a''(t) = v\, \omega^2 \sin(\omega t) \quad (3.18)$$

Therefore, the harmonic node point response amplitude is given by the solution of the following set of linear equations:

$$\{ [K] - \omega 2\, [M] \}\, v = f \qquad \text{or} \qquad \lambda v = f \quad (3.19)$$

Normal solution for static loads is nothing more than a solution of this equation for zero frequency for all loads/ it is apparent that the computational effort required for the calculation of undamped steady-state response is almost identical to that required by a static load analysis. It is not necessary to evaluate mode shapes or frequencies to solve for this very common type of loading. The resulting node point displacements and member forces vary as sin (ωt).

3.3.2 DYNAMIC ANALYSIS USING REPOSNE SPECTRUM SEISMIC LOADING

3.3.2.1 INTRODUCTION

The curve showing the maximum response versus structural frequency relationship is called the response spectrum. There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member fasces in each mode using smooth design spectra that are the average of several earthquake motions.

The recent increase in the speed of computers has made it practical to run many time history analyses in a short period of time. In addition, it is now possible to run design checks as function of time, which produces superior results, because each member is not designed for maximum peak values as required by the response spectrum method.

3.3.2.2 DEFINITION OF A RESPONSE SPECTRUM

For three-dimensional seismic motion, the typical modal Equation is written as

$$y(t)_n + 2\zeta_n\, \omega_n\, y(t)_n + \omega_n^2\, y(t)_n = P_{nx}\, a(t)_{gx} + P_{ny} a(t)_{gy} + P_{nz}\, a(t)_{gz} \tag{3.20}$$

Where, the three Mode Participation Factors are defined by $P_{ni} = \phi_n^T\,[M]_I$ in which i is equal to x, y or z. Two major problems must be solved in order to obtain an approximate response spectrum solution to this equation. First, for each direction of ground motion maximum peak forces and displacements must be estimated. Second, after the response for the three orthogonal directions is solved it is necessary to estimate the maximum response due to the three components of earthquake motion acting at the same time. This section will address the modal combination problem due to one component of motion only.

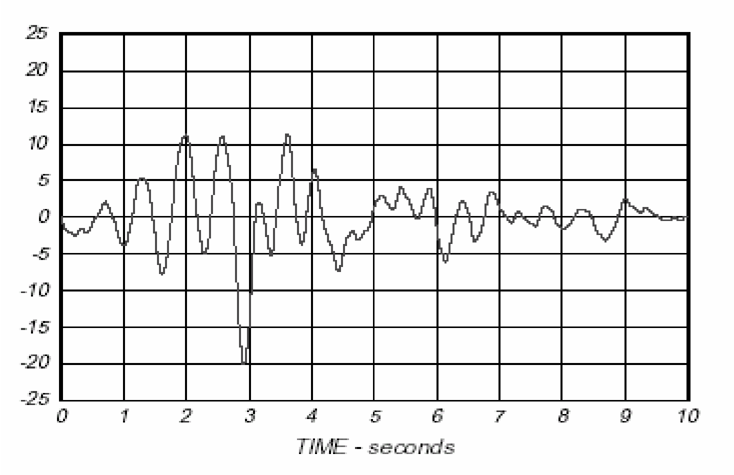
$$y(t)_n + 2\zeta_n \omega_n y(t)_n + \omega_n^2 y(t)_n = P_{ni} a(t)_{gi} \tag{3.21}$$

Given a specified ground motion $a(t)_g$, damping value and assuming P_{ni} = -1.0 it is possible to solve Equation (4.21) at various values of ω and plot a curve of the maximum peak response $y(\omega)_{MAX}$. For this acceleration input, the curve is by definition the displacement response spectrum for the earthquake motion. A different curve will exist for each different value of damping.

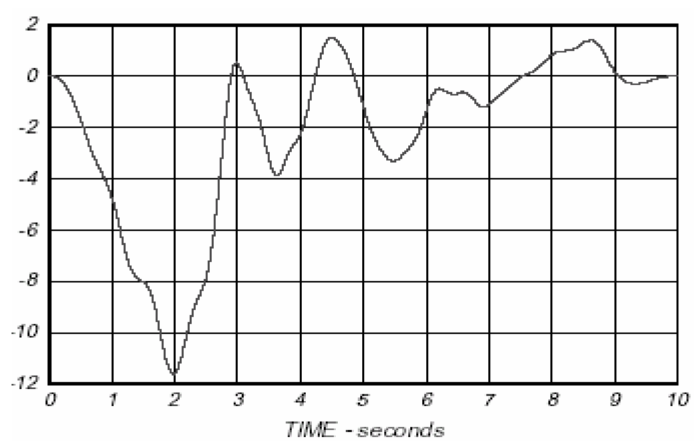
A plot of $\omega y(\omega)_{MAX}$ is defined as the pseudo-velocity spectrum and a plot of $\omega^2 y(\omega)_{MAX}$ defined as the pseudo-acceleration spectrum. These three curves are normally plotted as one curve on special log paper. However, these pseudo values have minimum physical significance and are not an essential part of a response spectrum analysis. The true values for maximum velocity and acceleration must be calculated from the solution of Equation (4.21).

3.3.2.3 TYPICAL RESPONSE SPECTRUM CURVES

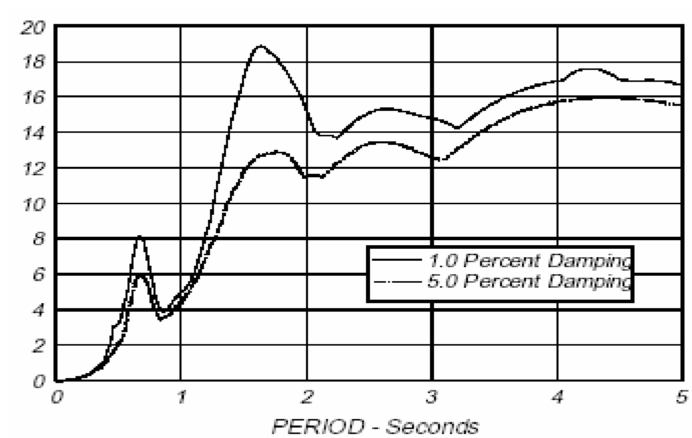
A ten second segment of the Loma Prieta earthquake motions, recorded on a soft site in the San Francisco Bay Area, is shown in Figure 4.1.For the earthquake motions given in Figure 3.4a, the response spectrum curves for displacement and pseudo-acceleration are summarized in Figure 3.5a and 3.5b



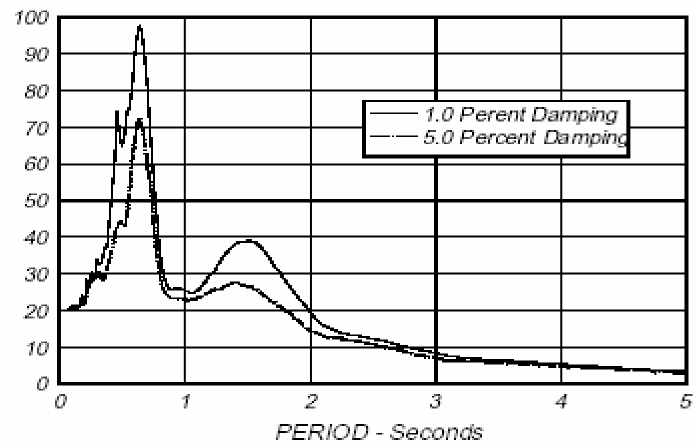
3.4a Typical Earthquake Ground Acceleration-Percent of Gravity



3.4b Typical Earthquake Ground Displacements – inches



3.5a Relative Displacement Spectrum $y(\omega)_{MAX}$ -inches



3.5b Pseudo-Acceleration Spectrum $\omega^2 y(\omega)_{MAX}$ - Percent of Gravity

3.3.3 MODAL PARTICIPATION FACTOR AND EFFECTIVE MASS

A common structural analysis procedure is to analyze a structure to predict responses that will occur during a sinusoidal or random vibration. The response analyses are often performed in two stages: a modal analysis to determine the eigenvalues and eigenvectors "cantilevered". The result of the modal analysis, does not give a sufficiently clear indication of which modes will be important contributors in the subsequent frequency response analysis.

By using the eigenvector data obtained in the normal mode analysis, modal participation factors (MPF's) and effective masses (EM's) can be calculated which do give a clear indication of the relative importance of each mode in terms of its response to any base motion input. These factors, like the generalized mass or stiffness are a property of the structure. In addition, however, they are also a property of the form of the base acceleration.

3.3.4 METHOD OF MODAL COMBINATION

3.3.4.1 SUM OF THE ABSOLUTE OF MODAL RESPONSE

The most conservative method that is used to estimate a peak value of displacement or force within a structure is to use the sum of the absolute of the modal response values. This approach assumes that the maximum modal values, or all modes, occur at the same point in time.

$$F = \Sigma f_c \qquad 3.22$$

3.3.4.2 SQUARE ROOT OF THE SUM OF THE SQUARES

Another very common approach is to use the Square Root of the Sum of the Squares, SRSS, on the maximum modal values in order to estimate the values of displacement or forces. The SRSS method assumes that all of the maximum modal values are statistically independent. For three-dimensional structures, in which a large number of frequencies are almost identical, this assumption is not justified.

$$F = \sqrt{\sum_{n} (f_n)^2} \qquad 3.23$$

3.3.4.3COMPLETE QUADRATIC COMBINATION

CQC, is relatively new method of modal combination. CQC, method was first published in 1981. It is based on random vibration theories and has found wide acceptance by most engineers and has been incorporated as an option in most modern computer programs for seismic analysis.

The peak response quantity (F) of a typical force can be estimated, from the maximum modal values, by the CQC method with the application of the following double summation equation:

$$F = \sqrt{\sum_{n} \sum_{m} f_n \rho_{nm} f_m} \qquad 3.24$$

Where,

n,m = Number of modes being considered

ρ_{nm} = Cross modal coefficient

f_n = Response quantity in mode n

f_m = Response quantity in mode m

$$\rho_{nm} = \frac{8\zeta^2 (1+\beta)\beta^{1.5}}{(1+\beta^2)^2 + 4\zeta^2 \beta (1+\beta)^2}$$

β = Frequency ratio

CHAPTER 4

FINITE ELEMENT MODELING: THEORETICAL ASPECTS

4.1 GENERAL

Finite element method is a powerful tool in structural analysis of simple to complicated geometries. In recent years with the coming of fast computers the job of performing finite element analysis of a complicated geometry has become easy. ANSYS 8.0 is one of the powerful software tools for finite element analysis. Any complicated geometry can be analyzed easily using ANYS 8.0. This chapter describes the finite elements and techniques used to model and study the behavior of raft and soil mass.

4.2 ELEMENTS USED FOR THE MODELLING

4.2.1 SOLID ELEMENT

Solid elements enable the solution of structural problems involving general three-dimensional stresses. There is a class of problems such as stress distribution in concrete dams, soil and rock strata where finite element analysis using solid elements provides a powerful tool.

4.2.1.1 THEORETICAL BASIS

The solid element used in ANSYS is of eight nodded isoperimetric types. These elements have three translations degrees-of-freedom per node.

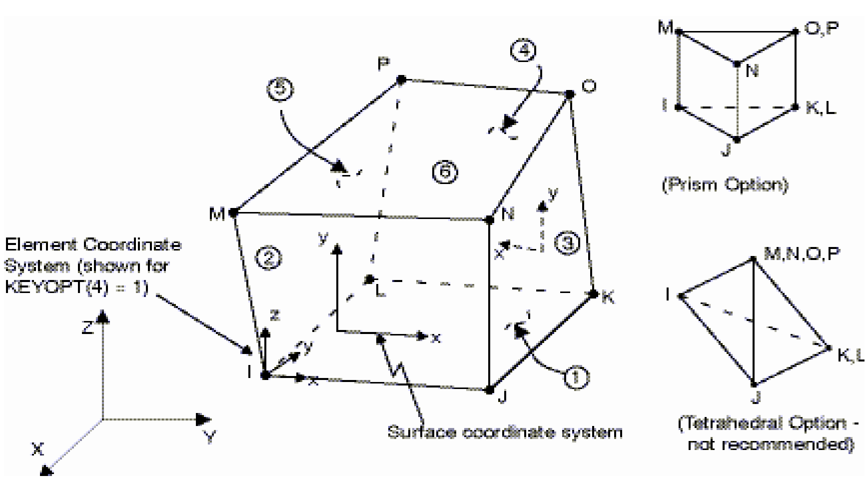


Figure 4.1 8-noded solid element

4.2.1.2 LOCAL COORDINATE SYSTEM

The local coordinate system used in solid element is the same as the global system as shown below:

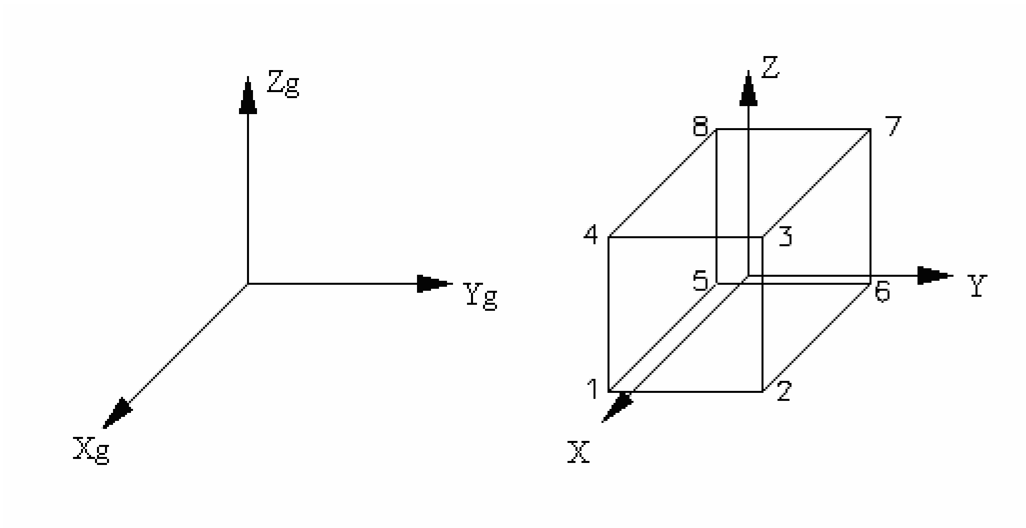


Figure 4.2 Local Coordinate System for solid element

4.2.1.3 PROPERTIES AND CONSTANTS

Unlike members and shell (plate) elements, no properties are required for solid elements. However, the constants such as modulus of elasticity and Poisson's ratio are to be specified.

Also, Density needs to be provided if self-weight is included in any load case.

4.2.1.4 OUTPUT OF ELEMENT STRESSES

Element stresses may be obtained at the center and at the joints of the solid element. The items that are printed are:

- Normal Stresses: SXX, SYY and SZZ
- Shear Stresses : SXY, SYZ and SZX
- Principal stresses: S1, S2 and S3.

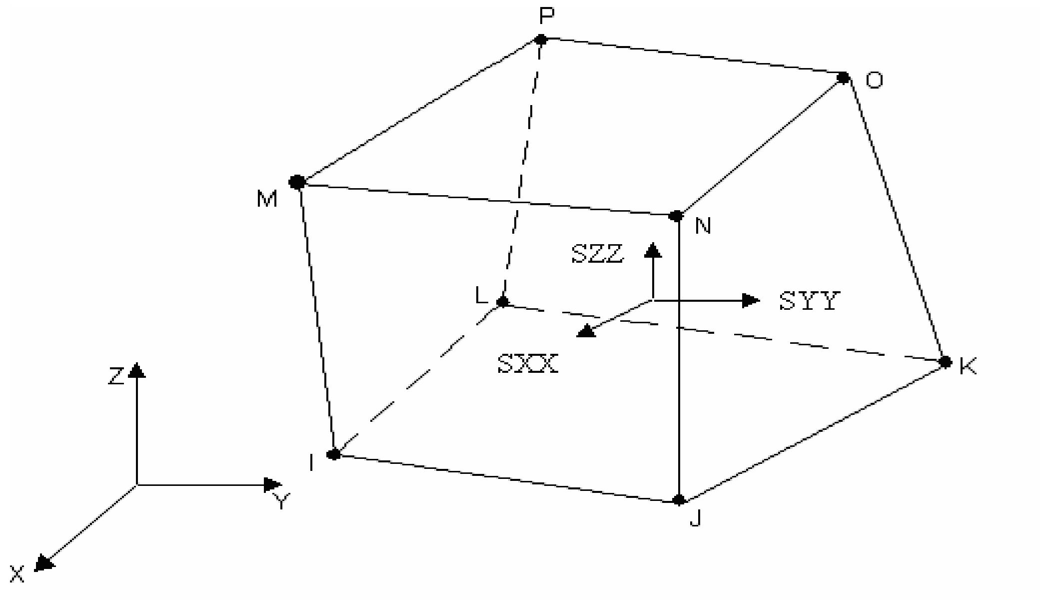


Figure 4.3 Stress output for solid element

4.2.1.5 SPECIAL FEATURES

Special features of the solid element are

- Plasticity
- Creep
- Large deflection
- Large strain

4.2.2 SHELL ELEMENT

"Surface structures" such as walls, slabs, plates and shells may be modeled using shell element. Shell element has both bending and membrane capabilities.

4.2.2.1 THEORETICAL BASIS

The shell element used in ANSYS is of four nodded isoperimetric types. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

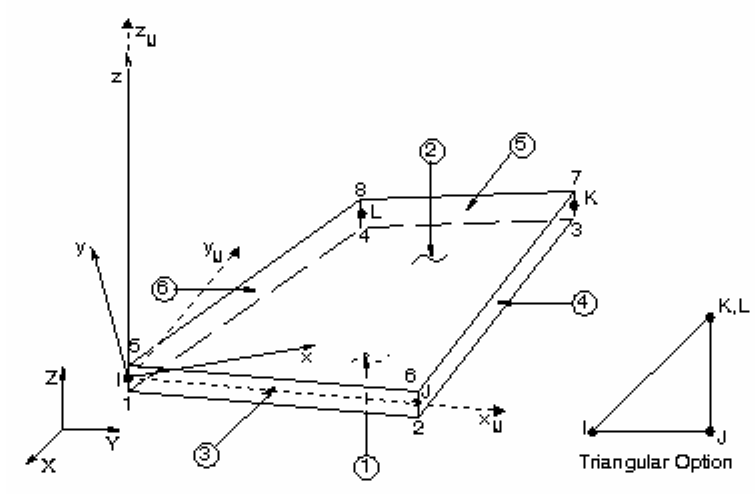


Figure 4.4 4-noded shell element

4.2.2.2 PROPERTIES AND CONSTANTS

Material properties required for shell elements are such as modulus of elasticity, Poisson's ratio and density to be specified. Constant such as thickness of the element at the all four node is to be specified.

4.2.2.3 OUTPUT OF ELEMENT STRESSES

Element stresses may be obtained at the center and at the joints of the shell element. The items that are printed are:

- Combined Membrane and Bending stresses: SXX, SYY, SXY
- Principal stresses: S1, S2 and S3.

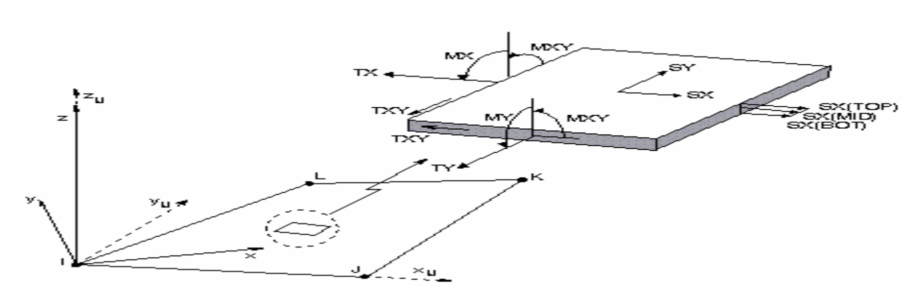


Figure 4.5 Stress output for shell element

4.2.2.4 SPECIAL FEATURES

Special features of the shell element are

- Stress stiffening
- Large deflection

4.2.3 BEAM ELEMENT

The beam element is assumed to be straight 2 node element of constant doubly symmetric cross-section. Beam is a uniaxial element with tension, compression, torsion, and bending capabilities.

4.2.3.1 THEORETICAL BASIS

The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

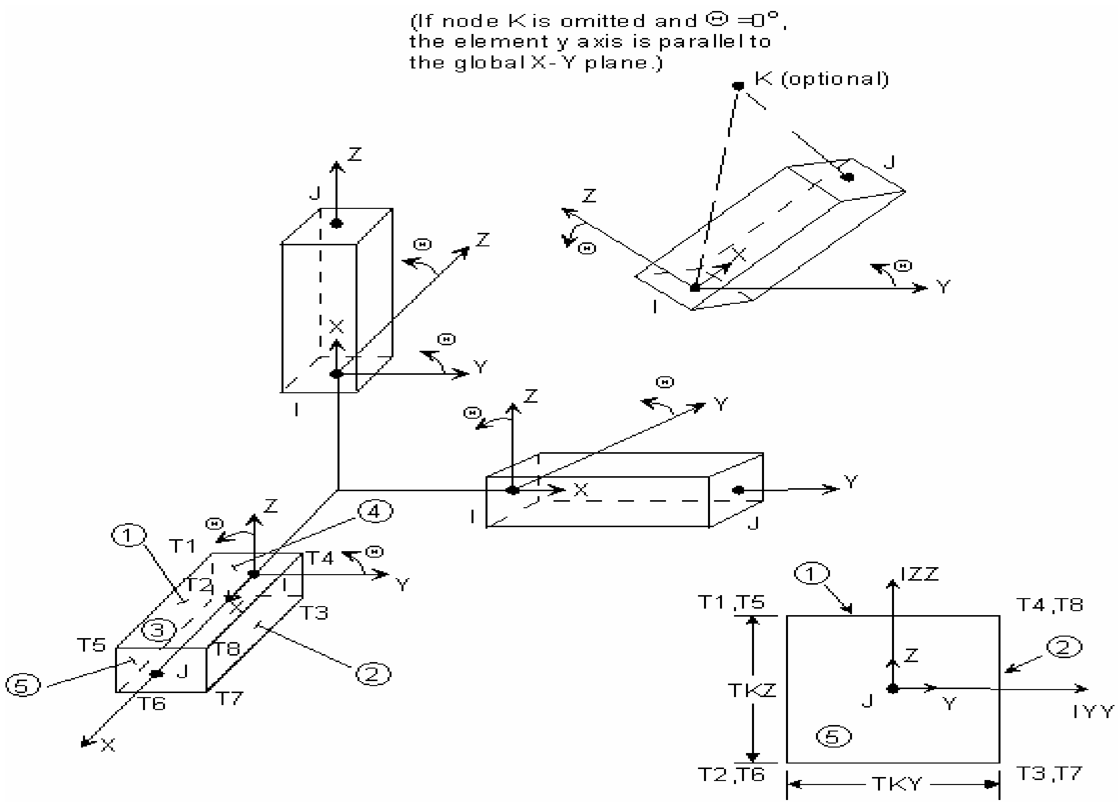


Figure 4.6 Beam element

4.2.3.2 PROPERTIES AND CONSTANTS

Material properties required for beam elements are such as modulus of elasticity, Poisson's ratio and density to be specified. Constant such as cross section, area and moment of inertia of the element is to be specified.

4.2.3.3 OUTPUT OF ELEMENT STRESSES

Element stresses may be obtained at the joints of the beam element. The maximum stress is computed as the direct stress plus the absolute values of both bending stresses. The minimum stress is the direct stress minus the absolute value of both bending stresses. The items that are printed are:

- SDIR : Axial direct stress
- SB : Bending stress on the element

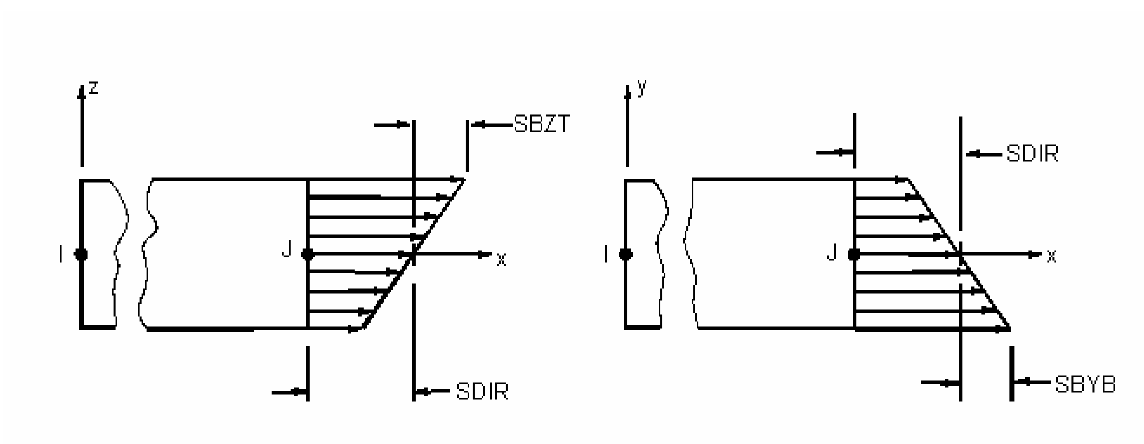


Figure 4.7 Stress output for Beam element

4.2.3.4 SPECIAL FEATURES

Special features of the beam element are

- Stress stiffening
- Large deflection

CHAPTER 5

EIGEN VALUE ANALYSIS OF AN ANTENNA SUPPORTING SYSTEM

5.1 BACK GROUND OF STUDY

In this piece of work, an attempt was made to study the given structure in its totality particularly in the dynamic analysis domain. As per the instructions, IIT-R, the theoretical approach suggested study was carried out for elements of the structure in the component approach and then takes all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario. This whole scenario of predicting the natural frequency of the entire system by incorporating the flexibility of a large volume of soil mass is termed as holistic approach in determining the natural frequencies of the entire structural system. First few modes are the high-energy modes, which are having maximum amplitude and our study is particularly from the point of view of bending, compression and torsion modes.

5.2 ANTENNA SUPPORTING STRUCTURE

5.2.1 GEOMETRY OF AN ANTENNA SUPPORTING STRUCTURE

The height of an earth-station antenna supporting structure is 45 m. A typical supporting structure for an 7.1 m diameter earth-station antenna is in the form of a RCC G+15 storey building frame topology from standard SP-22(S & T)-1982 problem resting on a raft slab is shown fig.5.1. The dimension of the building frame is 4 @ 7.5 m = 30 m x 3 @ 7.5 m = 22.5 m in plan. The height of the supporting frame is 15 @ 3.0 m = 45 m.

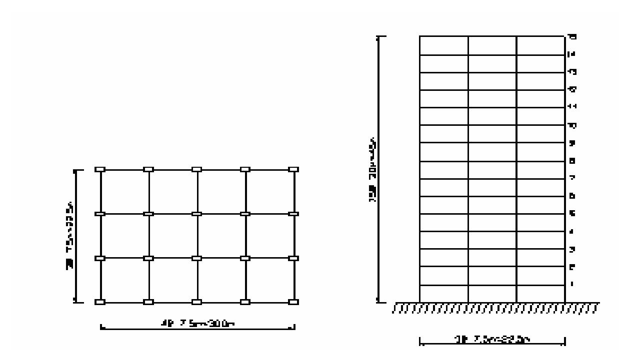


Figure 5.1 Plan and Elevation of an antenna supporting structure

5.2.2 MATERIAL PROPERTIES

The material properties considered for an antenna supporting structure are

- Elastic modulus of concrete = 2.5E+007 KN/m^2
- Mass density of concrete = 2.5 $KN.sec^2/m^4$.
- Poisson's ratio = 0.17

5.2.3 MODELING OF AN ANTENNA SUPPORTING STRUCTURE
5.2.3.1 STAAD PRO-2003 MODELING

Staad Pro-2003 was used to generate the mathematical model of the supporting structure. The total model was generated using the advantage of symmetry by the software.

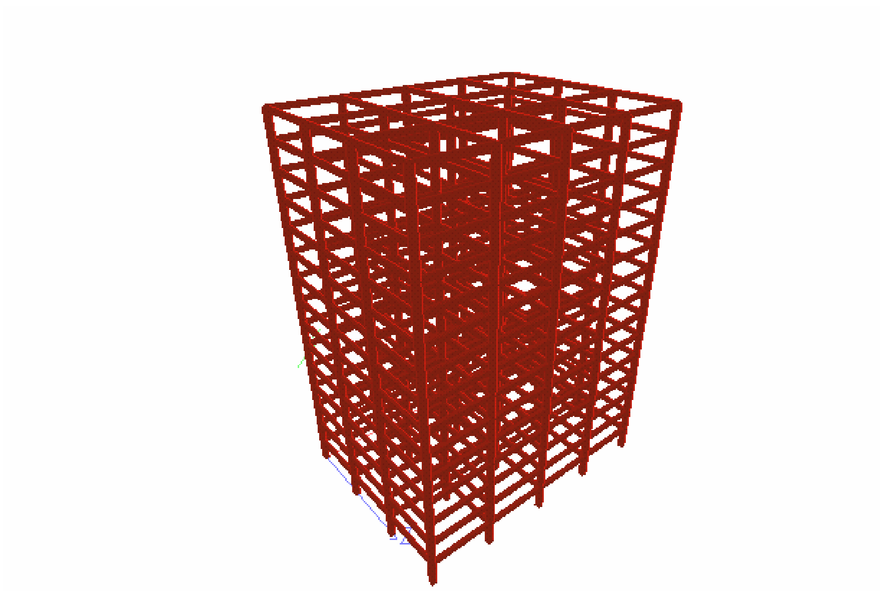


Figure 5.2 3-D modeling of an antenna supporting structure in Staad-pro2003

5.2.3.2 BOUNDARY CONDITION

In this analysis all the nodes at the base are fixed against movement in x, y and z directions.

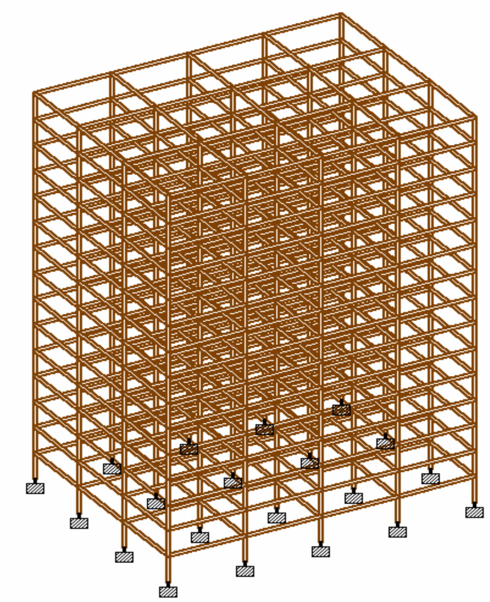


Figure 5.3 Antenna supporting structure with fixed base boundary conditions

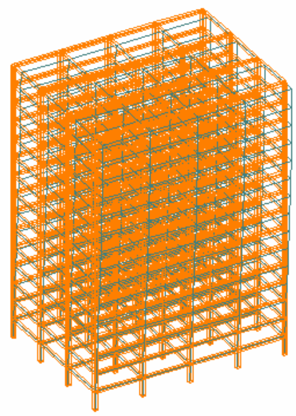
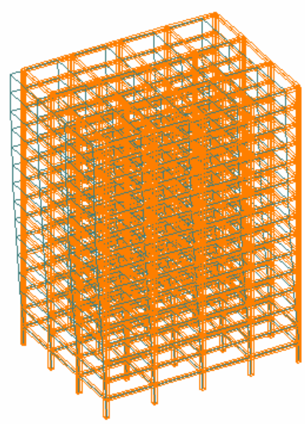
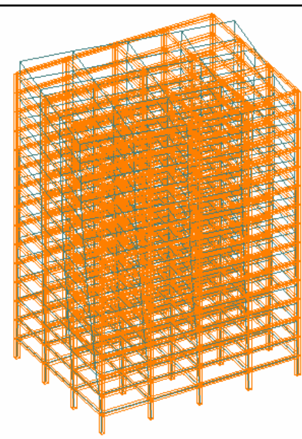
5.2.4 AN EIGEN VALUE ANALYSIS OF SUPERSTRUCTURE
5.2.4.1 FREE VIBRATION ANALYSIS

Free vibration analysis was carried out on an earth-station antenna supporting structure of G+15 storey RCC building frame using subspace iteration method. From the analysis the fundamental frequency of this model is observed as 1.072 Hz , which is almost identical to standard frequency results from SP-22. Table 5.1 shows the frequency results from SP-22 and Table 5.2 shows the frequency results and mode shape from Staad pro.2003.

TABLE 5.1
Standard frequency results from SP-22[1982]

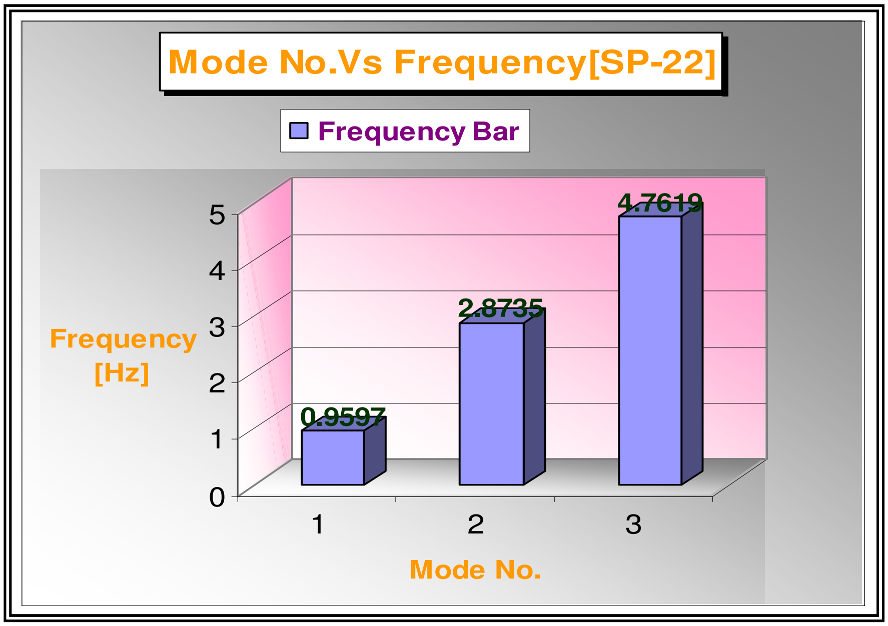
Mode No.	Frequency [Hz]	Period [sec]
1	0.9597	1.042
2	2.8735	0.348
3	4.7619	0.210

TABLE 5.2
Modes and mode shapes of an antenna supporting structure from Staad pro2003

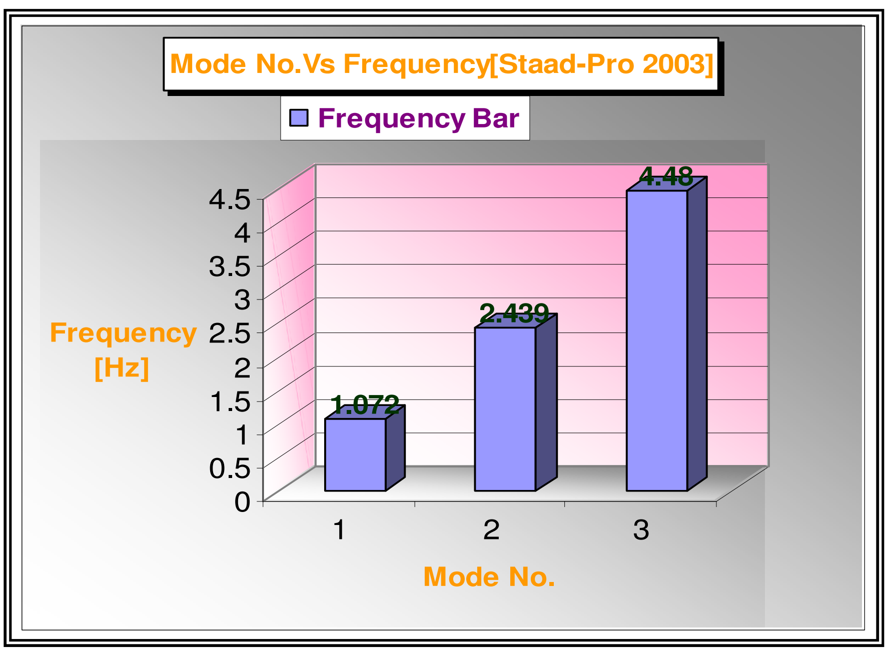
Mode No.	Frequency [Hz]	Mode Shape	Mode of vibration
1	1.072		Z-direction
2	2.439		X-direction
3	4.480		Torsion

5.2.5 COMPARATIVE STUDY OF FREQUENCY RESULTS

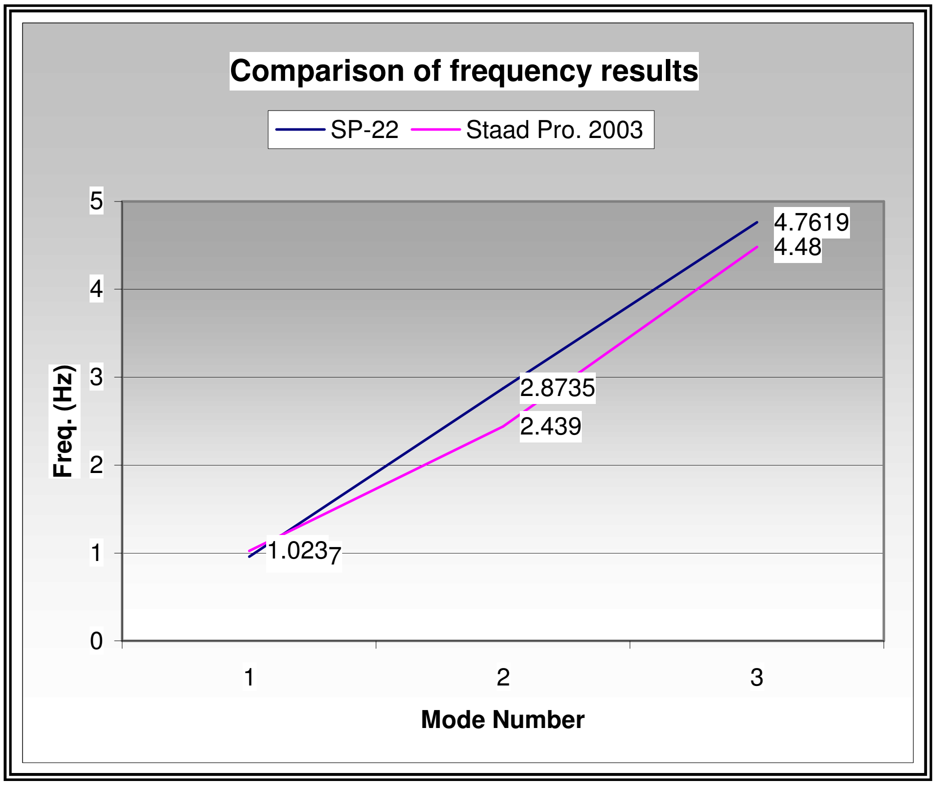
Comparison between the SP-22 frequency result and Staad.Pro2003 frequency result has been given below with the help of graphical presentation. Plot 5.1 – 5.2 shows the frequency Vs mode no. for two different sources of results and comparison for the same is given by plot 5.3..



Plot-5.1 Frequency Vs Mode No. [SP-22]



Plot-5.2 Frequency Vs Mode No. [Staad-Pro 2003]



Plot-5.3 Comparison of Frequency Results

5.3 RAFT

The role of a typical raft foundation is to transmit the load coming from the superstructure to the soil beneath without causing distress to any of the components of the superstructure or foundation. Generally, the raft is analyzed by the conventional method in which it is assumed to be rigid, resulting in uniform and linearly varying contact pressure distribution depending on whether the raft supports symmetric or eccentric loads. Thus, soil-structure interaction is an important aspect in the process of predicting overall structural response. Size of the raft is decided from the conversion and frequency criteria.

5.3.1 FINITE ELEMENT MODELING OF RAFT

The raft was modeled using 8-noded brick element. The element was assumed to be isotropic. The size of element was taken similar throughout the modeling. Figure 4.4 shows the mathematical model of raft for 48m x 32m x 1m. .

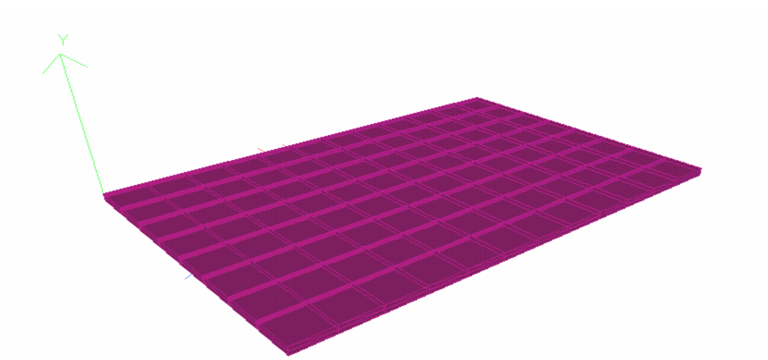


Figure 5.4 Finite Element Modeling of Raft

5.3.2 MATERIAL PROPERTIES

The material properties considered for raft are

- Elastic modulus of concrete = 2.5E+007 KN/m^2
- Mass Density of concrete = 2.5 KN.Sec^2 /m^4.
- Poisson's ratio = 0.17

5.3.3 BOUNDARY CONDITION

In order to get the most suitable model for analysis of holistic model, various boundary conditions were simulated from the realistic soil behavior point of view.

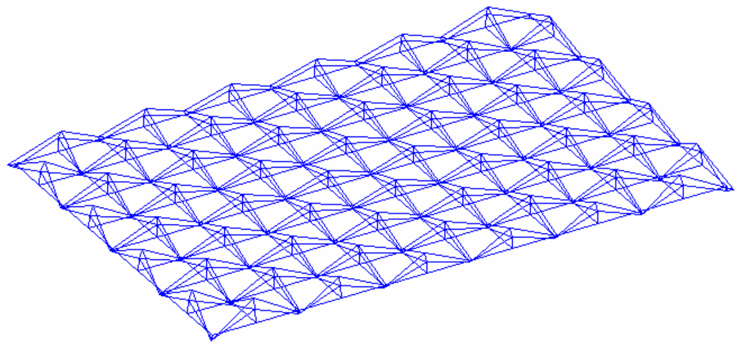
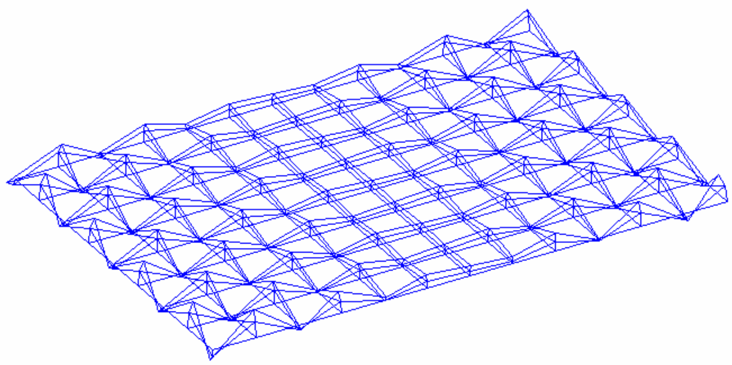
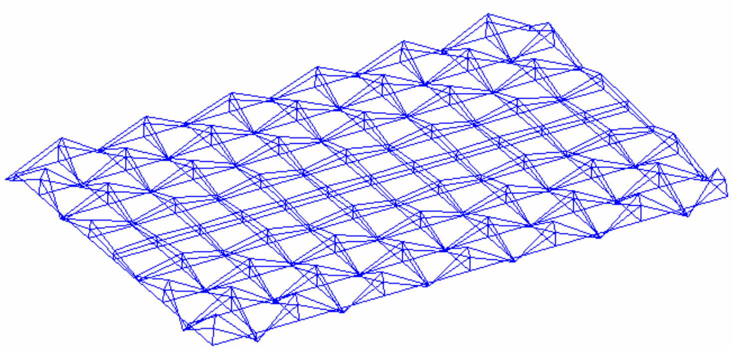
5.3.4 AN EIGEN VALUE ANALYSIS OF RAFT

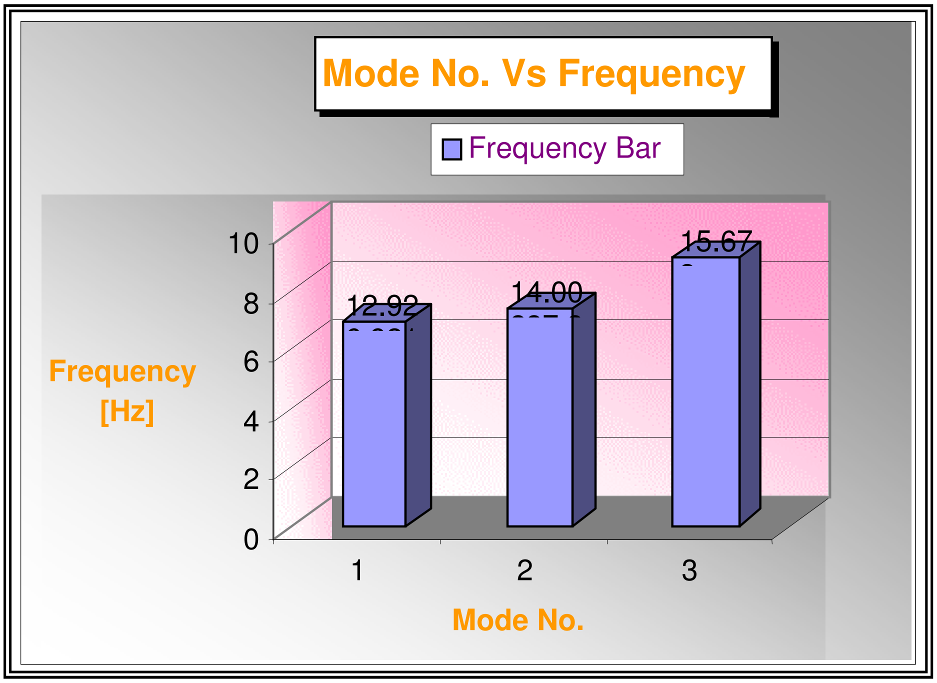
Free vibration analysis was carried out on the raft using subspace iteration method. From the analysis the fundamental frequency of selected model is observed as 12.92 Hz, which is more than the fundamental frequency of an antenna supporting structure. Modes and mode of vibration obtained from the analysis are given in Table 5.3 and 5.4.

TABLE 5.3
Frequency Results of Raft from Staad-pro2003

Boundary Condition Description	Mode No.	Frequency [Hz]	Time Period [sec]
All three translational D.O.F are constrained at the Base	1	12.92	0.0773
	2	14.0023	0.07141
	3	15.673	0.0638

TABLE 5.4
Modes and mode shapes of raft from Staad-pro2003

Mode No.	Frequency [Hz]	Mode Shape
1	12.92	
2	14.0023	
3	15.673	



Plot 5.4
Frequency Vs. Mode No. for Raft with all the three translational D.O.F are constrained at base

5.4 SOIL

Structural response of any structure depends on foundation support conditions and nature of soil below it. A structure always has finite dimensions and its mathematical model with number of degrees of freedom can always be constructed. The soil on the other hand is a semi-infinite medium, or an unbounded medium and construction of its mathematical model is quite difficult. Therefore the influence of subsoil on the dynamic response of the structure is to be properly accounted for to arrive at satisfactory results. The soil adjacent to the structure has considerable effect on the structure than the soil in the far field. The soil near the structure can be modeled with finite element idealization to consider the properties of soil and the soil boundaries at far field are to be constrained w.r.t all the translational D.O.F. From the conversion and frequency criteria size of the mathematical model of soil is decided as 78m X 36m X 48m.

5.4.1 FINITE ELEMENT MODELING OF SOIL

The soil adjacent to raft was modeled using 8-noded brick element. The element was assumed to be isotropic. The size of the element was taken similar throughout the modeling.

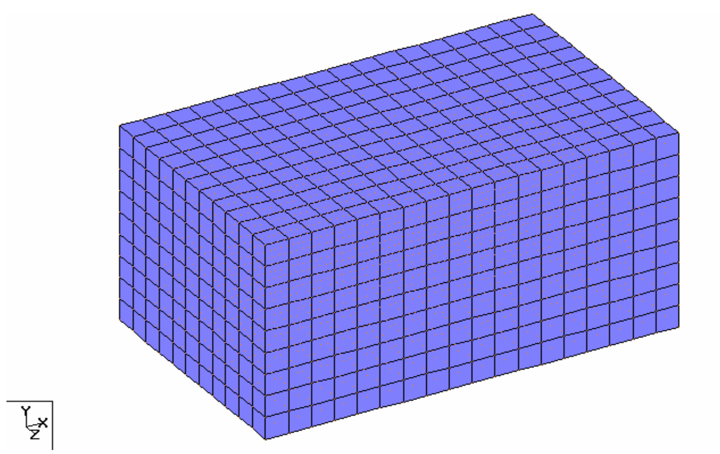


Figure 5.5 Finite Element Modeling of Soil Mass

5.4.2 MATERIAL PROPERTIES

The material properties considered for soil are

- Elastic modulus of concrete = 110319.3 KN/m^2
- Mass Density of concrete = 1.85 $KN.Sec^2 /m^4$.
- Poisson's ratio = 0.17

5.4.3 BOUNDRY CONDITIONS

As the supporting structure plan is rectangular in shape, the finite element model of soil mass was modeled as a solid rectangular. The outer vertical surface and base of the soil mass is restrained in X, Y and Z directions.

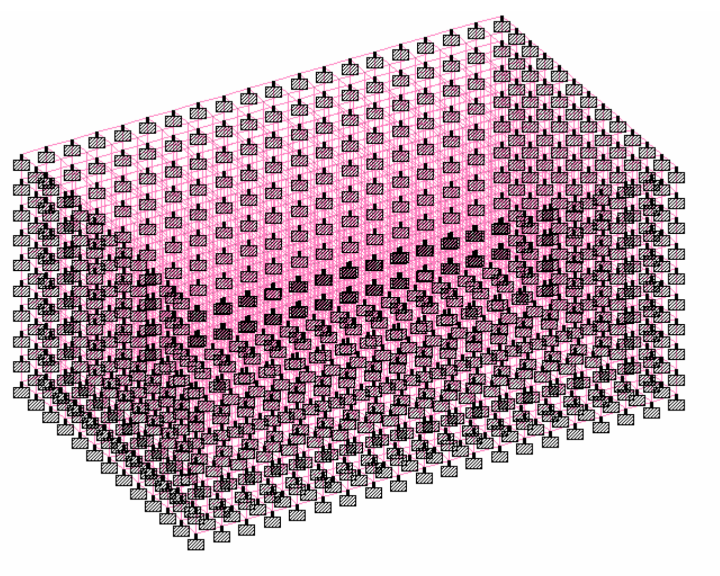


Figure 5.6 Boundary Condition for Finite Element Model of Soil Mass

5.4.4 PARAMETRIC STUDY

In order to get the most suitable model for analysis of holistic model, a parametric study has been carried out, by changing the size of the soil mass modeling, by changing the size of 8-noded brick solid element for different model to satisfy the convergence requirements of model, by considering the different values of shear wave velocity. Considering both frequency and convergence criteria, model with 2052 solid elements and 2600 nodes of size 76m x 48m x 36m is most suitable model as it has adequate value of frequency. As per the standard literature and interaction with IIT, Roorkee the fact dawned upon us for the size of soil mass to be modeled.

5.4.5 AN EIGEN VALUE ANALYSIS OF SOIL

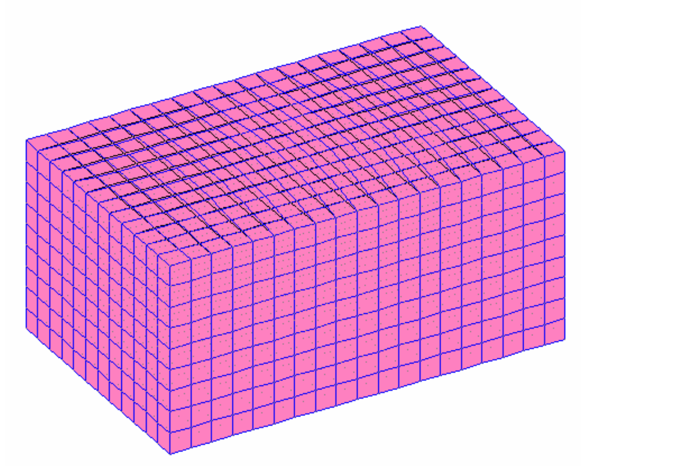
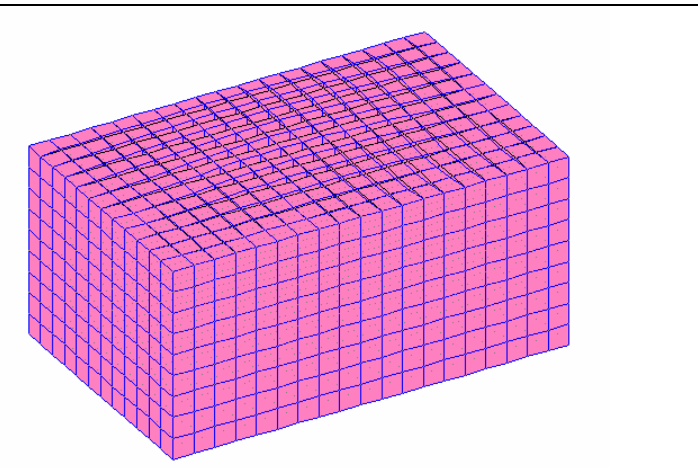
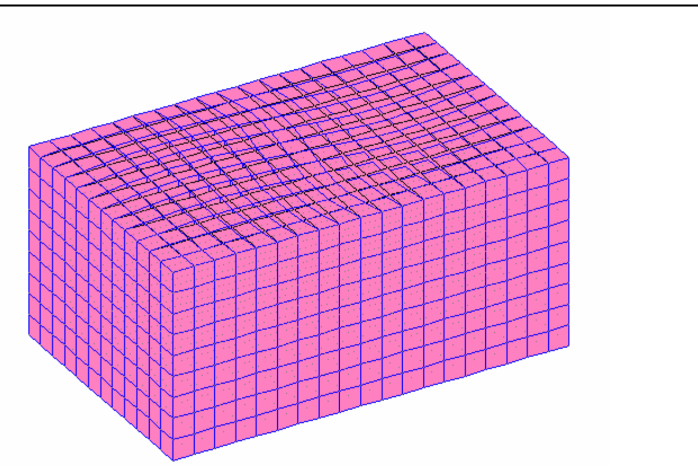
Free vibration analysis was carried out on the soil using subspace iteration method. From the analysis the fundamental frequency of selected model is observed as 3.24 Hz. Modes and mode of vibration obtained from the analysis are given in Table 5.5 and 5.6.

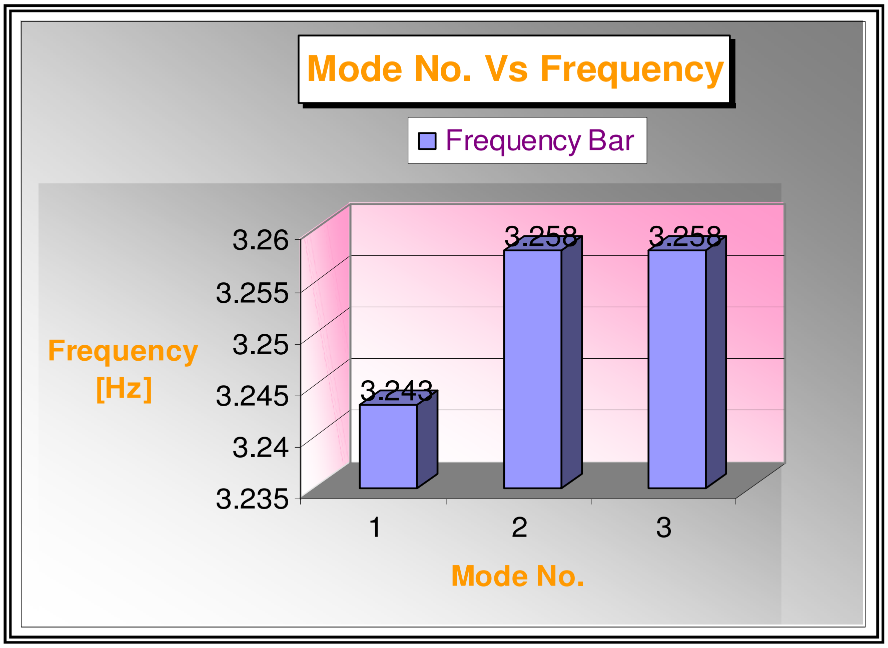
TABLE 5.5

Frequency Results of soil Staad-pro2003

Boundary Condition Description	Mode No.	Frequency [Hz]	Time Period [sec]
The outer vertical surface and base of the soil mass is restrained in X, Y and Z directions.	1	3.243	0.3083
	2	3.258	0.3069
	3	3.258	0.3069

TABLE 5.6
Modes and mode shapes of soil mass of size 76m x 48m x 36m [Shear Wave Velocity = 150 m/s] from Staad-pro2003

Mode No.	Frequency [Hz]	Mode Shape
1	3.243	
2	3.258	
3	3.258	



Plot 5.5
Frequency Vs. Mode No. for Soil Mass Model of Size 76mx48mx36m with Solid Element of Size 4mx4mx4m. [Shear Wave Velocity = 150m/s]

5.5 STRUCTURE AS A WHOLE: A HOLISTIC APPROACH

As per the instruction, IITR, the theoretical approach suggested was to study elements of the structure in the component approach and then take all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario. This whole scenario of predicting the natural frequency of the entire system by incorporating the flexibility of a large volume of soil mass is termed as holistic approach in determining the natural frequencies of the entire structural system. First few modes are the high-energy modes, which are having maximum amplitude and our study particularly from the point of view of bending, compression and torsional mode.

5.5.1` MODELING OF AN ANTENNA MASS

The mass of antenna is concentrated on a mass less beam at some distance above the G+15 storey RCC building top. The mass of antenna affects the behavior of supporting structure. An earth-station antenna has not been model but in order to consider the effect of antenna on supporting structure the 3D translation and rotational mass have been taken on a mass less beam

5.5.2 FINITE ELEMENT MODELING OF WHOLE STRUCTURE WITH SOIL MASS

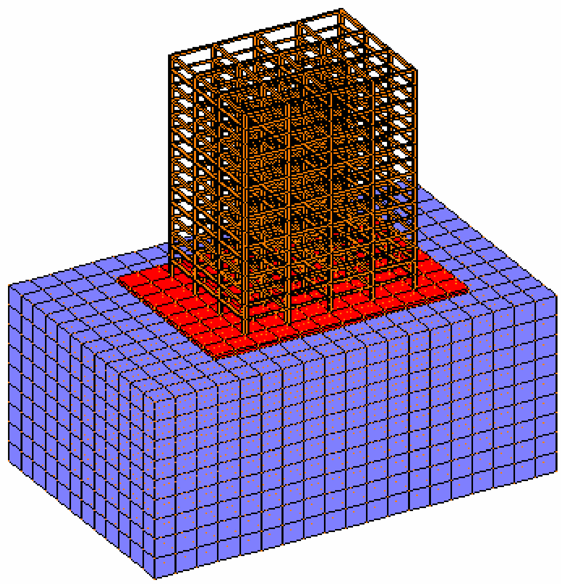


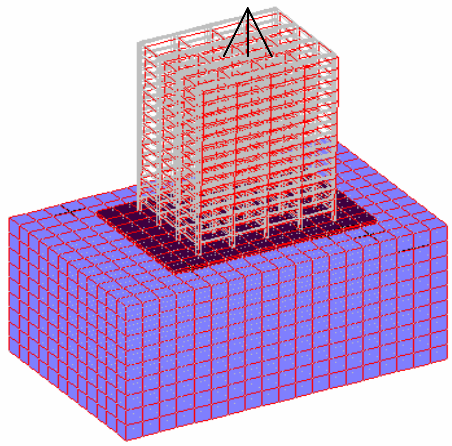
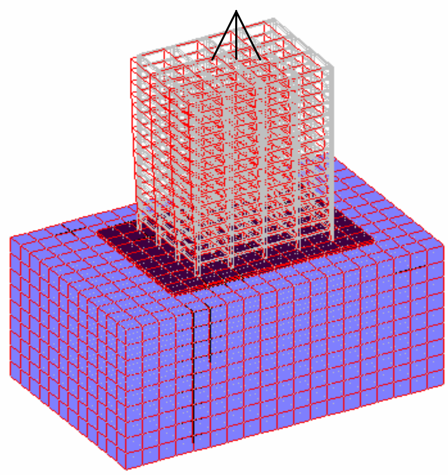
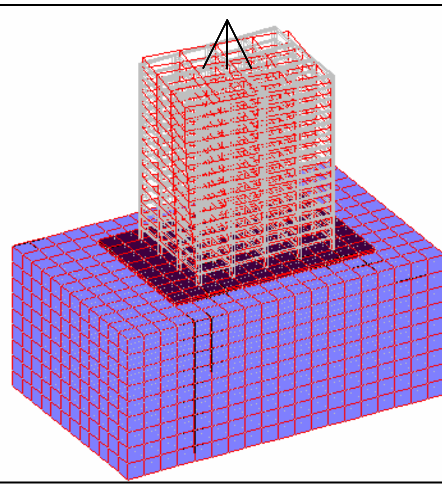
Figure 5.7 Finite Element Model of Supporting Structure with Soil Mass

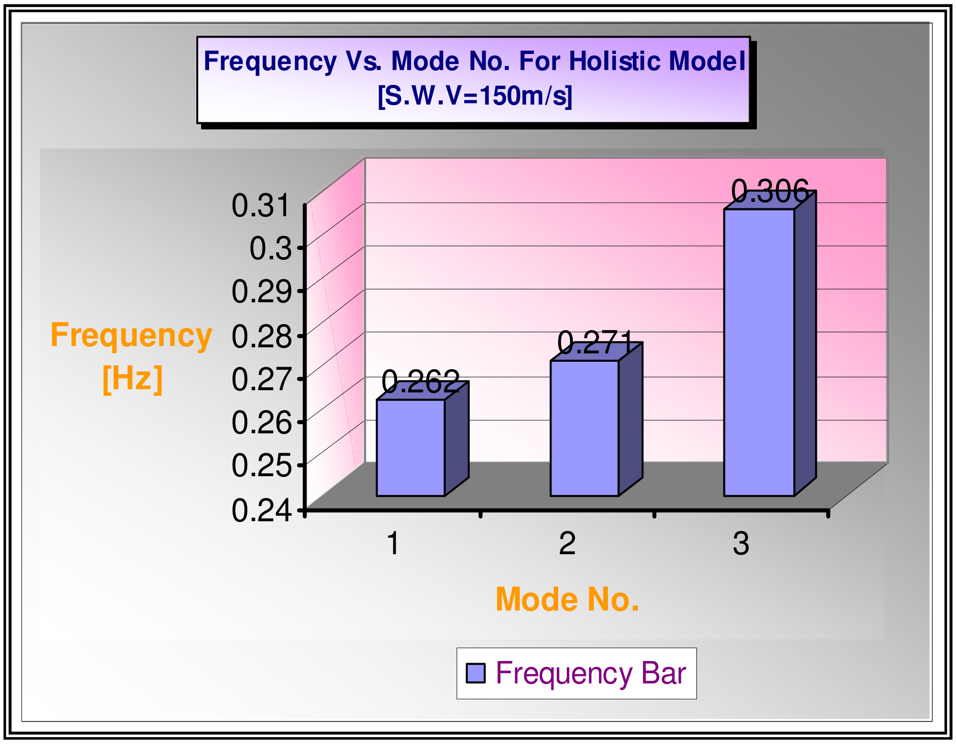
The soil adjacent to raft was modeled using 8-noded brick element. The element is assumed to be isotropic. The finite element model used for analysis is shown in figure 5.7. The size of the element is kept identical throughout the model.

5.5.3 AN EIGEN VALUE ANALYSIS OF HOLISTIC MODEL

Free vibration analysis was carried out on a holistic model. The results of frequency are shown in Table 5.7. The fundamental frequency for the holistic analysis is coming around 0.262 Hz which is almost 80% lower than the frequency of supporting structure.

TABLE 5.7
Frequency and Mode shapes of superstructure with antenna mass and soil mass

Mode No.	Frequency[Hz]	Mode Shape	Mode of Vibration
1	0.262		Z-direction
2	0.271		X-direction
3	0.306		Torsion



Plot 5.6 Frequency Vs Mode No. for Superstructure with antenna and soil mass

5.5.4 SUMMARY

When compared with the frequency of the SP-22 frame which was modeled without foundation, there is significant drop in the frequency of the total system, when antenna mass is also considered on the frame along with the foundation soil mass. In order to compare the lowest possible bound with the antenna servo frequency as well as lock rotor frequency, the lowest possible bound for the holistic model was estimated by considering the stiffness of soil and neglecting the mass density of soil mass. For a typical 10 tone antenna on the roof along with soil mass brought down the natural frequency of the RCC frame [SP-22 problem] from 0.9795 to 0.261.

CHAPTER 6

RESPONSE SPECTRUM ANALYSIS IN COMPONENT APPROACH

6.1 INTRODUCTION

In this piece of work, an attempt was made to study the given structure in its totality particularly in the dynamic analysis domain. As per the instructions, IIT-R, the theoretical approach suggested study was carried out for elements of the structure in the component approach and then takes all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario. In the previous chapter free vibration analysis results were given. Using free vibration analysis result response spectrum analysis has been carried out for the finding out the response in component approach as well as in holistic approach. For finding out the response two type of forcing functions are used. First one is spectrum given in IS: 1893 (Part 1) (2002) for hard soil and second one is the actual Bhuj earthquake data (N78^0 E: comp) recorded at Ahmedabad.

6.2 FORCING FUNCTION USED IN RESPONSE SPECTRUM ANALYSIS

6.2.1 SPECTRUM GIVEN IN IS: 1893 (PART 1) (2002) FOR HARD SOIL

Figure 6.1 shows the response spectrum given in IS : 1893 (Part 1)(2002) for hard soil which one was used for finding out the response in component approach and holistic approach.

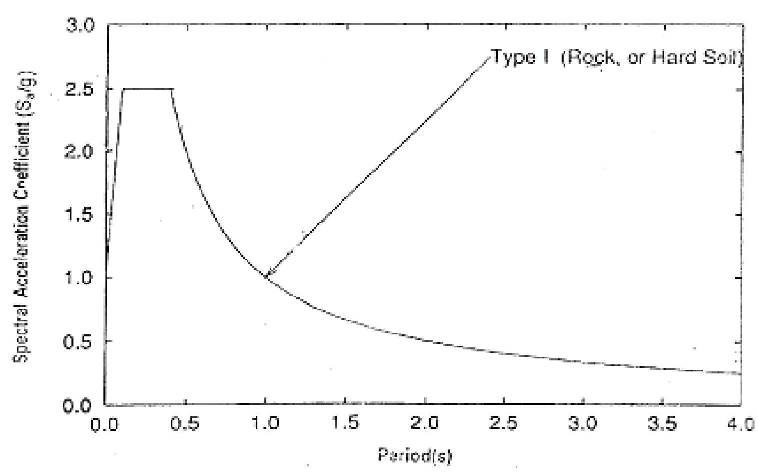


Figure 6.1 Response Spectrum given in IS : 1893 (Part 1)(2002) for hard soil

6.2.2 BHUJ EARTHQUAKE

A Mw 7.7 earthquake struck the Kachchh region of Gujarat state in western India at 8:46 a.m. in January 26,2001. This was the most damaging earthquake in the last fifty years in India. Figure 6.1 shows the corrected displacement time histories recorded at ahmedabad (comp : N78^0 E). Figure 6.2 shows the elastic response spectra for the three-recorded components of ground motion for 5 percent damping for the same component.

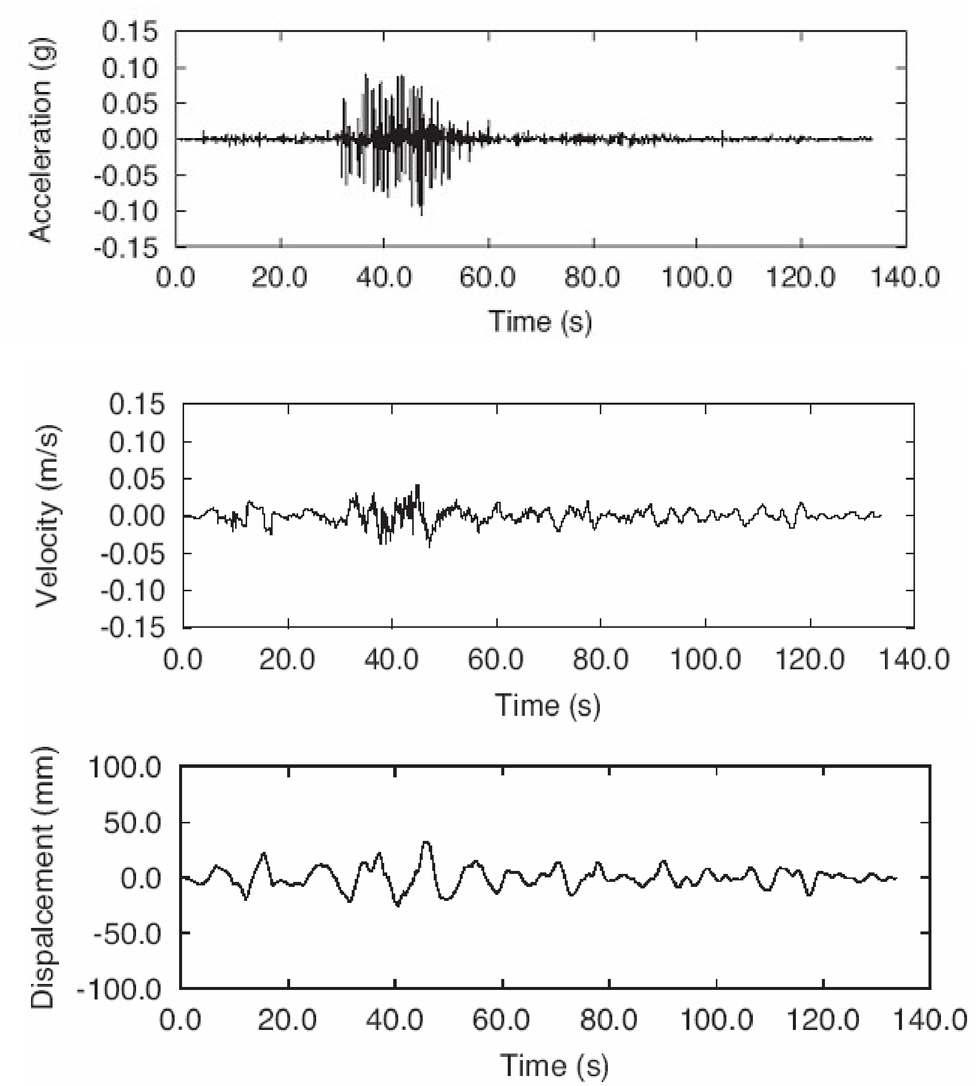


Figure. 6.2 Corrected acceleration and derived velocity and displacement Time histories recorded at Ahmedabad (comp : N78^0 E)

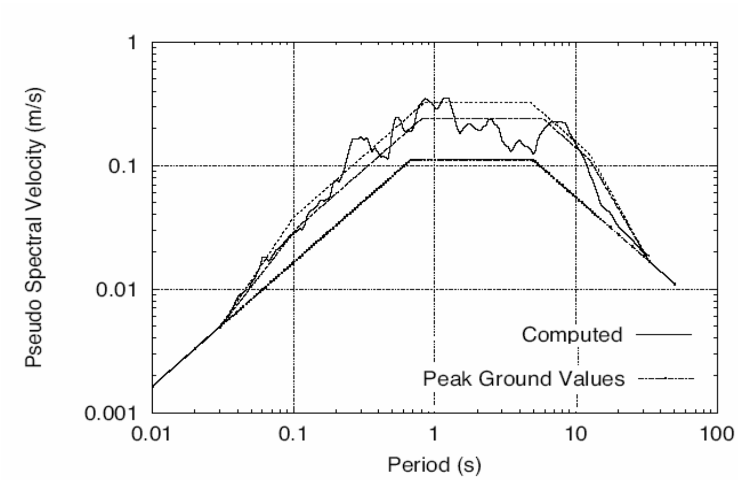


Figure 6.3 Response Spectrum for N78^0 E component (5% damping)

6.3 AN ANTENNA SUPPORTING STRUCTURE

6.3.1 MODAL ANALYSIS OF AN ANTENNA SUPPORTING STRUCTURE

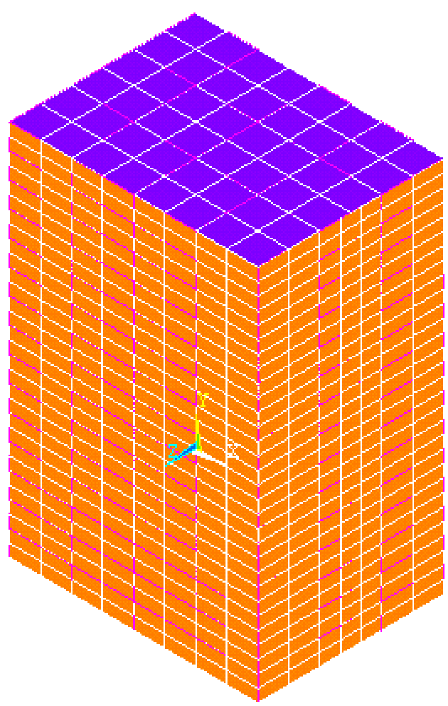
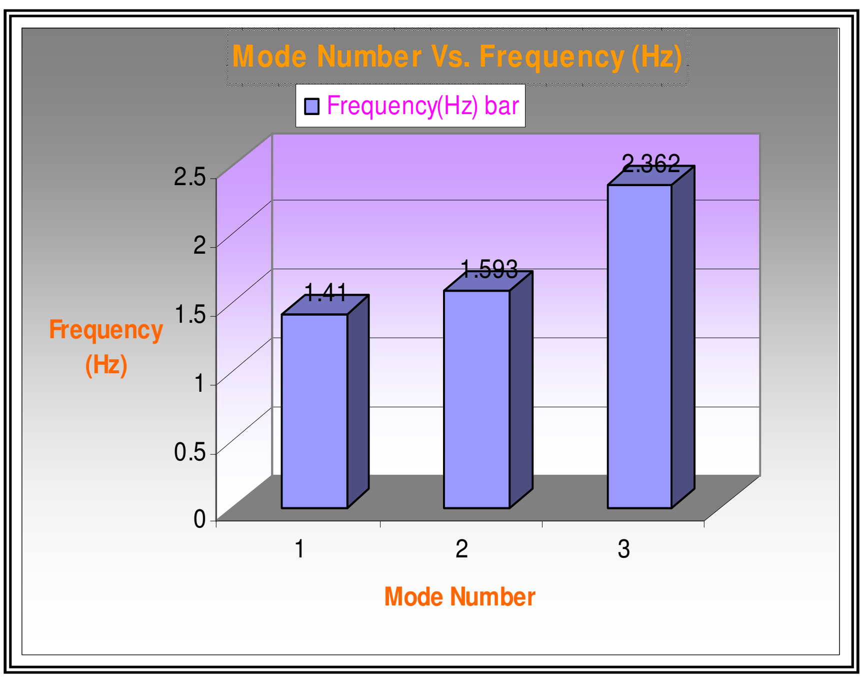


Figure 6.4 3-D Modeling of an antenna supporting structure without soil model in ANSYS 8.0

Geometry of an antenna supporting structure, material properties and boundary condition used in the modeling of an antenna supporting structure are kept same as explained in chapter 5. For finding out the response of an antenna support structure modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 1.41 Hz. Figure 6.4 shows the 3-d modeling of an antenna supporting structure without soil model in ANSYS 8.0. Table 6.1 shows the free vibration result of an antenna supporting structure. Plot 6.1 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

TABLE 6.1
Standard frequency results of
an antenna supporting frame from ANSYS 8.0

Mode No.	Frequency [Hz]	Period [sec]
1	1.410	0.709
2	1.593	0.628
3	2.362	0.423



Plot-6.1 Mode No. Vs. Frequency (Hz) for Frame [ANSYS 8.0]

6.3.2 RESPONSE SPECTRUM ANALYSIS OF AN ANTENNA SUPPORTING STRUCTURE

Using modal analysis result response spectrum analysis is carried out for spectrum given in IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method are used. Table 6.2 and Table 6.3 shows the maximum displacement at the top of an antenna supporting structure due to IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X-direction and Z–direction respectively. Plot 6.2 and plot 6.3 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for IS 1893 data given as forcing function in X-direction and Z-direction respectively. Plot 6.4 and plot 6.5 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for Bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 6.6 and plot 6.7 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to IS: 1893 data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 6.8 and 6.9 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to IS: 1893 data given as forcing function in z-direction for SRSS method and CQC method respectively. Plot 6.10 and 6.11 shows the response history plot for two different extreme nodeds at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 6.12 and 6.13 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in z-direction for SRSS method and CQC method respectively.

TABLE 6.2

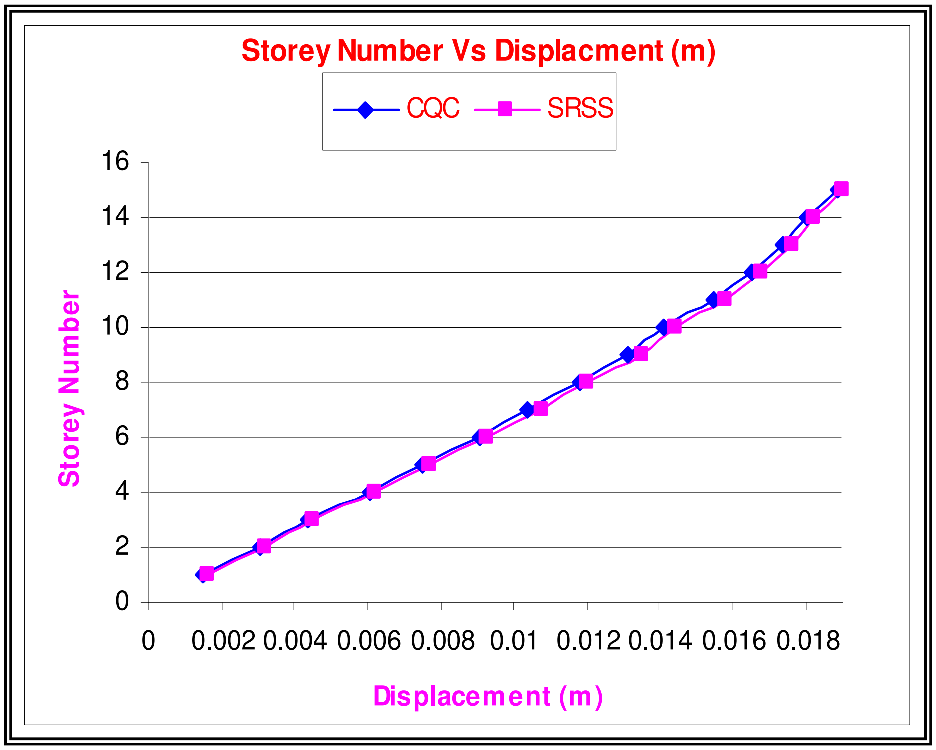
Maximum displacement result of an antenna supporting frame for forcing function given in X-direction

Data	Max. Displacement(m) at the top of an antenna supporting structure	
	SRSS Method	CQC Method
IS : 1893 Data	0.0189	0.0189
Bhuj Earthquake Data	0.0251	0.0251

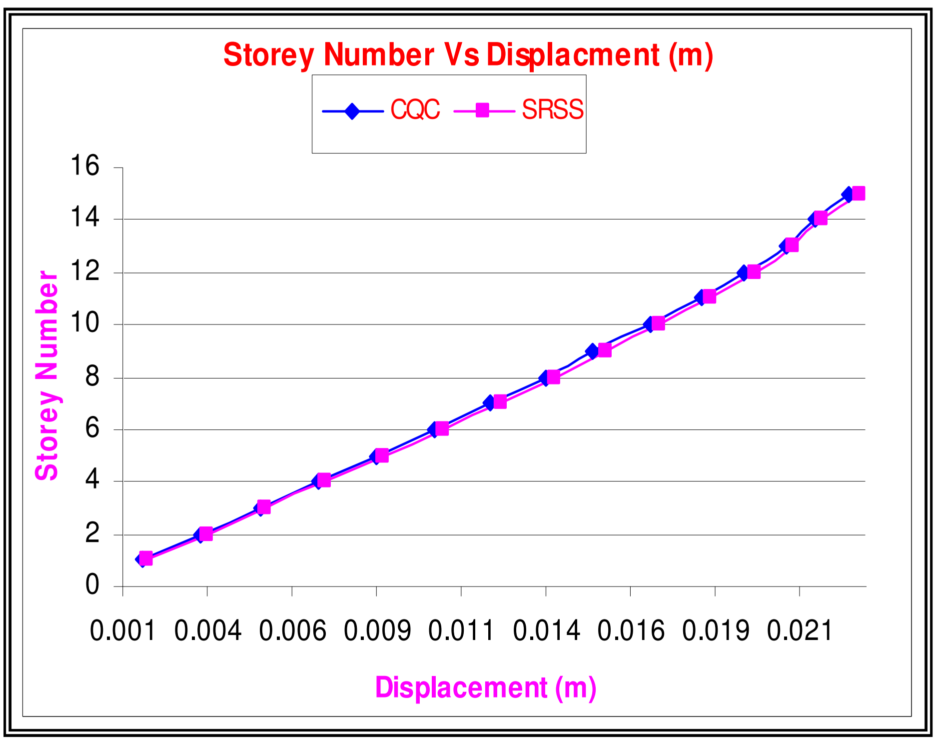
TABLE 6.3

Maximum displacement result of an antenna supporting frame for forcing function given in Z-direction

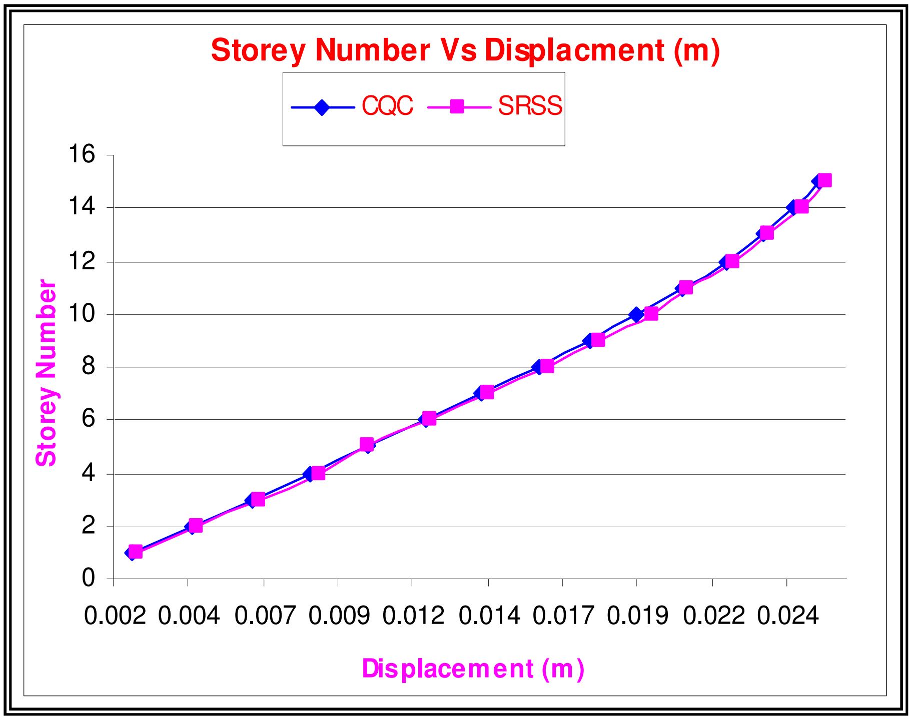
Data	Max. Displacement(m) at the top of an antenna supporting structure	
	SRSS Method	CQC Method
IS : 1893 Data	0.0226	0.0225
Bhuj Earthquake Data	0.0301	0.0299



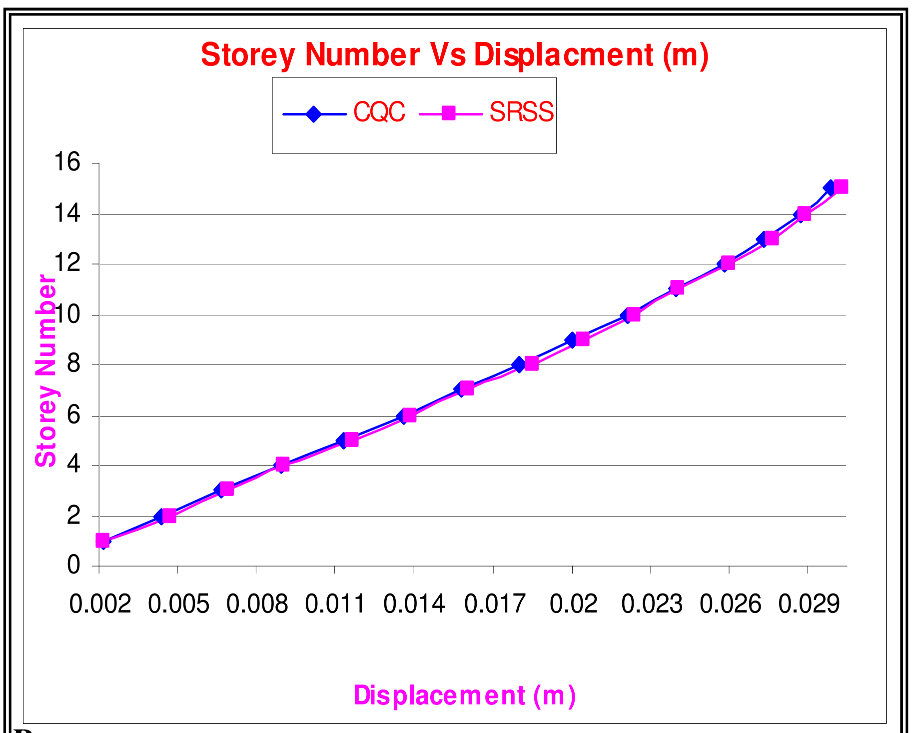
Plot-6.2 Storey Number Vs. Displacement (m) for IS : 1893 data in X-Direction for frame



Plot-6.3 Storey Number Vs. Displacement (m) for IS : 1893 data in Z-Direction for frame

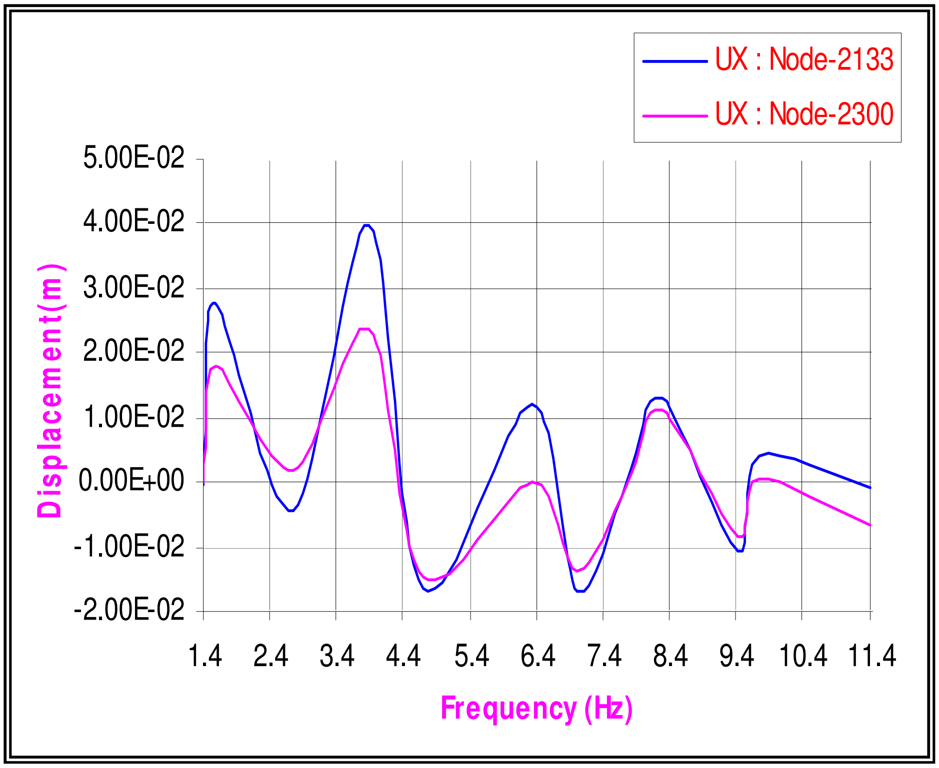


Plot-6.4 Storey Number Vs. Displacement (m) for Bhuj E.Q data in X-Direction for frame

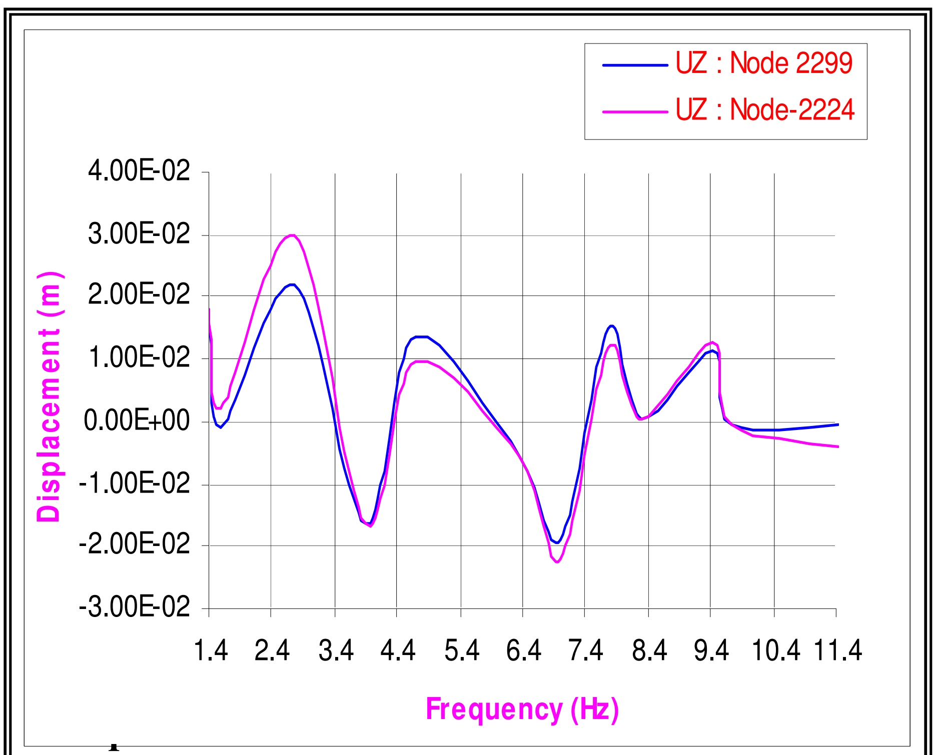


P

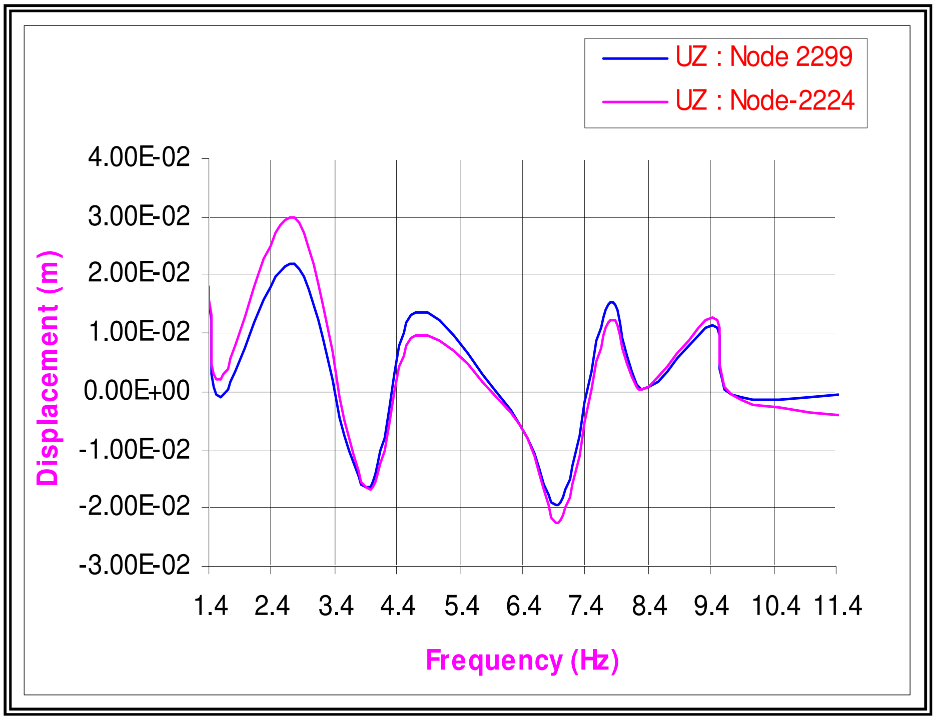
lot-6.5 Storey Number Vs. Displacement (m) for Bhuj E.Q data in Z-Direction for frame



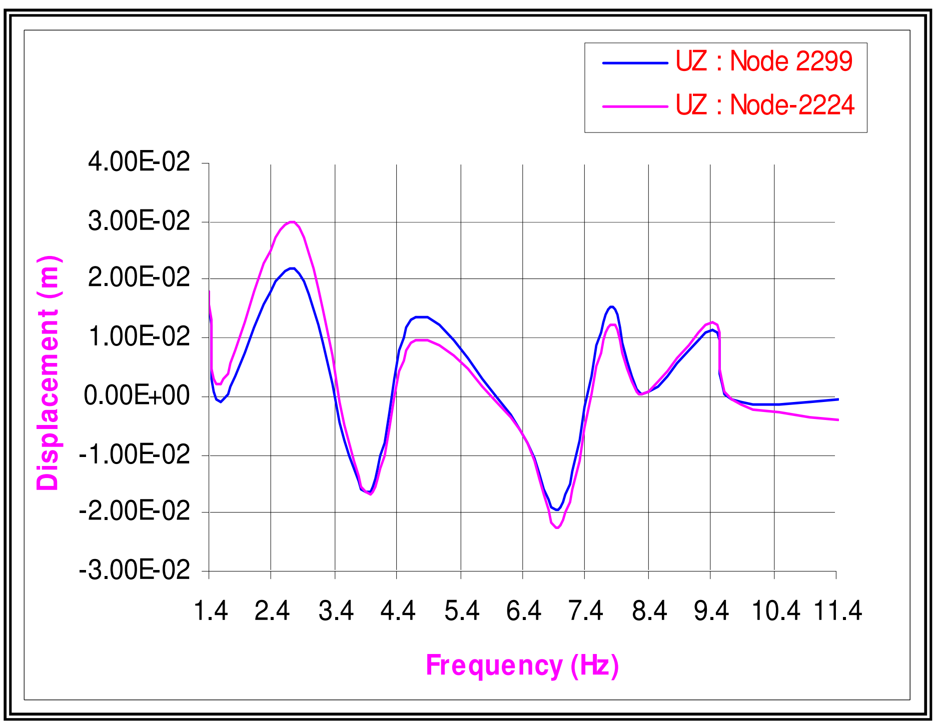
Plot-6.6 Time history plot for SRSS method for IS: 1893 data in X-Direction for frame



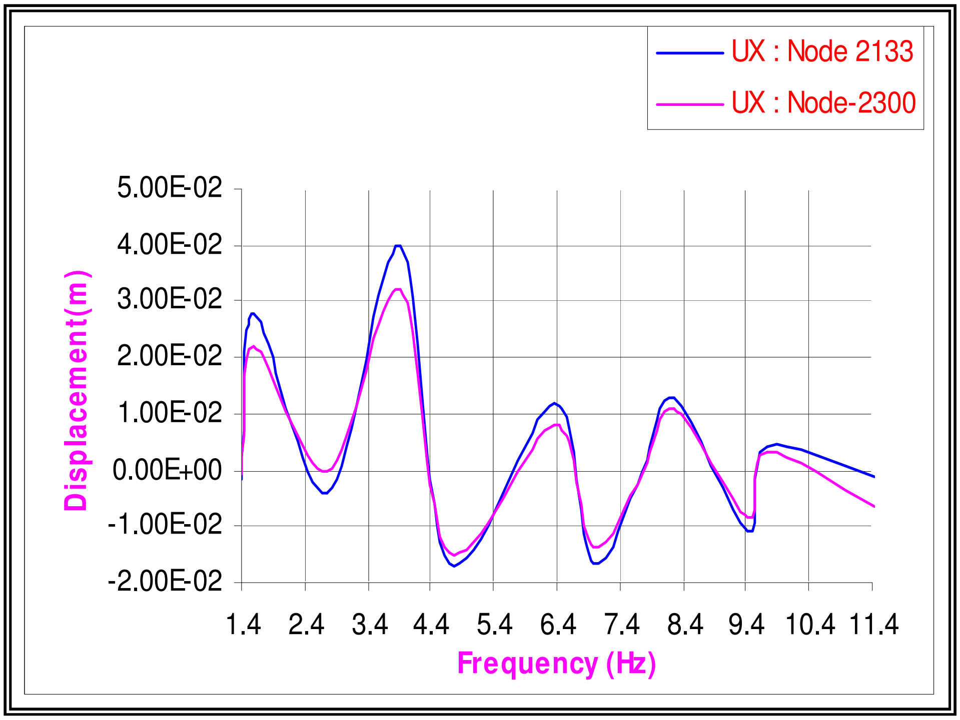
Plot-6.7 Time history plot for CQC method for IS: 1893 data in X-Direction for frame



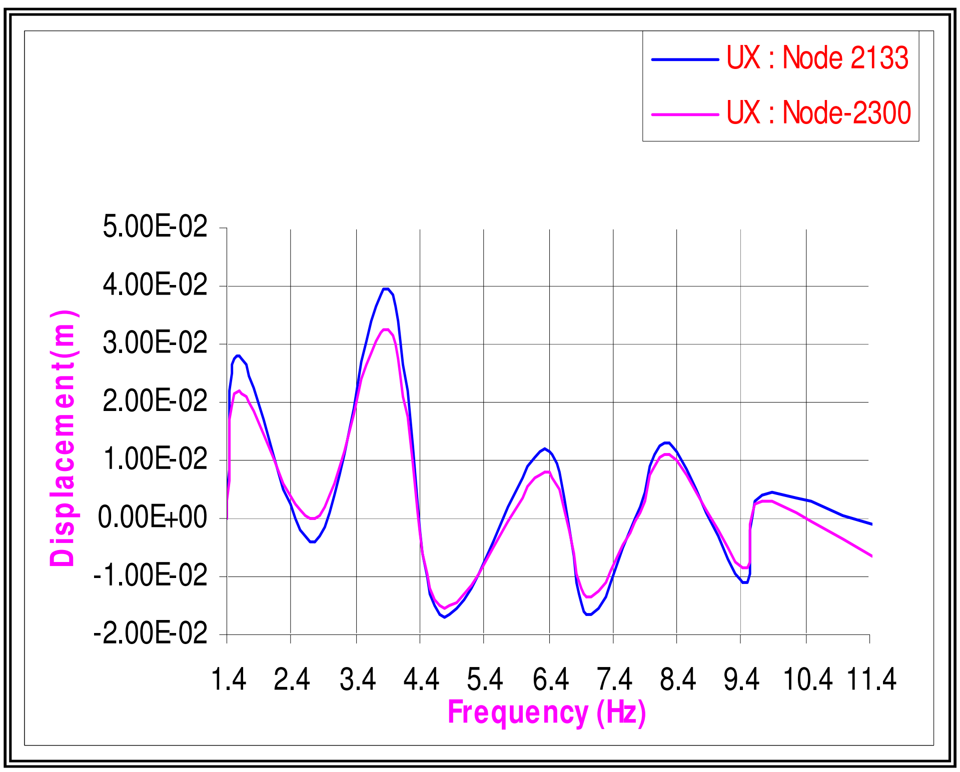
Plot-6.8 Time history plot for SRSS method for IS: 1893 data in Z-Direction for frame



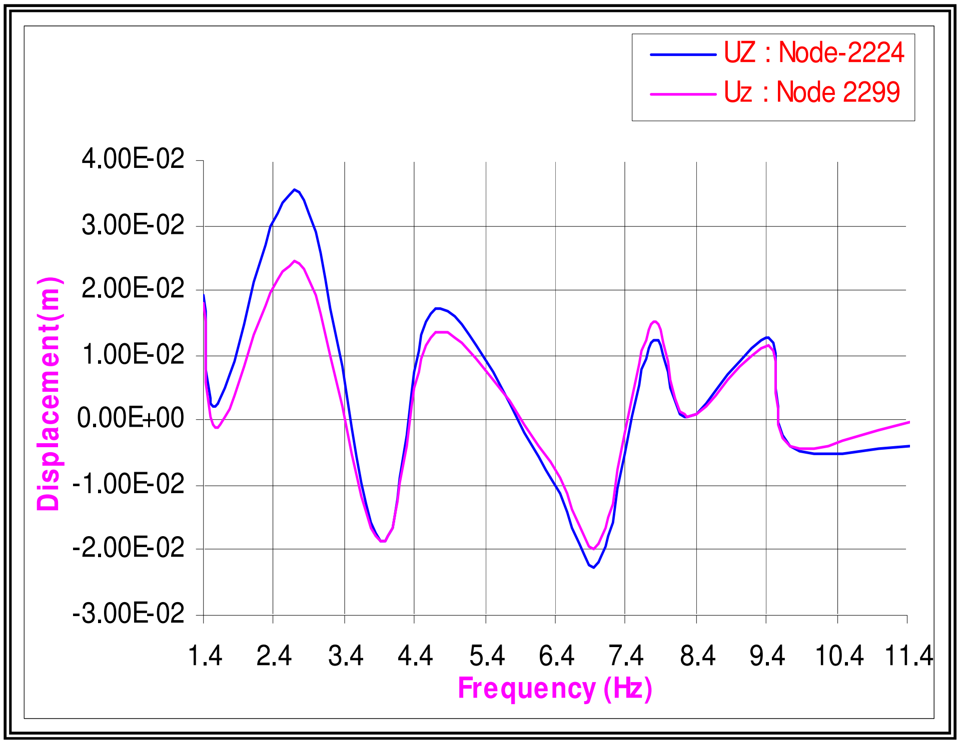
Plot-6.9 Time history plot for CQC method for IS: 1893 data in Z-Direction for frame



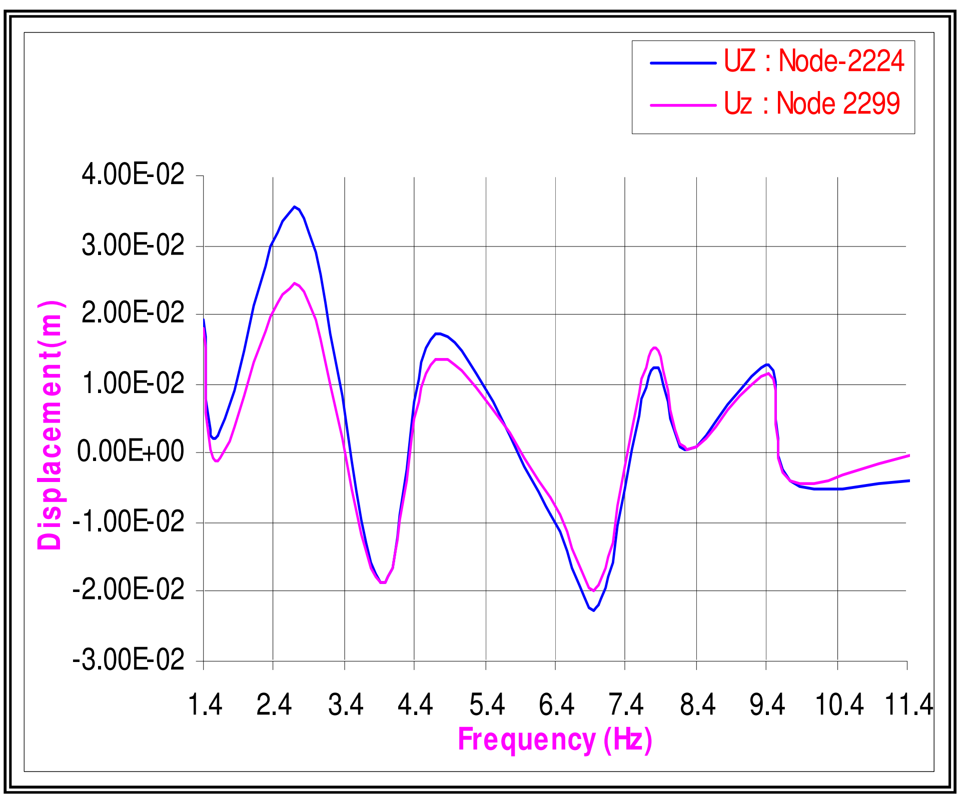
Plot-6.10 Time history plot for SRSS method for Bhuj E.Q data in X-Direction for frame



Plot-6.11 Time history plot for CQC method for Bhuj E.Q data in X-Direction for frame



Plot-6.12 Time history plot for SRSS method for Bhuj E.Q data in Z-Direction for frame



Plot-6.13 Time history plot for CQC method for Bhuj E.Q data in Z-Direction for frame

6.4 RAFT
6.4.1 MODAL ANALYSIS OF RAFT

Size, material properties and boundary conditions used in the modeling of raft are kept same as explained in chapter 5. For finding out the response of raft modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 11.34 Hz.. Figure 6.5 shows the 3-d modeling of raft in ANSYS 8.0. Table 6.4 shows the free vibration result of raft. Plot 6.14 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

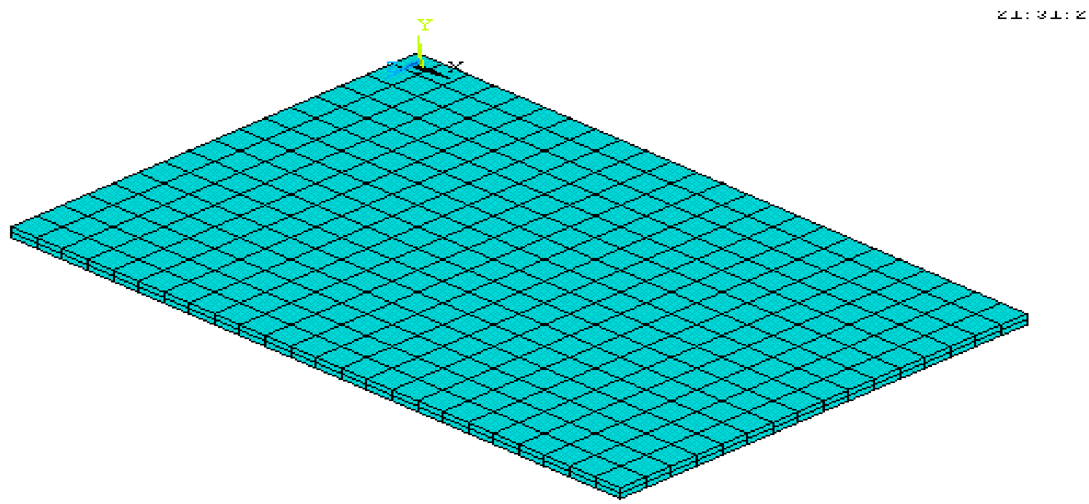
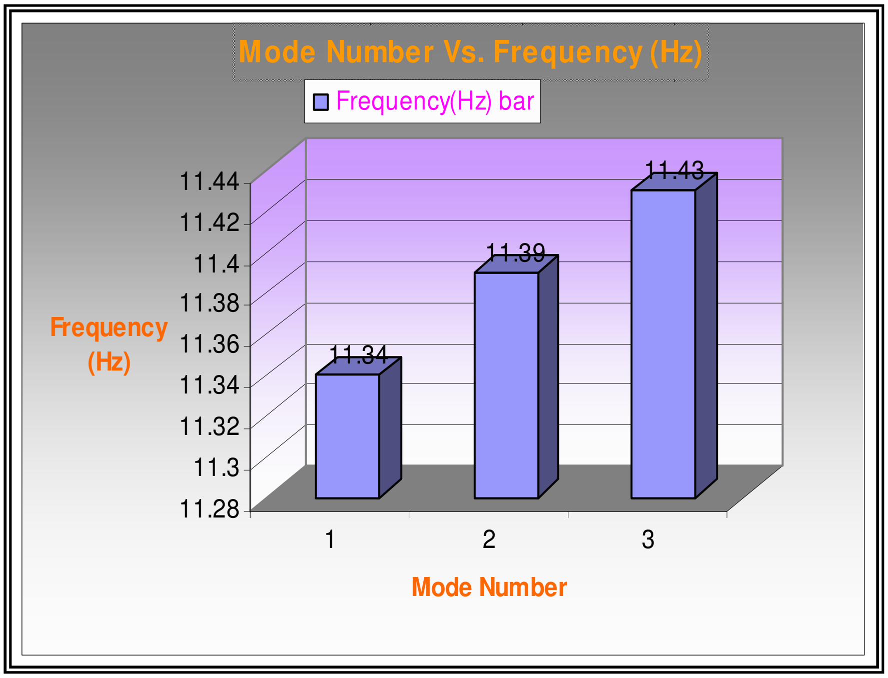


Figure 6.5 Finite Element Modeling of Raft (ANSYS 8.0)

TABLE 6.4
Standard frequency results of Raft from ANSYS 8.0

Mode No.	Frequency [Hz]	Period [sec]
1	11.340	0.0881
2	11.390	0.0877
3	11.430	0.0874



Plot 6.14
Frequency Vs. Mode No. for Raft with displacement in all three direction are restrained at base

6.4.2 RESPONSE SPECTRUM ANALYSIS OF RAFT

Using modal analysis result response spectrum analysis is carried out for spectrum given in IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 6.5 and Table 6.6 shows the maximum displacement at the top of the raft due to IS: 1893 (Part 1) (2002) and bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively.

Plot 6.15 and plot 6.16 shows the response history plot for two different extreme nodes at top of the raft due to IS: 1893 data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 6.17 and 6.18 shows the response history plot for two different extreme nodes at top of raft due to IS: 1893 data given as forcing function in Z-direction for SRSS method and

CQC method respectively. Plot 6.19 and 6.20 shows the response history plot for two different extreme nodes at top raft due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 6.21 and 6.22 shows the response history plot for two different extreme nodes at raft due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

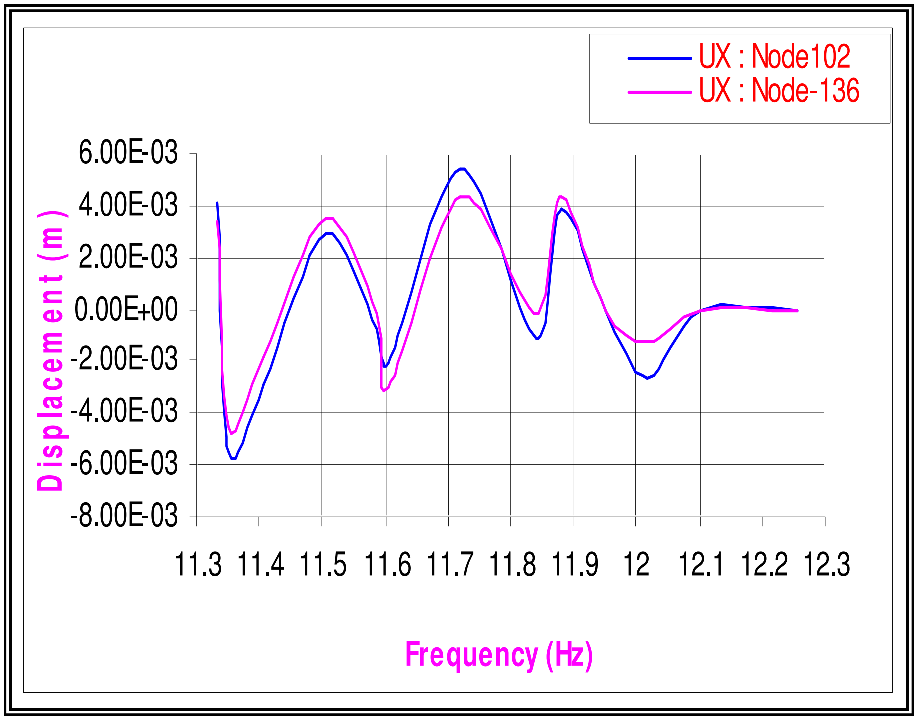
TABLE 6.5

Maximum displacement result of raft for forcing function given in X-direction

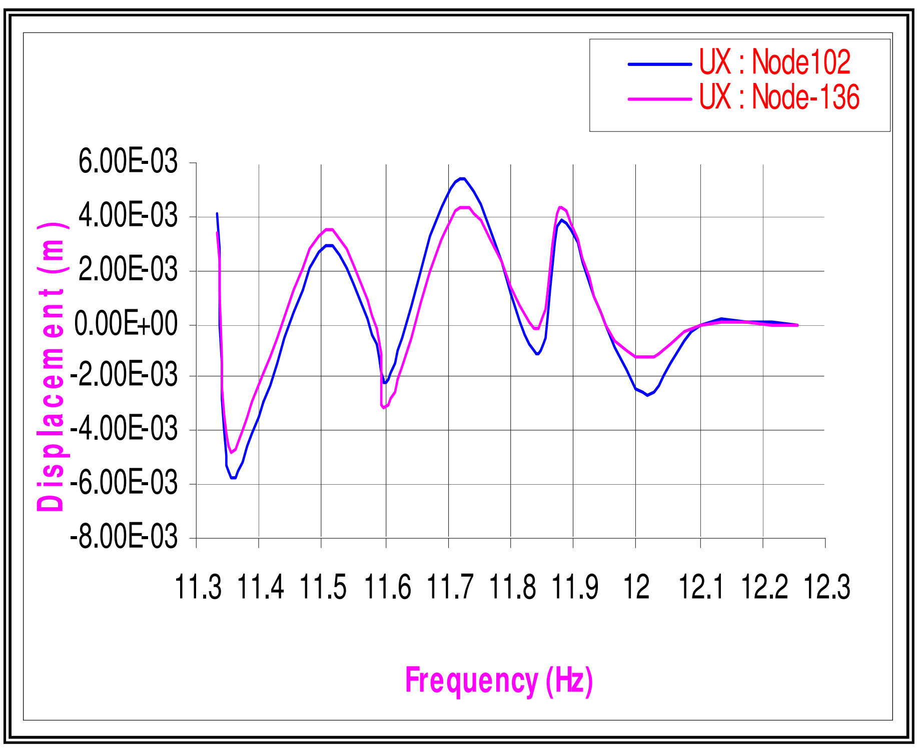
Data	**Max. Displacement(m) at the top raft**	
	SRSS Method	**CQC Method**
IS : 1893 Data	6.7E-03	6.7E-03
Bhuj Earthquake Data	8.13E-03	8.13E-03

TABLE 6.6
Maximum displacement result of raft for forcing function given in Z-direction

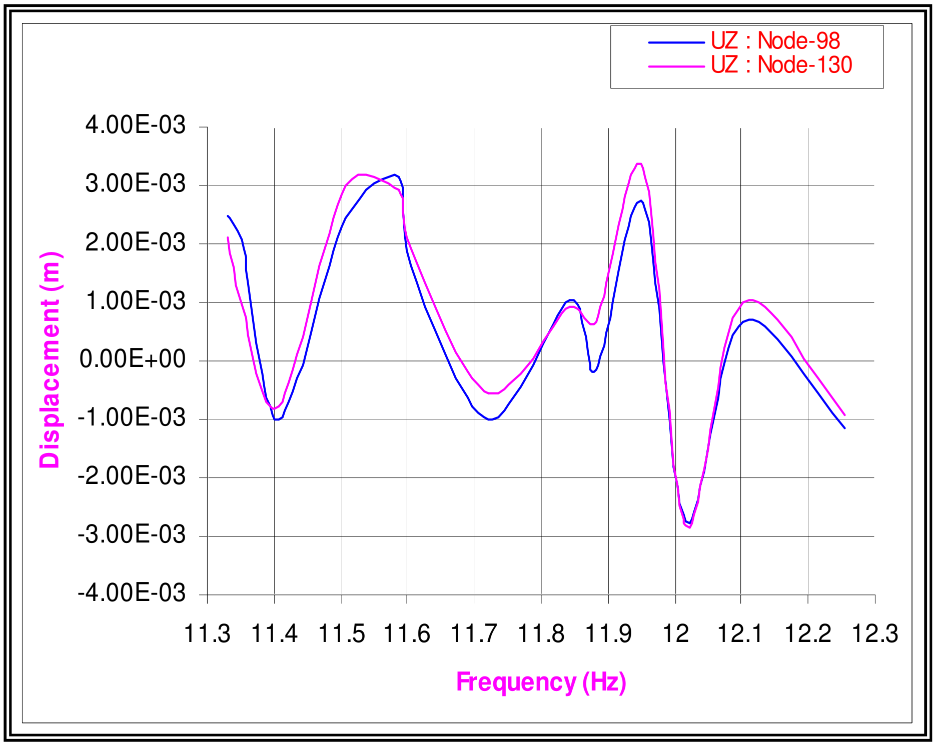
Data	**Max. Displacement(m) at the top of raft**	
	SRSS Method	**CQC Method**
IS : 1893 Data	4.6E-04	4.6E-04
Bhuj Earthquake Data	5.57E-04	5.57E-04



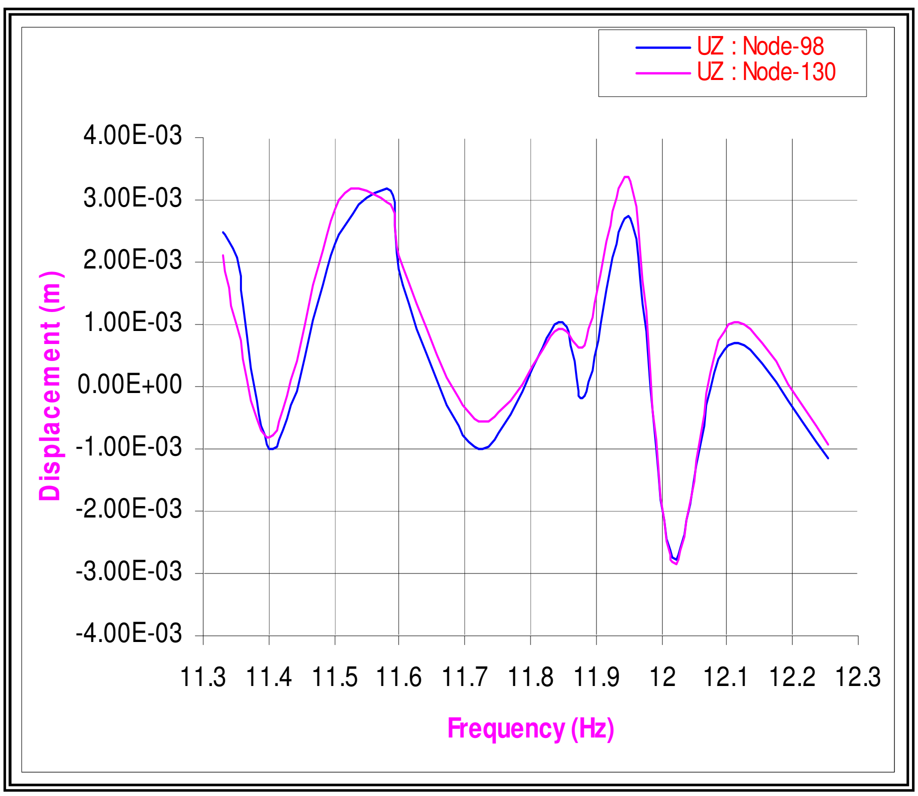
Plot-6.15 Time history plot for SRSS method for IS: 1893 data in X-Direction for raft



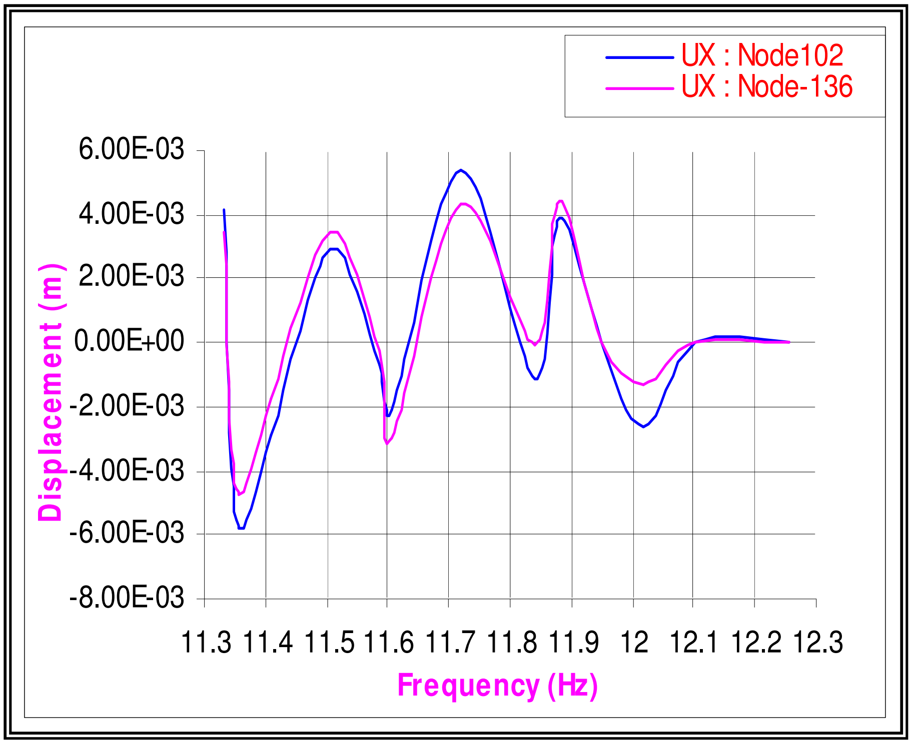
Plot-6.16 Time history plot for CQC method for IS: 1893 data in X-Direction for raft



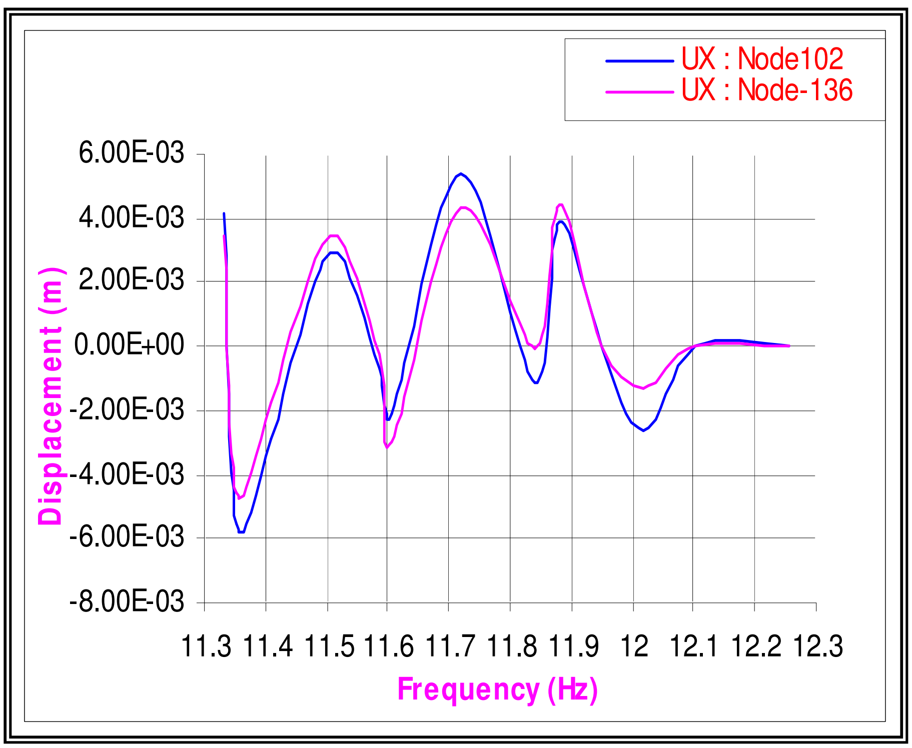
Plot-6.17 Time history plot for SRSS method for IS: 1893 data in Z-Direction for raft



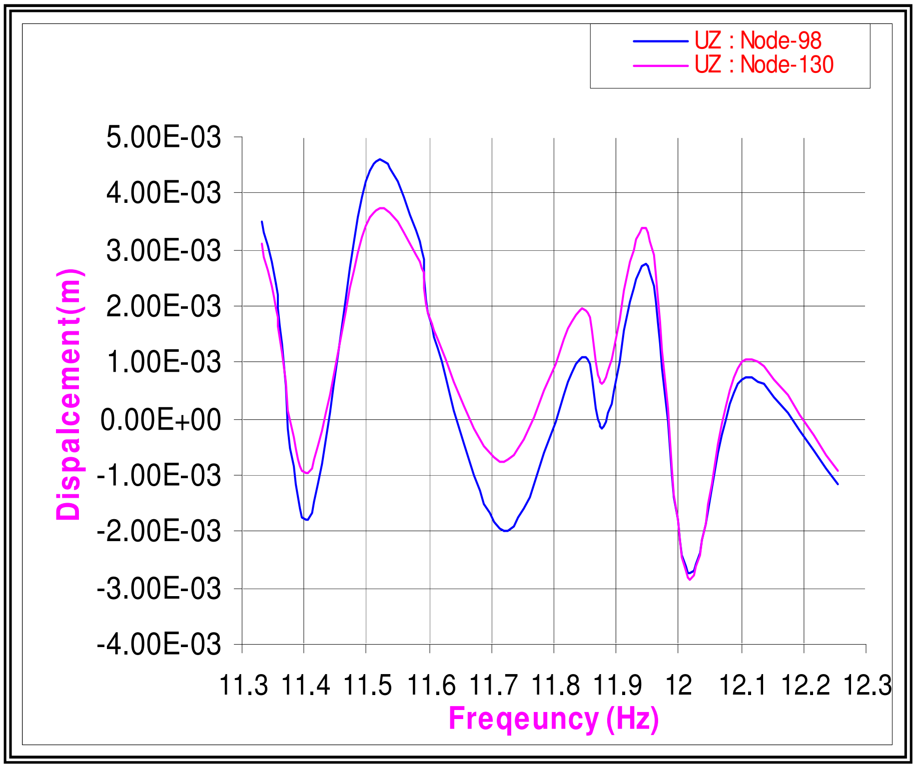
Plot-6.18 Time history plot for CQC method for IS: 1893 data in Z-Direction for raft



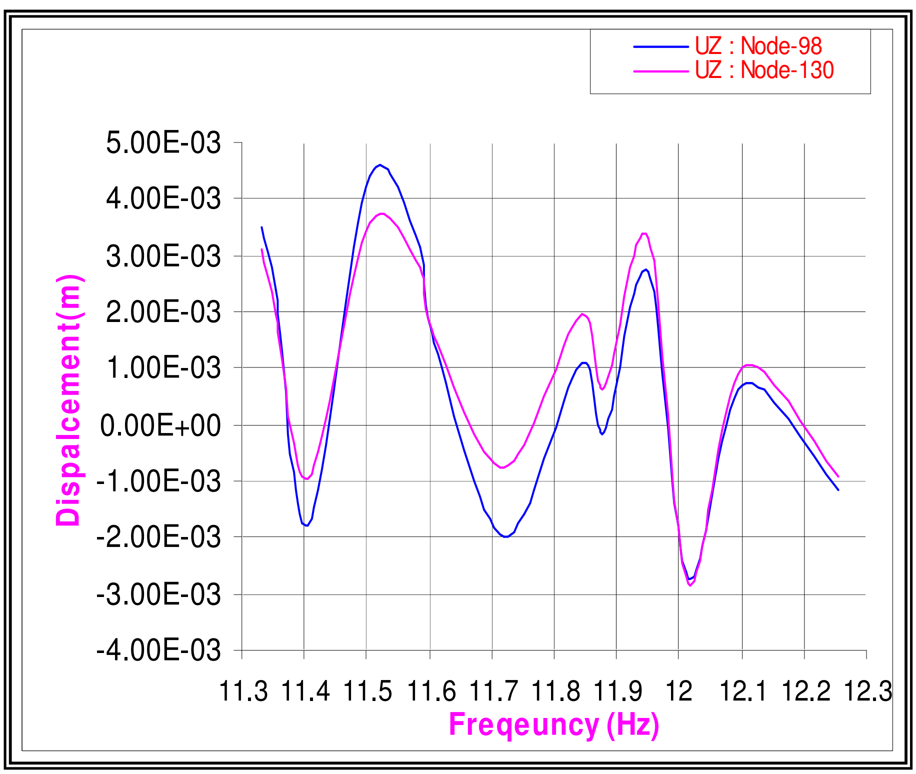
Plot-6.19 Time history plot for SRSS method for Bhuj E.Q data in X-Direction for raft



Plot-6.20 Time history plot for CQC method for Bhuj E.Q data in X-Direction for raft



Plot-6.21 Time history plot for SRSS method for Bhuj E.Q data in Z-Direction for raft



Plot-6.22 Time history plot for CQC method for Bhuj E.Q data in Z-Direction for raft

6.5 SOIL

6.5.1 MODAL ANALYSIS OF SOIL

Size, material properties and boundary condition used in the modeling of soil are kept same as explained in chapter 5. For finding out the response of soil modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 11.34 Hz. Figure 6.6 shows the 3-d modeling of raft in ANSYS 8.0. Table 6.7 shows the free vibration result of soil. Plot 6.23 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

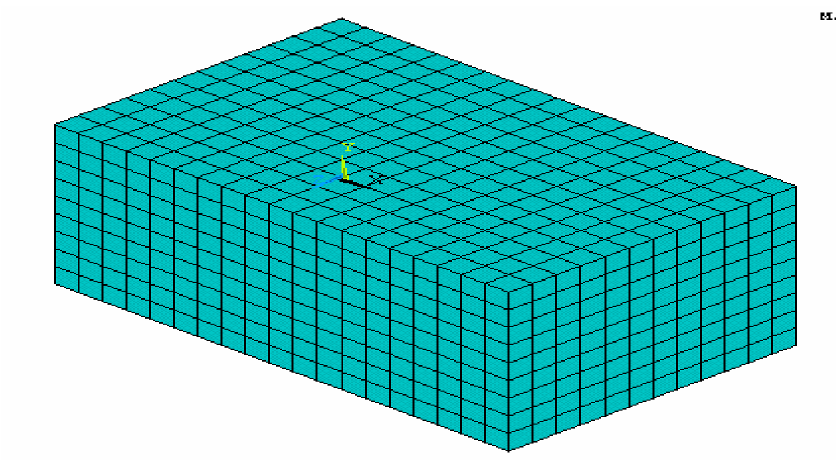
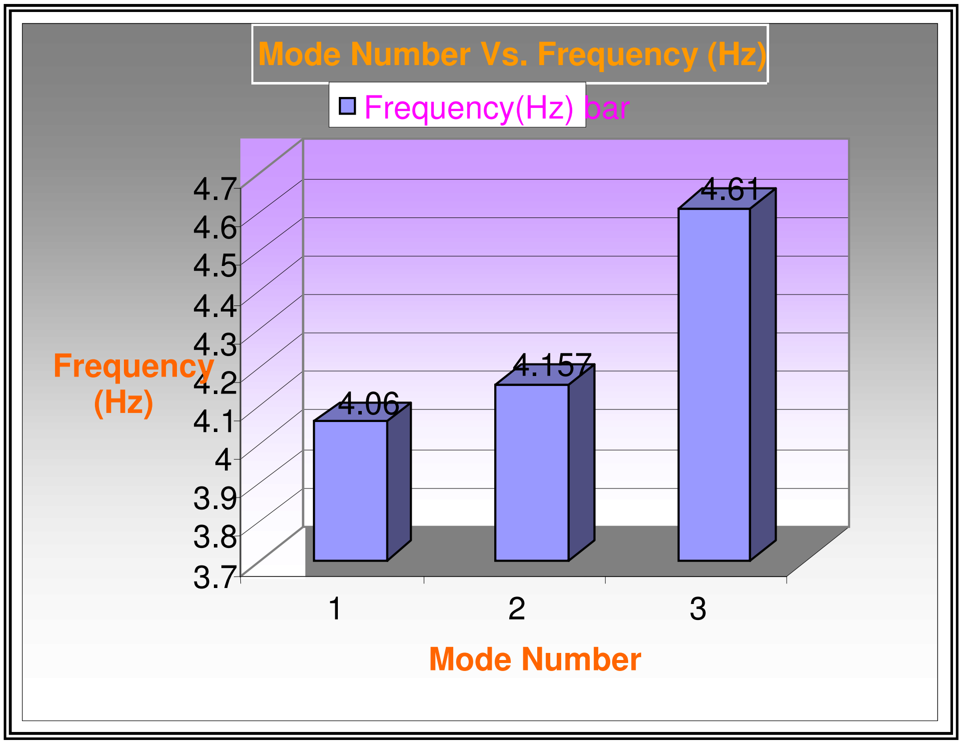


Figure 5.6 Finite Element Modeling of Soil Mass (ANSYS 8.0)

TABLE 6.7
Standard frequency results of soil from ANSYS 8.0

Mode No.	Frequency [Hz]	Period [sec]
1	4.060	0.246
2	4.157	0.240
3	4.610	0.217



Plot 6.23
Frequency vs. Mode No. for soil

6.5.2 RESPONSE SPECTRUM ANALYSIS OF SOIL

Using modal analysis result response spectrum analysis is carried out for spectrum given in IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 6.8 and Table 6.9 shows the maximum displacement at the top of the soil due to IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively.

Plot 6.24 and plot 6.25 shows the response history plot for two different nodes at top of the soil due to IS: 1893 data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 6.26 and 6.27 shows the response history plot for two different nodes at top of soil due to IS: 1893 data given as forcing function in Z-direction for SRSS method and CQC method respectively. Plot 6.28 and 6.29 shows the response history plot for two different nodes at top of soil due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 6.30 and 6.31 shows the response history plot for two different nodes at top of soil due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

TABLE 6.8

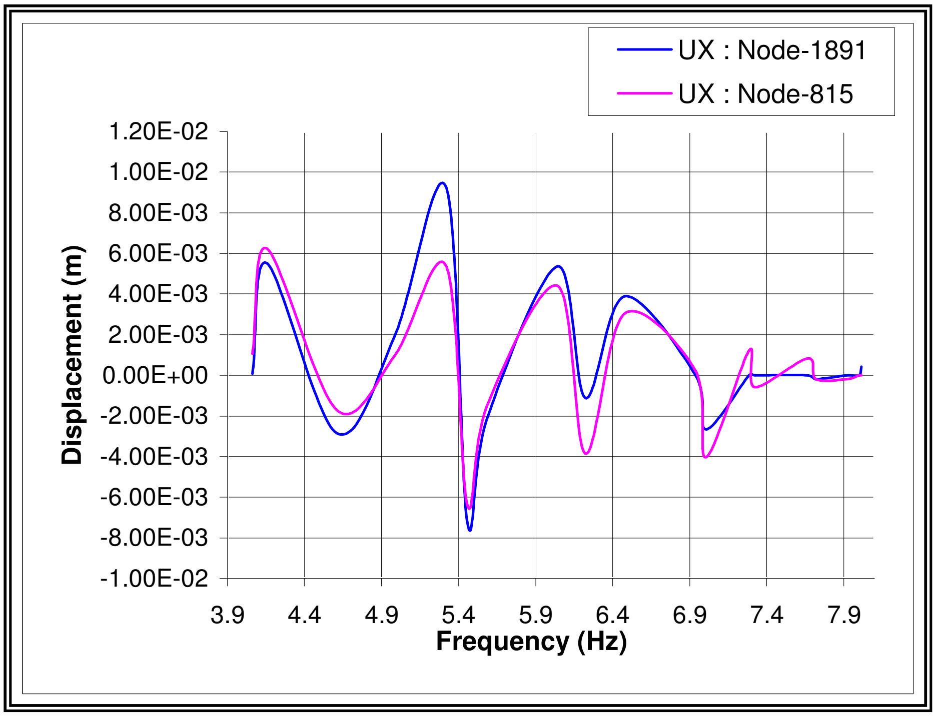
Maximum displacement result of soil for forcing function given in X-direction

Data	**Max. Displacement(m) at the top of soil**	
	SRSS Method	**CQC Method**
IS : 1893 Data	0.705E-02	0.717E-02
Bhuj Earthquake Data	0.912E-02	0.927E-02

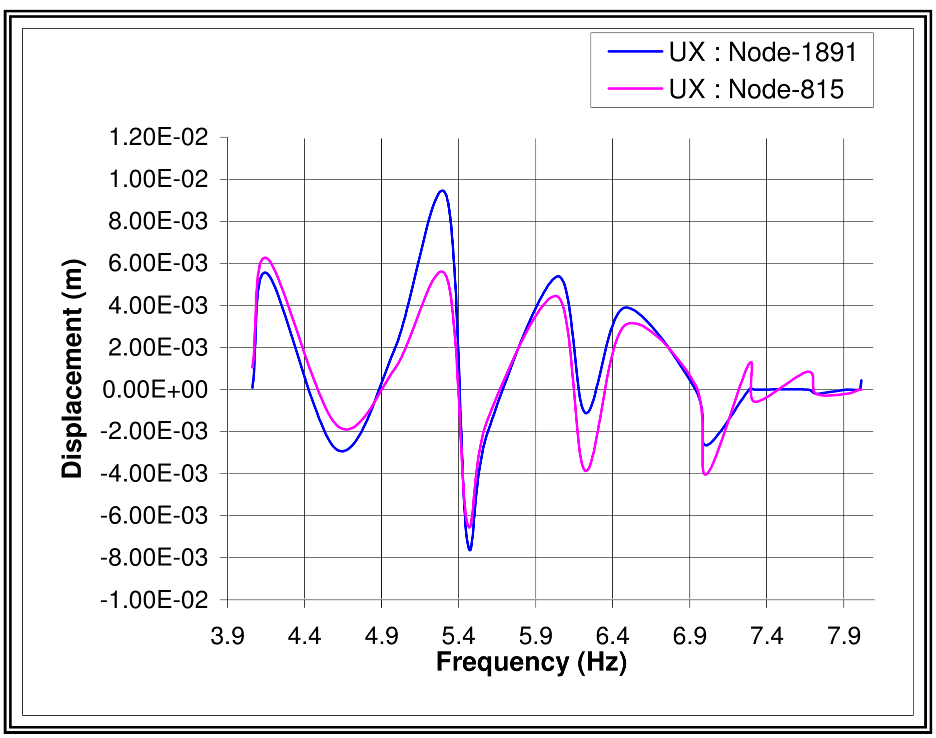
TABLE 6.9

Maximum displacement result of soil for forcing function given in Z-direction

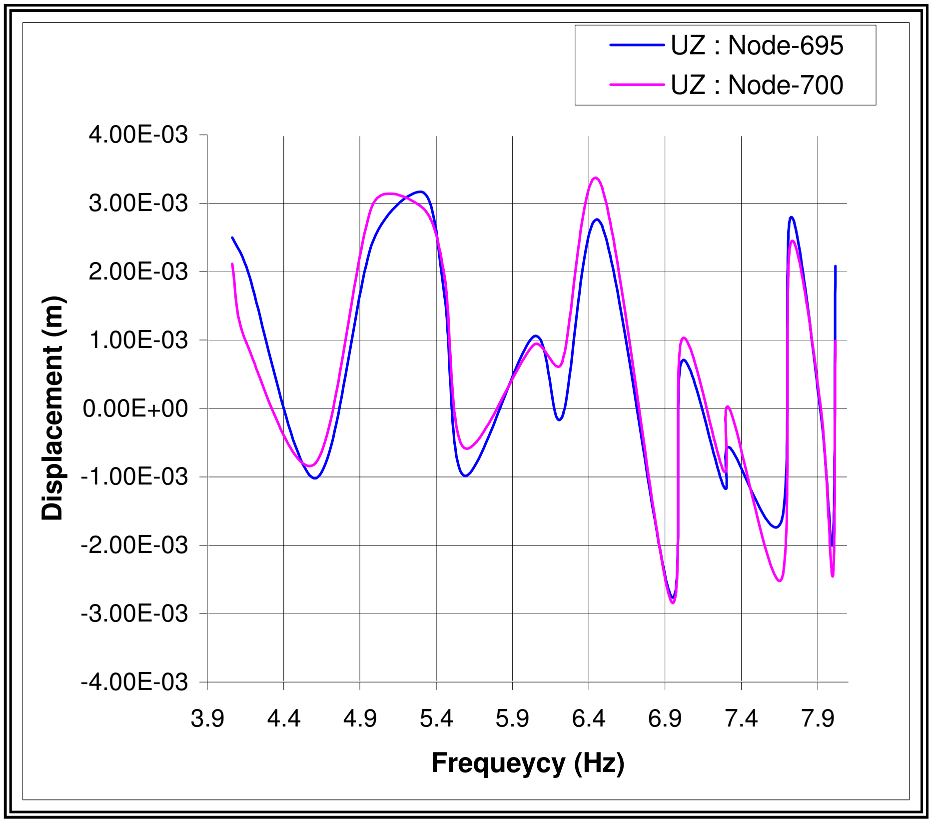
Data	**Max. Displacement(m) at the top of soil**	
	SRSS Method	**CQC Method**
IS : 1893 Data	0.495E-02	0.485E-02
Bhuj Earthquake Data	0.693E-02	0.676E-02



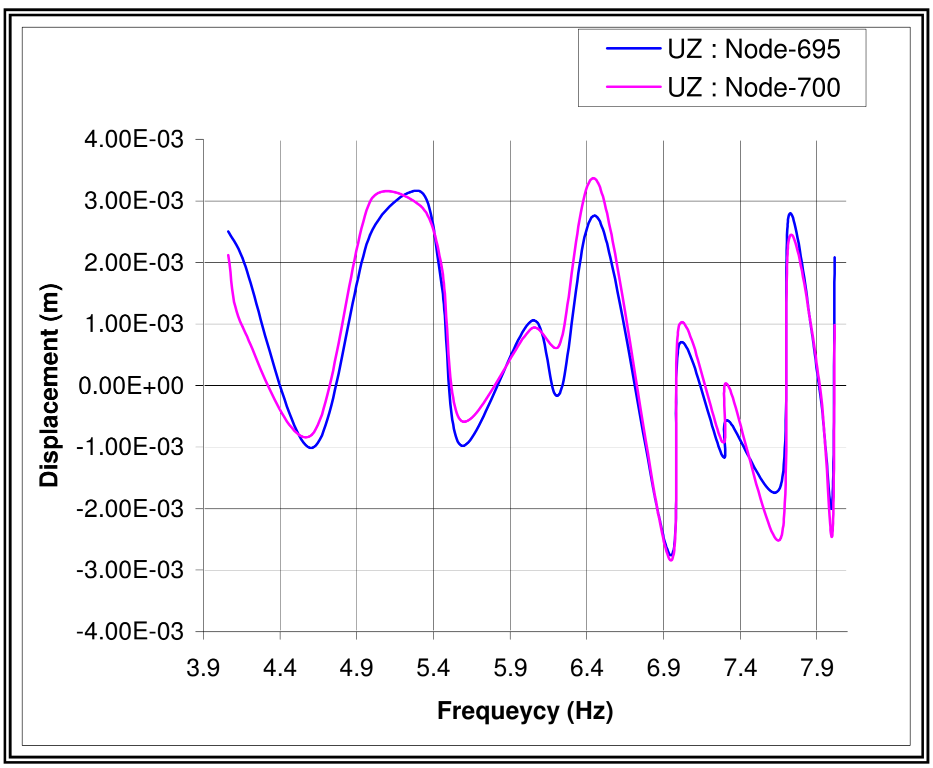
Plot-6.24 Time history plot for SRSS method for IS: 1893 data in X-Direction for soil



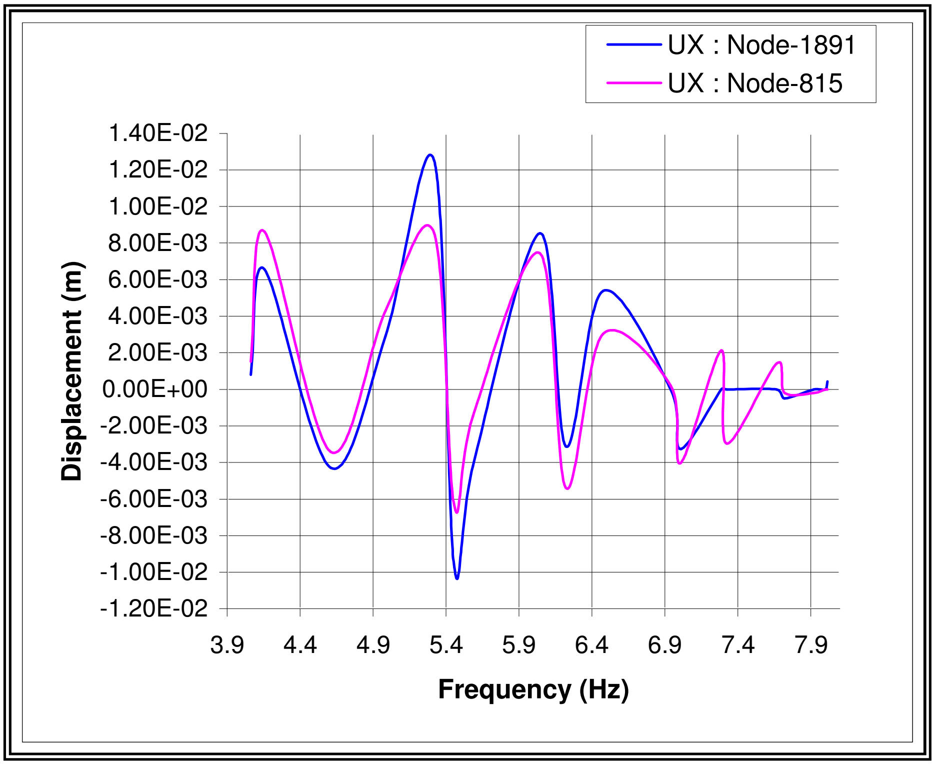
Plot-6.25 Time history plot for CQC method for IS: 1893 data in X-Direction for soil



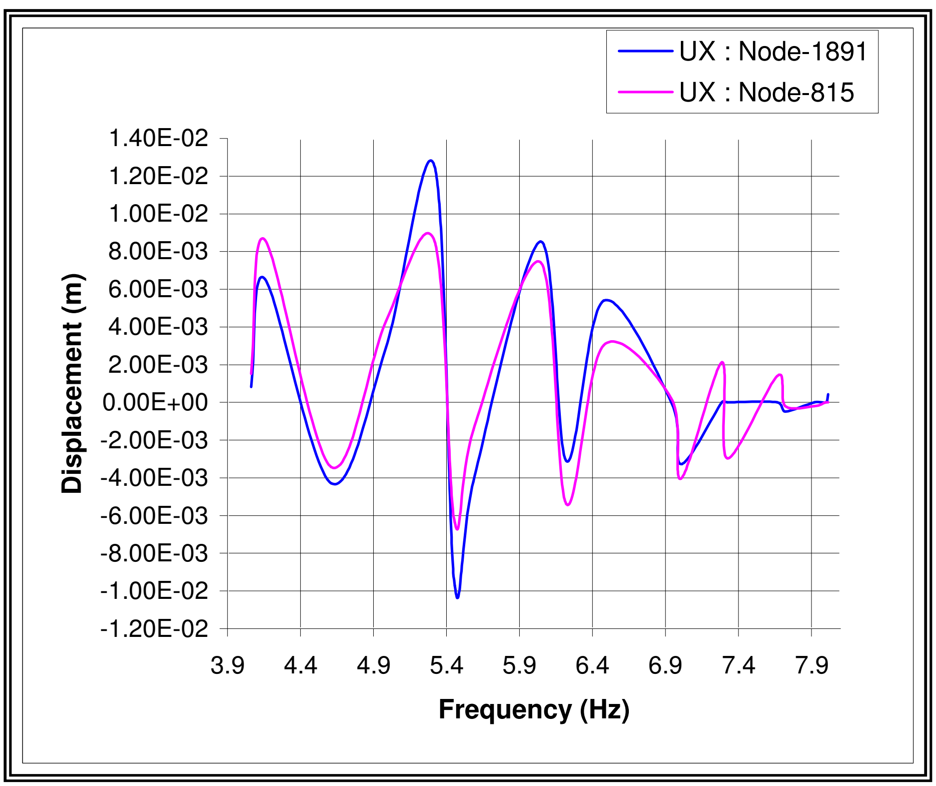
Plot-6.26 Time history plot for SRSS method for IS: 1893 data in Z-Direction for soil



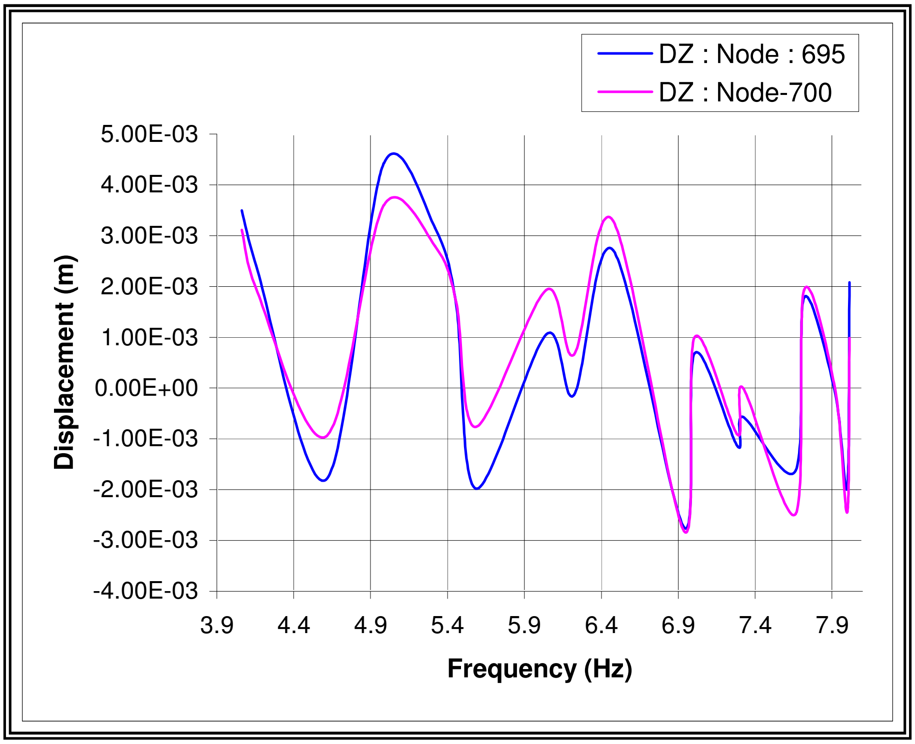
Plot-6.27 Time history plot for CQC method for IS: 1893 data in Z-Direction for soil



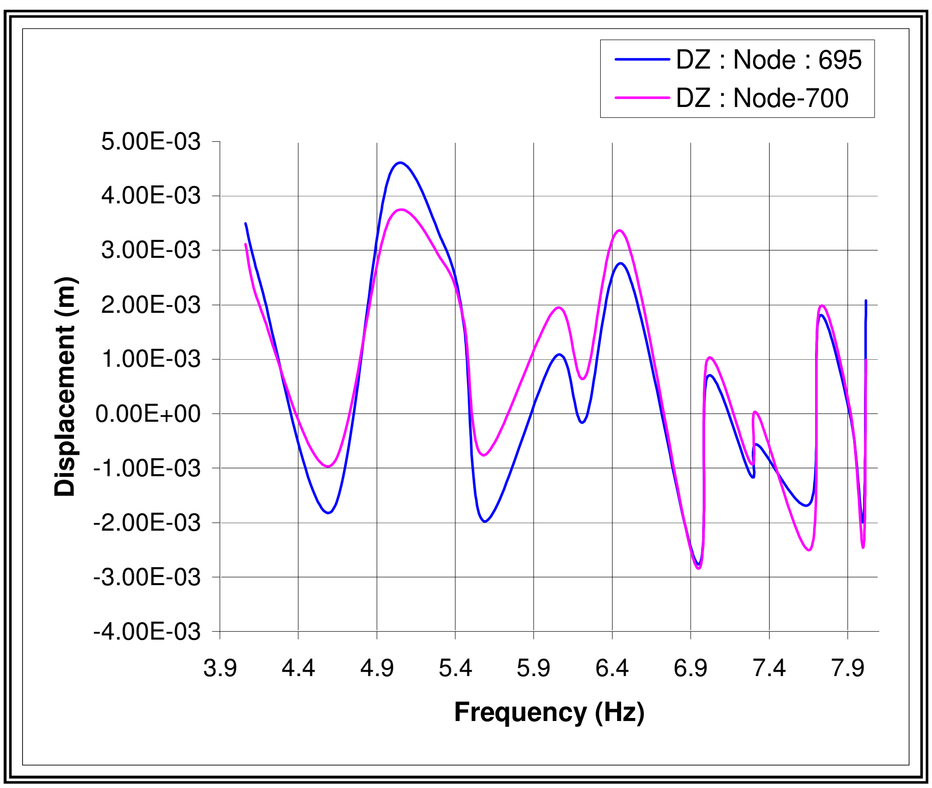
Plot-6.28 Time history plot for SRSS method for Bhuj E.Q data in X-Direction for soil



Plot-6.29 Time history plot for CQC method for Bhuj E.Q data in X-Direction for soil



Plot-6.29 Time history plot for SRSS method for Bhuj E.Q data in Z-Direction for soil



Plot-6.29 Time history plot for CQC method for Bhuj E.Q data in Z-Direction for soil

6.6 SUMMARY

As per the suggestion of IIT-R Response Spectrum Analysis is carried in component approach for actual Earthquake spectra (Bhuj Earthquake-2001) and spectrum given in IS: 1893 for hard soil in both X- Direction and Z-Direction. It is observed that structural responses are more in actual Earthquake Spectra. From the Structure Response graph it is observed that for antenna supporting frame damping take place at higher frequency in the Z-direction From Structural Response graph it is observed that for raft damping take place at higher frequency in X-Direction. It becomes almost straight line beyond 12.1Hz. From Structural Response graph it is observed that for soil damping take place at higher frequency in X-Direction. It becomes almost straight line beyond 7.8Hz.

CHAPTER 7

RESPONSE SPECTRUM ANALYSIS IN HOLISTIC APPROACH

7.1 STRUCTURE AS A WHOLE: A HOLISTIC APPROACH

As per the instruction, IITR, the theoretical approach suggested was to study elements of the structure in the component approach and then take all components together for the system approach. This system approach of all the components of the structure when taken together along with the soil mass gives the whole scenario. This whole scenario of predicting the response of entire system by incorporating the flexibility of a large volume of soil mass is termed as holistic approach in determining the response of the entire structural system for given forcing function.

7.2 MODELING OF ANTENNA MASS

Modeling of an earth-station antenna is not done because of paucity of time, but in order to consider the effect of antenna on antenna supporting structure the mass of the antenna is simulated as 3D translational mass at the C.G of the antenna system using the concept of mass less beams arranged in form of a tripod. In this piece of work, the details regarding an earth-station antenna has been taken from standard literature. [See Appendix A]

7.3 DYNAMIC ANALYSIS INCLUDING SSI EFFECTS

Two different approaches have been adopted in the past to investigate the problems of soil-structural interaction and incorporate the effect of soil compliance in the dynamic analysis: (1) the direct approach, and (2) the substructure approach.

The Direct Approach

It is based on including the soil medium in the mathematical model development for dynamic analysis. This is typically done by using finite element discretisation of the domain with appropriate absorbing/transmitting boundaries. These special boundary elements are necessary to simulate the effect of unbounded soil medium which requires that the seismic energy should radiate away from the vibration source. The use of absorbing/transmitting boundaries prevents the seismic energy being reflected back into the problem domain. Although the method is quite simple in concept, its implementation for analysis of practical problems presents a formidable computational task. The requirement of including model for dynamic analysis leads to a very large system of equations to be solved. Further, the development of absorbing/transmitting boundaries is based on the assumption of the presence of soil layer that is bounded by a rocky stratum at the base. The computed results could be erroneous if the site has deep soil deposits and the bottom boundary of the finite element model is placed at a shallow depth instead of at the bedrock level. Further, the lower modes of the complete soil-structural system will be dominated by soil deformation modes with the superstructure riding on top of soil mass as a rigid body owing to the more flexible nature of soil in comparison with the structural system. Since the deformations and stresses in structural system are of primary interest for the purpose of design, huge computational effort and storage is required to compute and store the Eigen-pairs required for inclusion of all modes ensuring more that the cumulative effective modal mass in more than 90% of the total structural mass. A common numerical trick to force the lower modes of the combined soil-structure system to correspond to deformations in structural system is to consider the soil medium to be mass less. These forces are structural modes at the lower end of the Eigen spectrum.

The Substructure Approach

The three step solution for SSI problems consists of

1. Determination of foundation input motion by solving by solving the kinematic interaction problem,
2. Determination of the frequency dependent impedance functions describing the stiffness and damping characteristics of the soil-foundation interacting system. This step should account for the geometric and material properties of

foundation and soil deposits and is generally computed using equivalent linear elastic properties for soil appropriate for the in-situ dynamic shear strains. This step yields the so-called soil springs.

3. Computation of response of the real structure supported on frequency dependent soil springs and subjected at the base of these springs to the foundation input motion computed in 1 above.

It should be noted that if the structural foundations were perfectly rigid, the solution by substructure approach would be identical to the solution by the direct method. Further, the superposition principle is valid for linear systems only. Since the shear modulus and damping properties of soil are strain dependent, the use of the principle of superposition can be questioned. However, it has been observed that most of the nonlinearity in soil behavior occurs as a result of the earthquake motion, and not as a result of soil-structure interaction itself.

7.4 FINITE ELEMENT MODELING OF WHOLE STRUCTURE WITH SOIL MASS

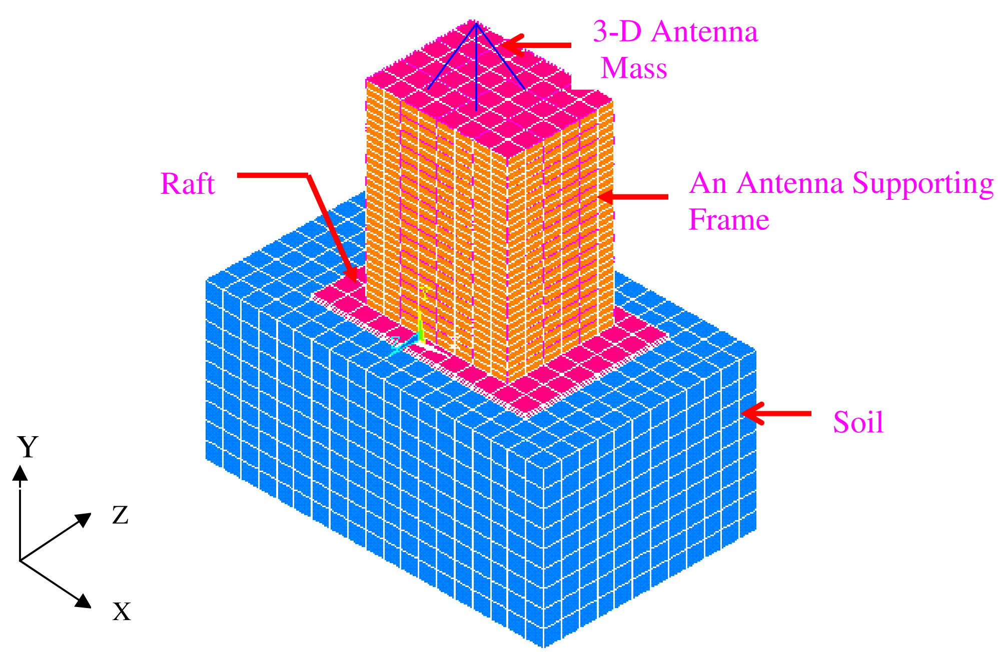


Figure 7.1 Finite Element Model of Supporting Structure with Soil Mass

The soil adjacent to raft is modeled using 8-noded brick element. The element is assumed to be isotropic. The finite element model used for analysis is shown in figure 7.1. The size of the element is kept identical throughout the model.

7.5 PARAMETRIC STUDY

As per IIT-R suggestion parametric study has been carried out for two different damping value, i.e. 5% damping and 10% damping of concrete .For holistic approach four different cases are given below,

- Without considering Center Elastic Effect in soil model
- Considering Center Elastic effect in soil model
- When soil Modulus of Elasticity of horizontal plane is about $2/3^{rd}$ of vertical plane
- Soil properties are modified up to 33.5%.

These cases are run eventually, to check the Pointing Error (PE) specifications w.r.t the dynamic displacements of the antenna during earthquake.

7.6 HOLISTIC APPROACH FOR 5% DAMPING VALUE OF CONCRETE

As per IIT-R suggestion response spectrum analysis was carried out for all above cases for actual bhuj earthquake data for 5% damping of concrete in both X-direction and Z-direction

7.6.1 CASE:-1 : WITHOUT CONSIDERING CENTER ELASTIC EFFECT IN SOIL MASS

7.6.1.1 MODAL ANALYSIS OF CASE-1

Geometry of holistic structure, material properties and boundary condition used in the modeling of an antenna supporting structure with raft and soil mass are kept same as explained in chapter 5. For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.281 Hz. Figure 7.2 shows the 3-d modeling of an antenna supporting structure with raft and soil mass without considering center elastic effect in soil in ANSYS 8.0. Table 7.1 shows the free vibration result of an antenna supporting structure. Plot 7.1 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

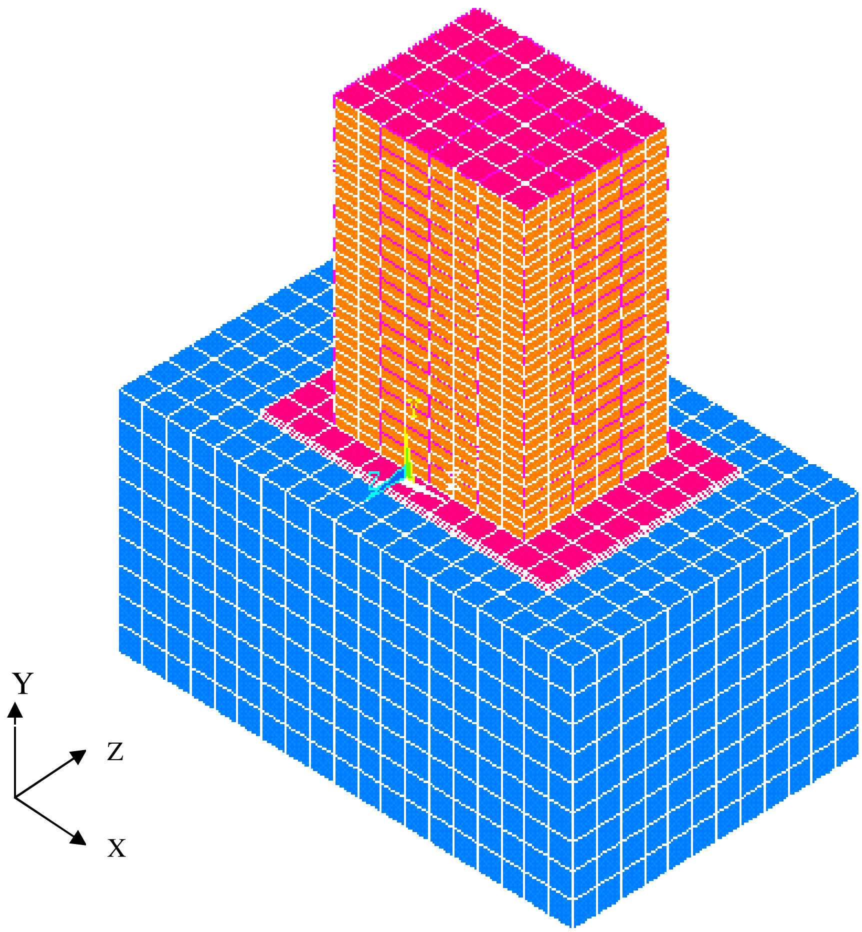
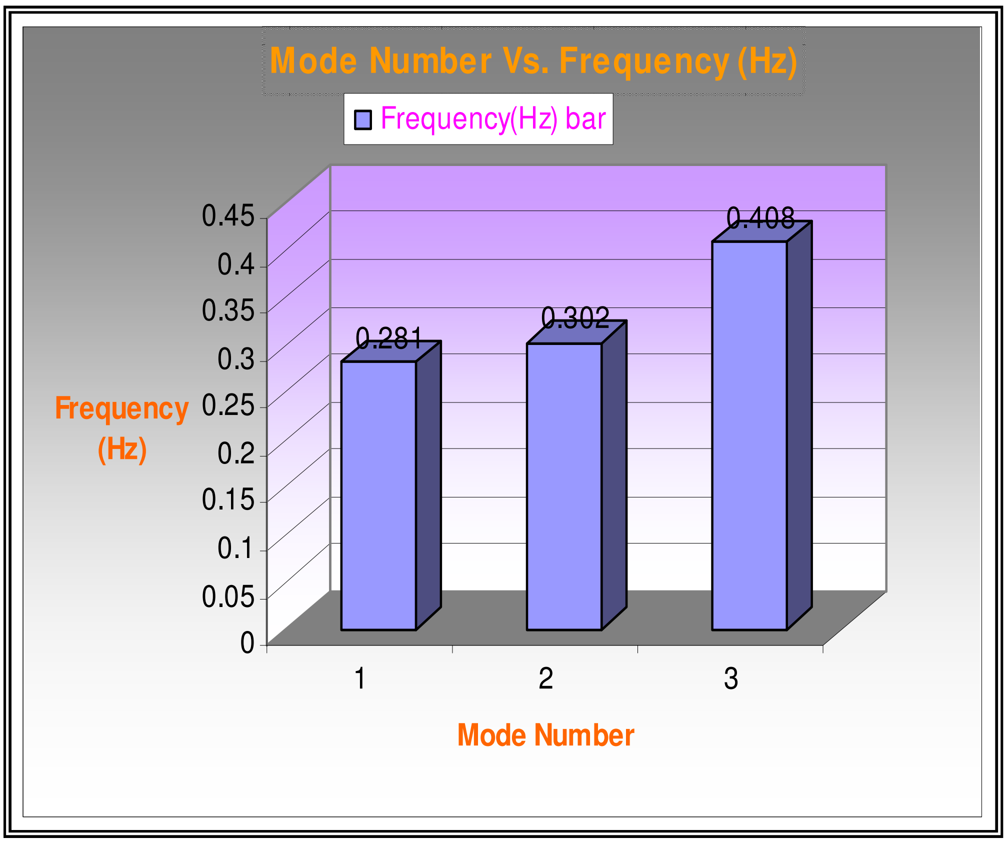


Figure 7.2 3-d modeling of system approach without considering center elastic effect in soil in ANSYS 8.0

TABLE 7.1
Standard frequency results of System Approach without considering center elastic effect in soil [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.281	3.559
2	0.302	3.311
3	0.408	2.450



Plot 7.1
Mode Number vs. Frequency (Hz) of system approach without considering center elastic effect for modal analysis result.

7.6.1.2 RESPONSE SPECTRUM ANALYSIS OF CASE-1

Using modal analysis results response spectrum analysis is carried out for spectrum given in IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.2 and Table 7.3 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to IS: 1893 (Part 1) (2002) and Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.2 and plot 7.3 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for IS 1893 data given as forcing function in X-direction and Z-direction respectively. Plot 7.4 and plot 7.5 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for Bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.6 and plot 7.7 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to IS: 1893 data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.8 and 7.9 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to IS: 1893 data given as forcing function in Z-direction for SRSS method and CQC method respectively. Plot 7.10 and 7.11 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.12 and 7.13 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

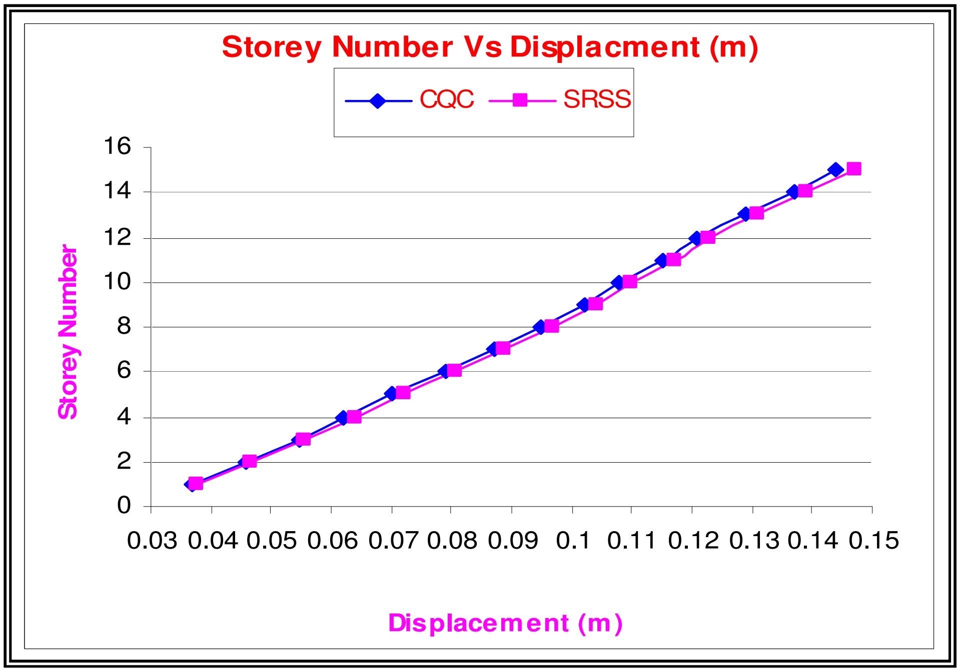
TABLE 7.2

Maximum displacement result of structural system without considering center elastic effect in soil for forcing function given in X-direction

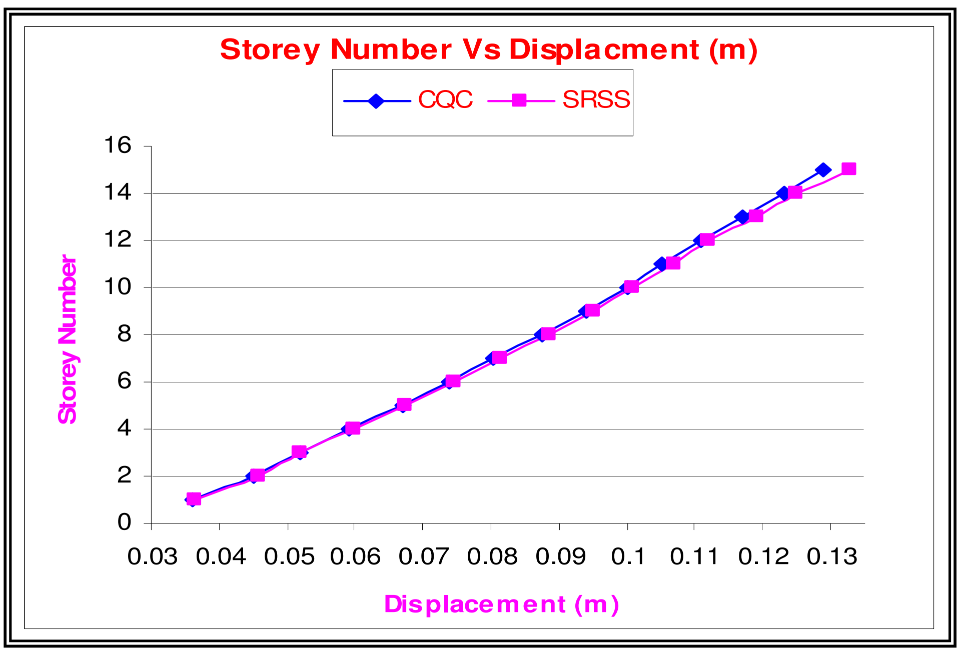
Maximum Displacement at	Data	Displacement(m)	
		SRSS Method	CQC Method
Top of an Antenna supporting frame	IS : 1893 Data	0.133	0.129
	Bhuj Earthquake Data	0.175	0.171
Top of Raft	IS : 1893 Data	0.362E-02	0.359E-02
	Bhuj Earthquake Data	0.477E-02	0.473E-02
Top of Soil	IS : 1893 Data	0.324E-02	0.32E-02
	Bhuj Earthquake Data	0.428E-02	0.422E-02

TABLE 7.3
Maximum displacement result of structural system without considering center elastic effect in soil for forcing function given in Z-direction

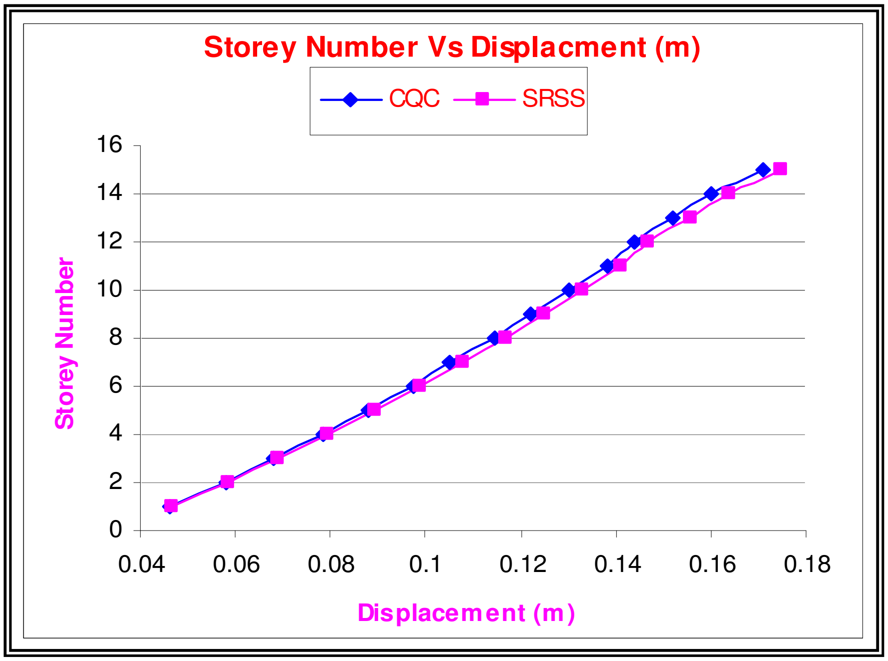
Maximum Displacement at	Data	Displacement(m)	
		SRSS Method	CQC Method
Top of an Antenna supporting frame	IS : 1893 Data	0.147	0.144
	Bhuj Earthquake Data	0.200	0.195
Top of Raft	IS : 1893 Data	0.301E-02	0.298E-02
	Bhuj Earthquake Data	0.413E-02	0.408E-02
Top of Soil	IS : 1893 Data	0.263E-02	0.285E-02
	Bhuj Earthquake Data	0.386E-02	0.380E-02



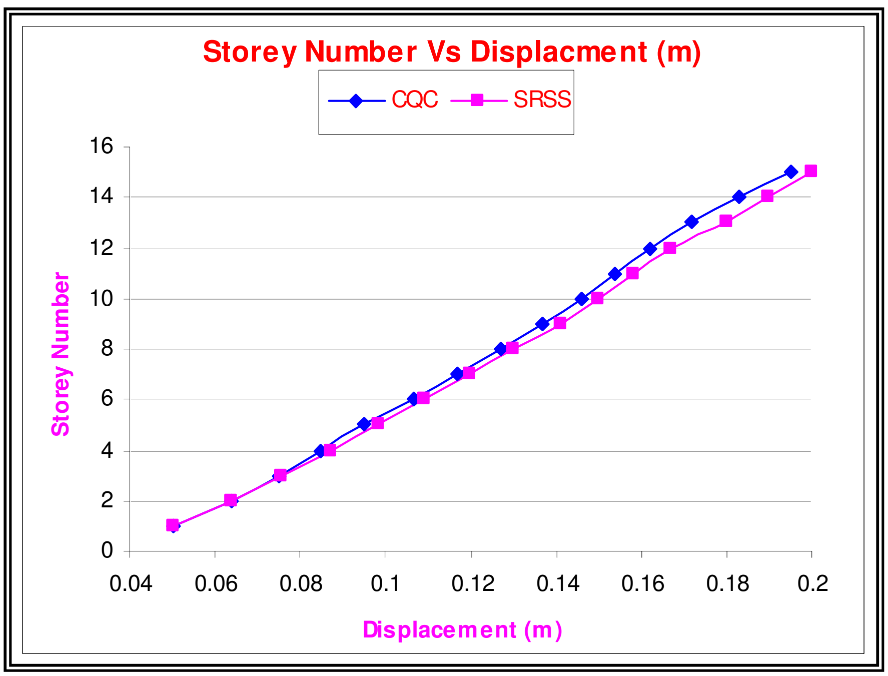
Plot 7.2
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach without considering center elastic effect for IS 1893 data given in X-direction



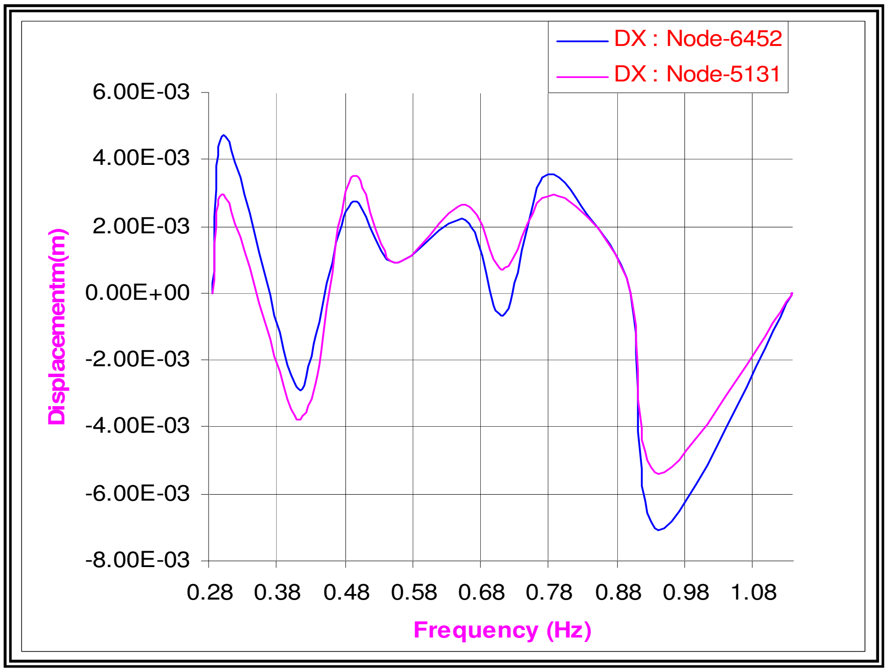
Plot 7.3
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach without considering center elastic effect for IS 1893 data given in Z-direction



Plot 7.4
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach without considering center elastic effect for Bhuj E.Q data given in X-direction



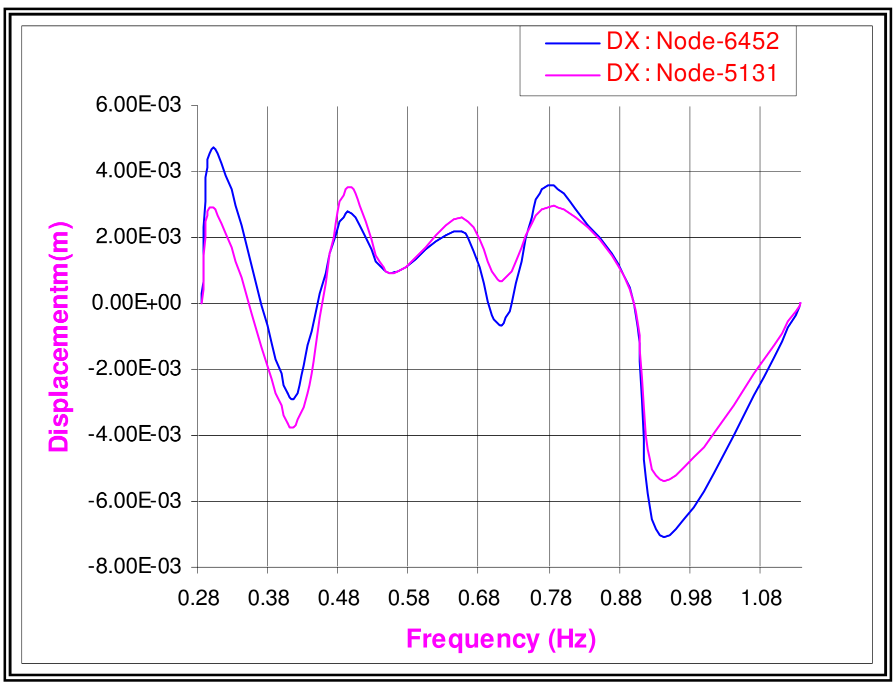
Plot 7.5
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach without considering center elastic effect for Bhuj E.Q data given in Z-direction



Plot-7.6

Time History plot for SRSS method for IS 1893 data in

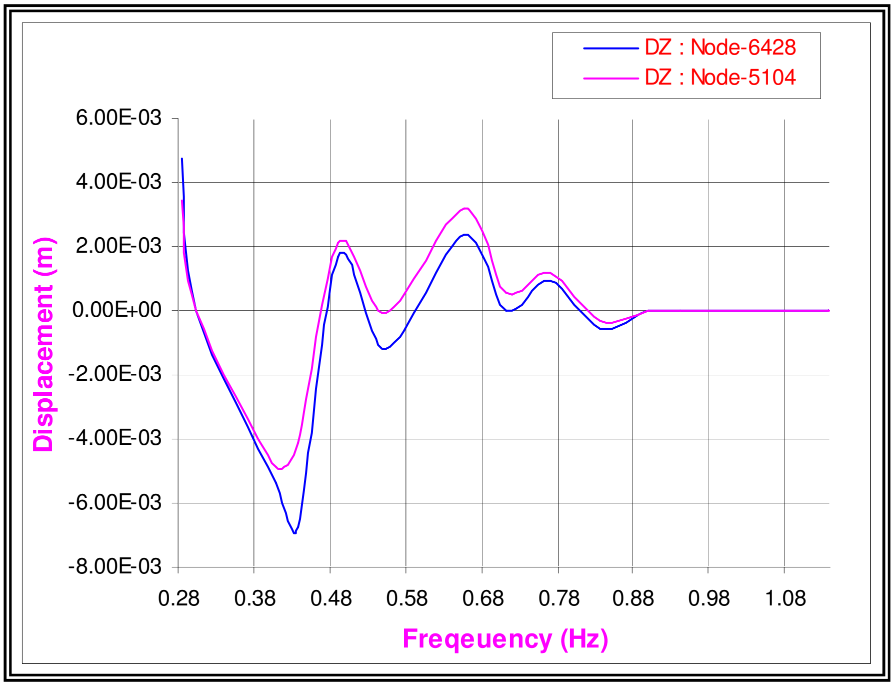
X-Direction for system approach without considering center elastic effect in soil



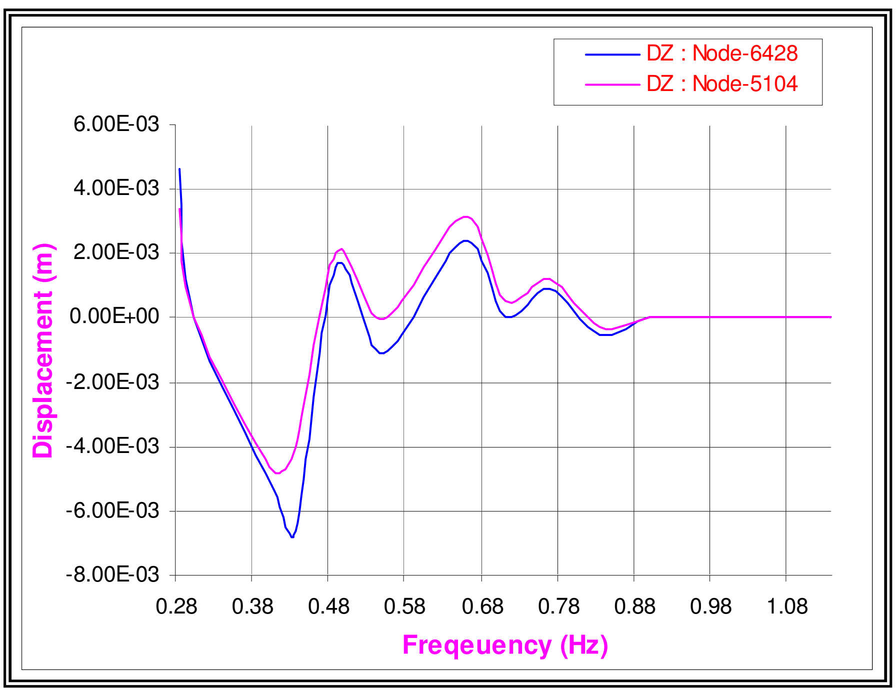
Plot-7.7

Time History plot for CQC method for IS 1893 data in

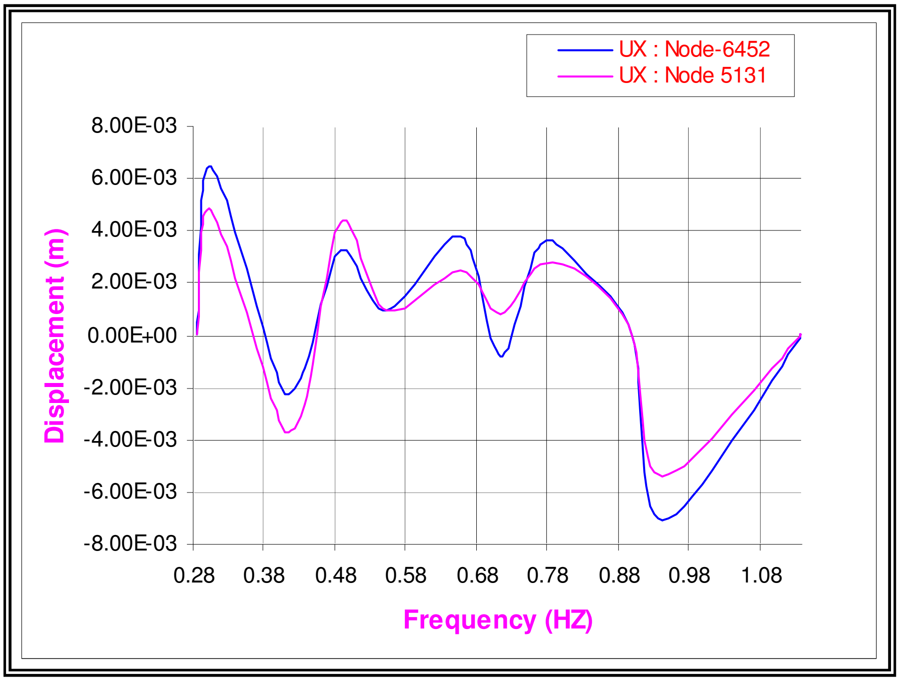
X-Direction for system approach without considering center elastic effect in soil



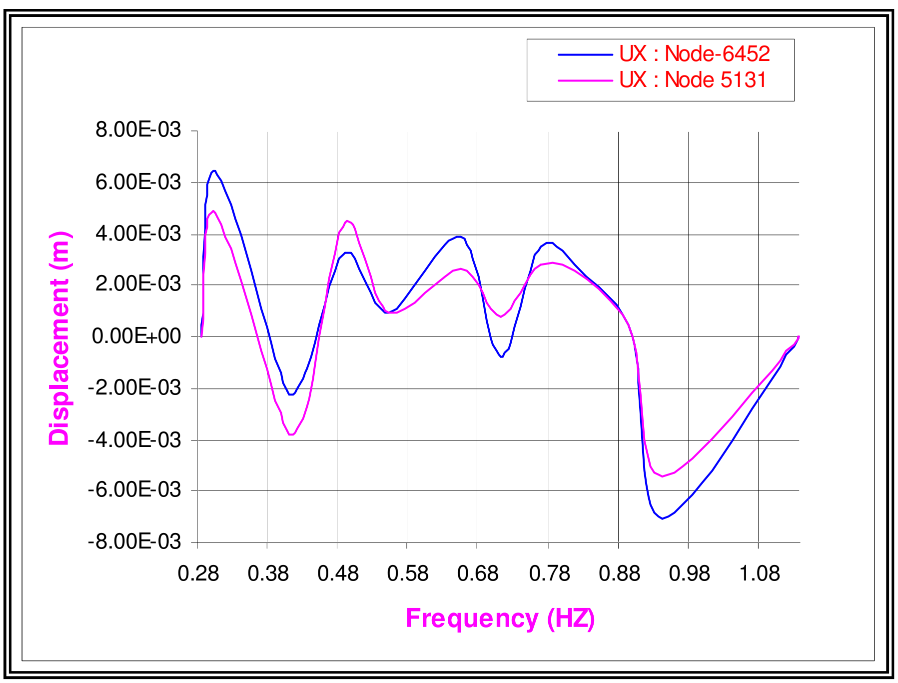
Plot-7.8
Time History plot for SRSS method for IS 1893 data in Z-Direction for system approach without considering center elastic effect in soil



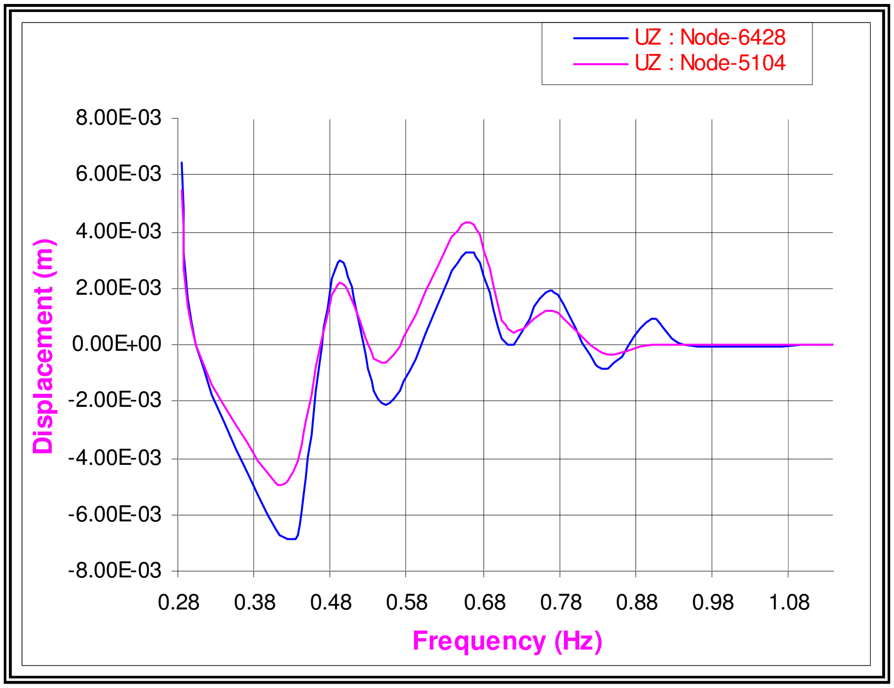
Plot-7.9
Time History plot for CQC method for IS 1893 data in Z-Direction for system approach without considering center elastic effect in soil



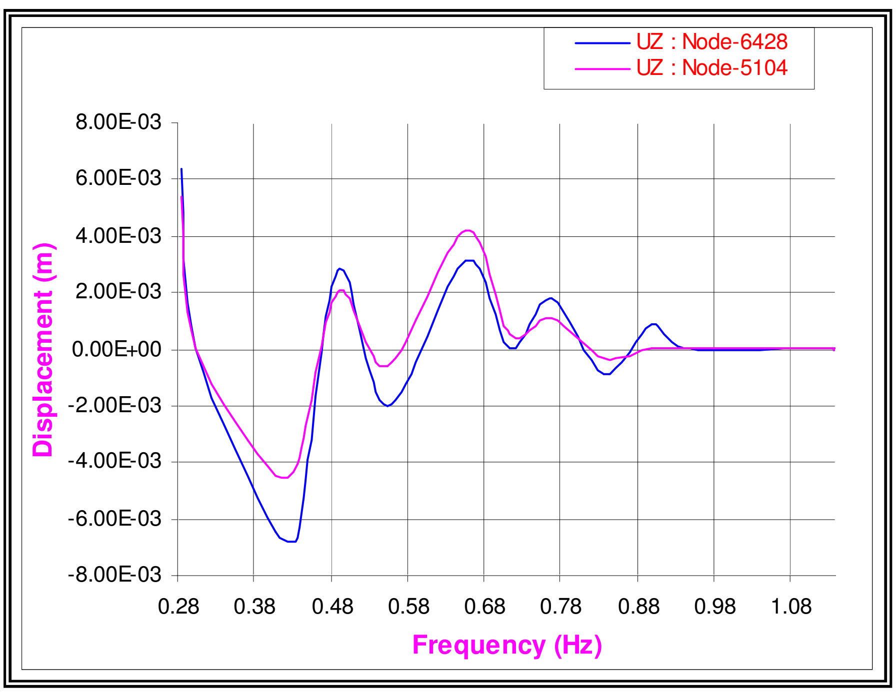
Plot-7.10
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach without considering center elastic effect in soil



Plot-7.11
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach without considering center elastic effect in soil



Plot-7.12
Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach without considering center elastic effect in soil



Plot-7.13
Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach without considering center elastic effect in soil

7.6.2 CASE:-2 : CONSIDERING CENTER ELASTIC EFFECT IN SOIL MASS

7.6.2.1 MODAL ANALYSIS OF CASE-2

As per the interaction with IIT-R, it was suggested that the flexibility of the soil mass can be incorporated in to FE model by increasing the density of solid element in the center of soil mass system. Therefore for precise understanding of the displacement pattern, finer mess was incorporated in the middle portion of the soil model in both directions. Material properties and boundary condition used in the modeling of an antenna supporting structure with raft and soil mass in this case are kept same as explained in chapter 5. For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.281 Hz. Figure 7.3 shows the 3-d modeling of an antenna supporting structure with raft and soil mass considering center elastic effect in soil in ANSYS 8.0. Table 7.4 shows the free vibration result of an antenna supporting structure. Plot 7.14 shows the Mode Number vs. Frequency (Hz) for modal analysis results.

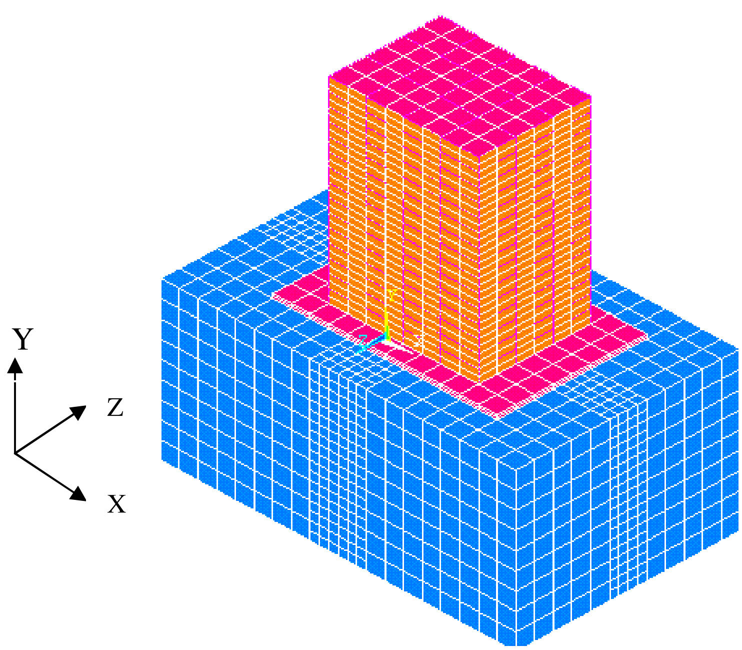
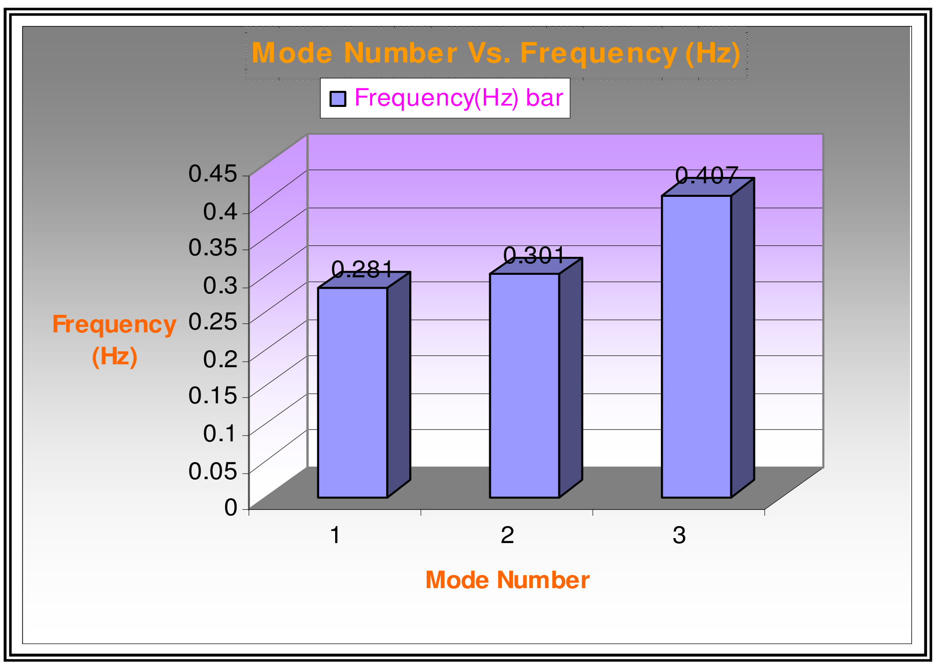


Figure 7.3 3-d modeling of system approach without considering center elastic effect in soil in ANSYS 8.0

TABLE 7.4
Standard frequency results of System Approach considering center elastic effect in soil [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.281	3.559
2	0.301	3.31
3	0.401	2.449



Plot 7.14
Mode Number vs. Frequency (Hz) for modal analysis result for system approach considering center elastic effect in soil

7.6.2.2 RESPONSE SPECTRUM ANALYSIS OF CASE-2

Using modal analysis results response spectrum analysis is carried out for Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.5 and Table 7.6 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.15 and plot 7.16 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for Bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

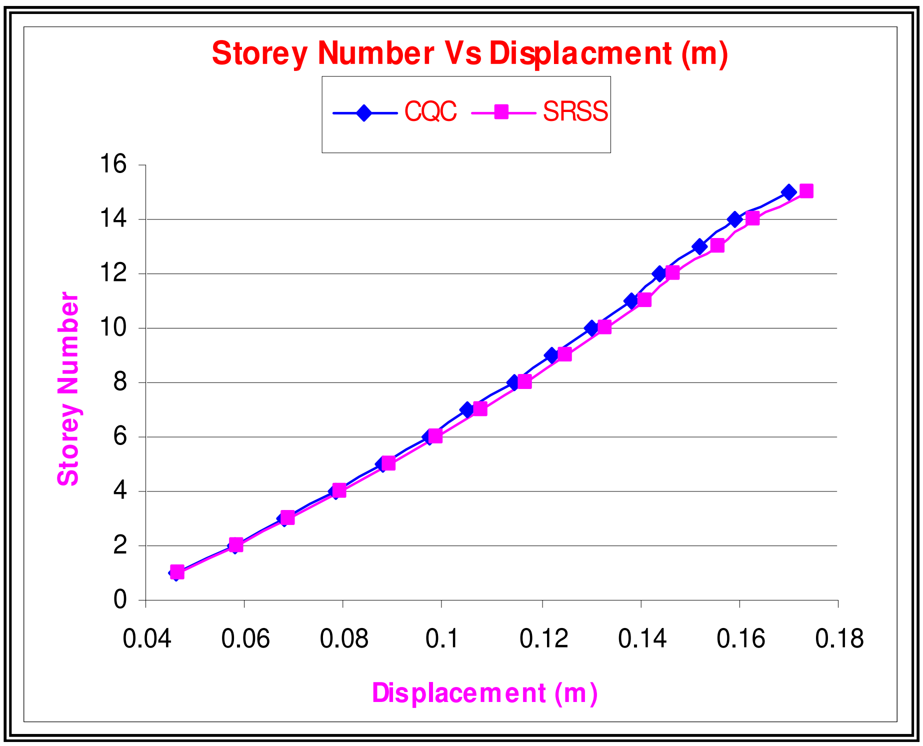
Plot 7.17 and plot 7.18 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.19 and 7.20 shows the response history plot for two different extreme node at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

Table 7.5
Maximum displacement result of system approach considering center elastic effect in soil for Bhuj E.Q data given as forcing function in X-direction

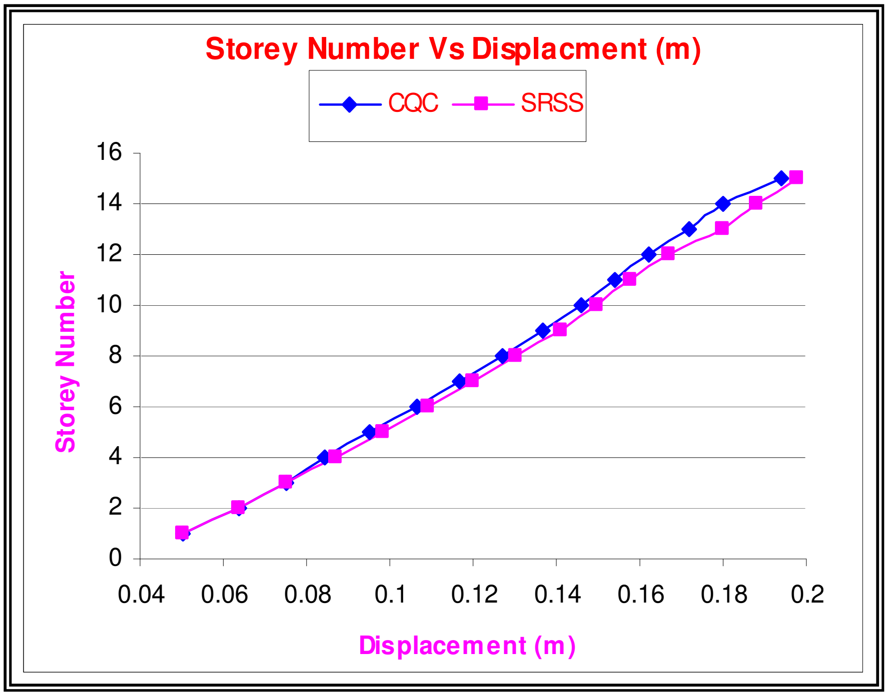
Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.174	0.170
Top of Raft	0.484E-02	0.481E-02
Top of Soil	0.433E-02	0.431E-02

Table 7.6
Maximum displacement result of system approach considering center elastic effect in soil for Bhuj E.Q data given as forcing function in Z-direction

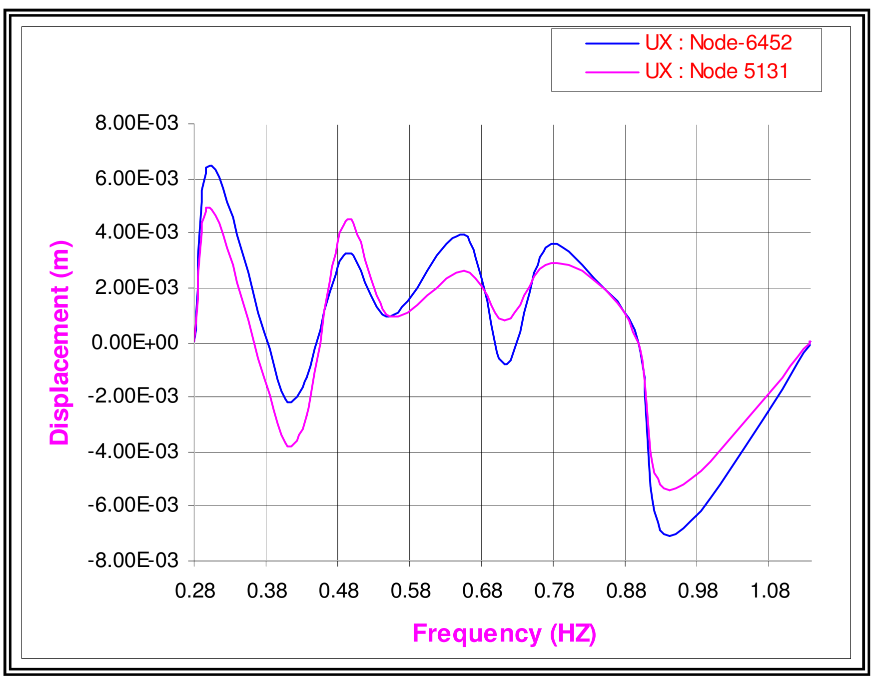
Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.198	0.194
Top of Raft	0.410E-02	0.405E-02
Top of Soil	0.384E-02	0.377E-02



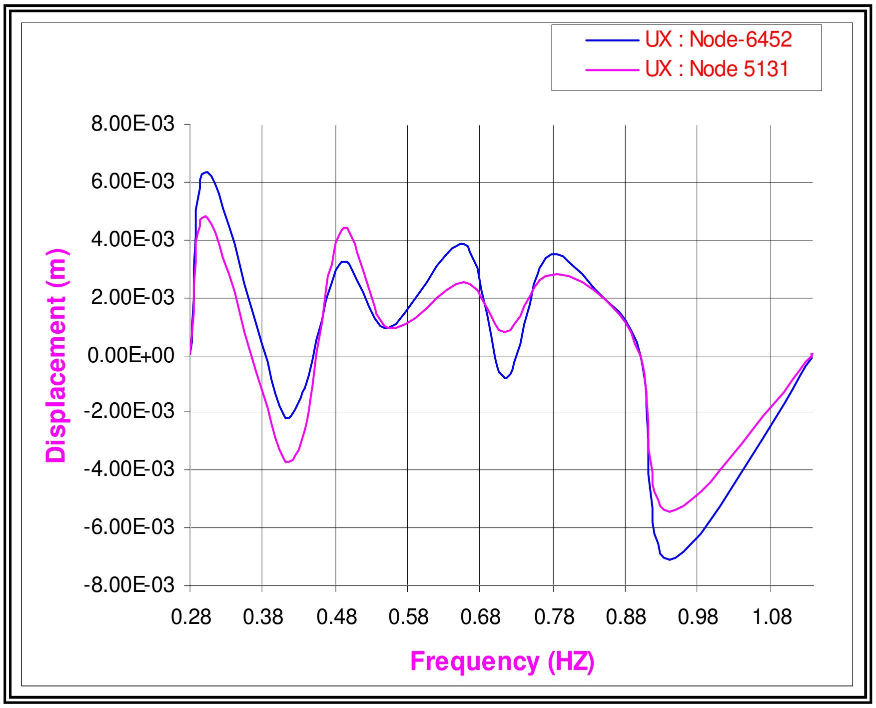
Plot 7.15
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach considering center elastic effect for Bhuj E.Q data given in X-direction



Plot 7.16
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach considering center elastic effect for Bhuj E.Q data given in Z-direction

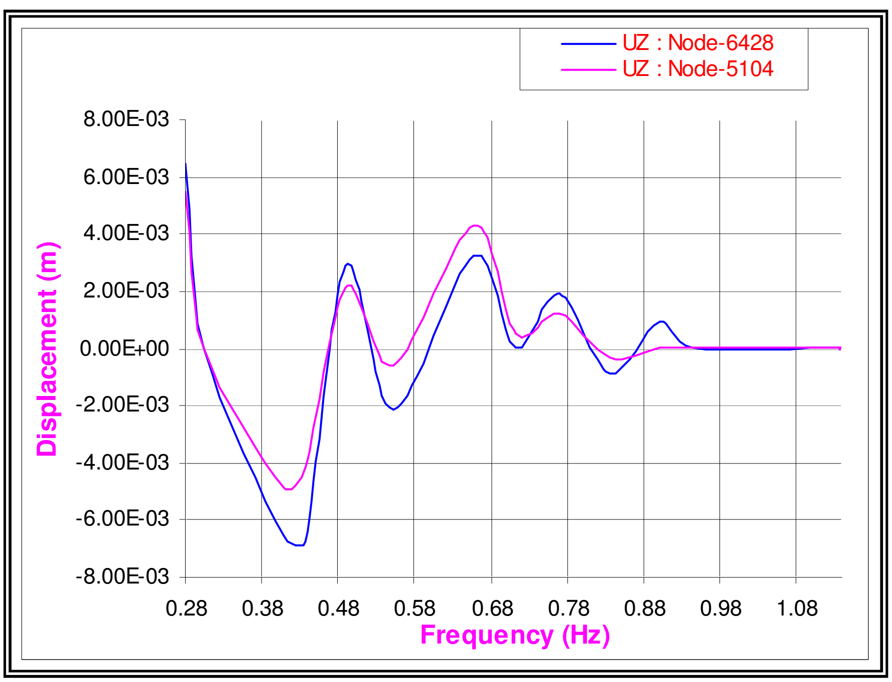


Plot-7.17
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach with considering center elastic effect in soil



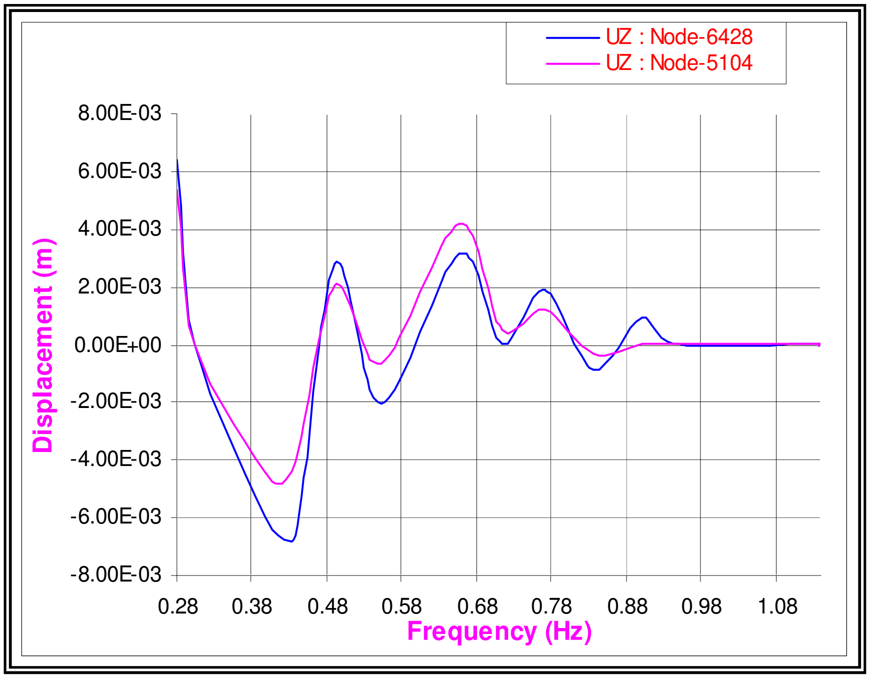
Plot-7.18

Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach with considering center elastic effect in soil



Plot-7.19

Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach with considering center elastic effect in soil



Plot-7.20

Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach with considering center elastic effect in soil

7.6.3 CASE:-3 : WHEN SOIL MODULUS OF ELASTICITY OF HORIZONTAL PLANE IS ABOUT 2/3 OF VERTICAL PLANE

7.6.3.1 MODAL ANALYSIS OF CASE-3

As per the advice of IIT-R this case is also studied. The soil properties considered for the analysis can be derived by using the following expression w.r.t. shear wave velocity, density of soil and Poisson's ratio. Using these soil properties, elastic modulus of soil can be calculated using the following relation

$$V_s = \sqrt{E / 2\rho(1+\upsilon)}$$

Where,

E = Elastic modulus of soil.

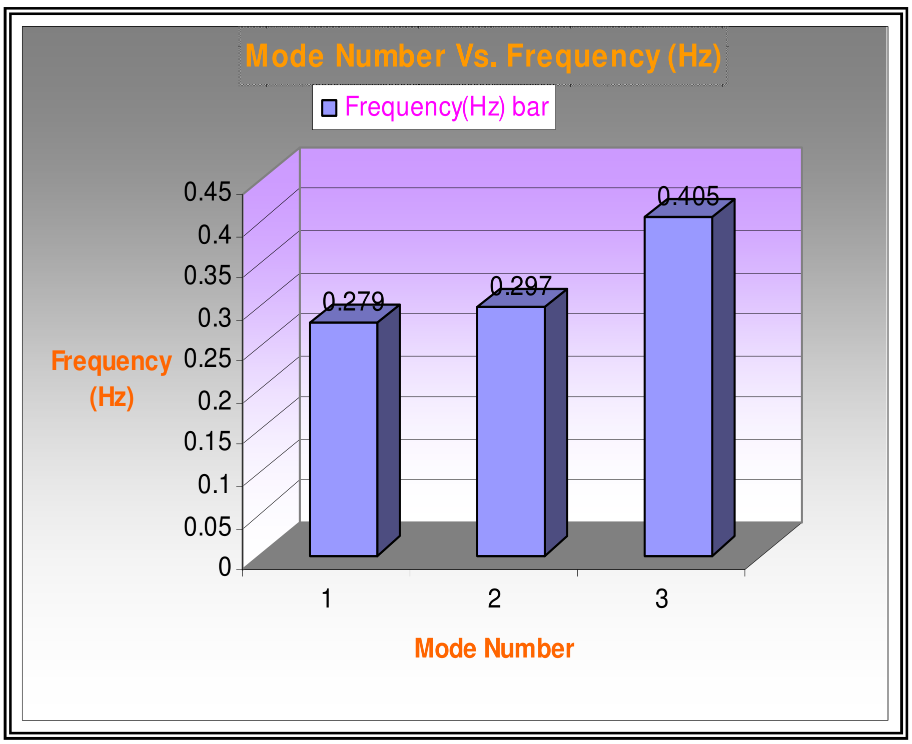
ρ = *Density of soil.*

υ = *Poisson's ratio of soil.*

Modulus of Elasticity of soil in vertical plane depends upon the shear wave velocity values. This approach of modeling the E of soil in horizontal plane is 2/3rd of value in vertical plane is adopted to estimate the upper bound in displacement domains in the horizontal plane. Material properties of other components are kept same as explained in chapter 5. Boundary conditions used in the modeling of an antenna supporting structure with raft and soil mass in this case are kept same as explained in chapter 5. For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.279 Hz. Table 7.7 shows the free vibration result of an antenna supporting structure. Plot 7.21 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

TABLE 7.7
Standard frequency results of
System Approach for Case-3 [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.279	3.584
2	0.297	3.367
3	0.405	2.469



Plot 7.21
Mode Number vs. Frequency (Hz) for modal analysis result for system approach for case-3

7.6.3.2 RESPONSE SPECTRUM ANALYSIS OF CASE-3

Using modal analysis result response spectrum analysis is carried out for Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.8 and Table 7.9 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.22 and plot 7.23 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.24 and plot 7.25 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.26 and 7.27 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

Table 7.8

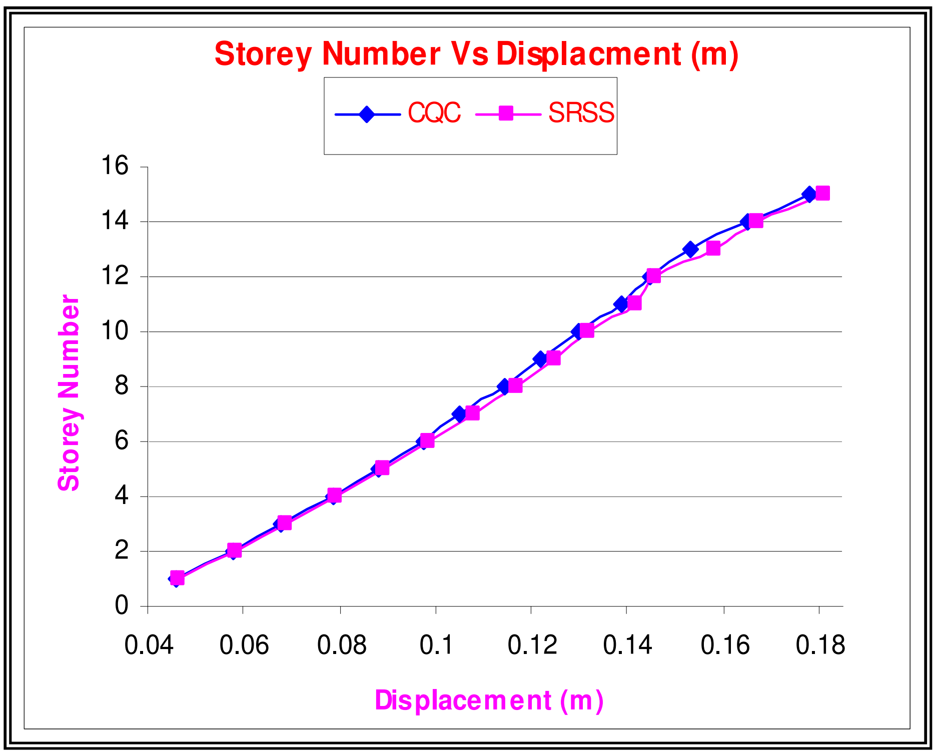
Maximum displacement result of system approach for case-3 for Bhuj E.Q data given as forcing function in X-direction

Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.181	0.178
Top of Raft	0.475E-02	0.470E-02
Top of Soil	0.425E-02	0.418E-02

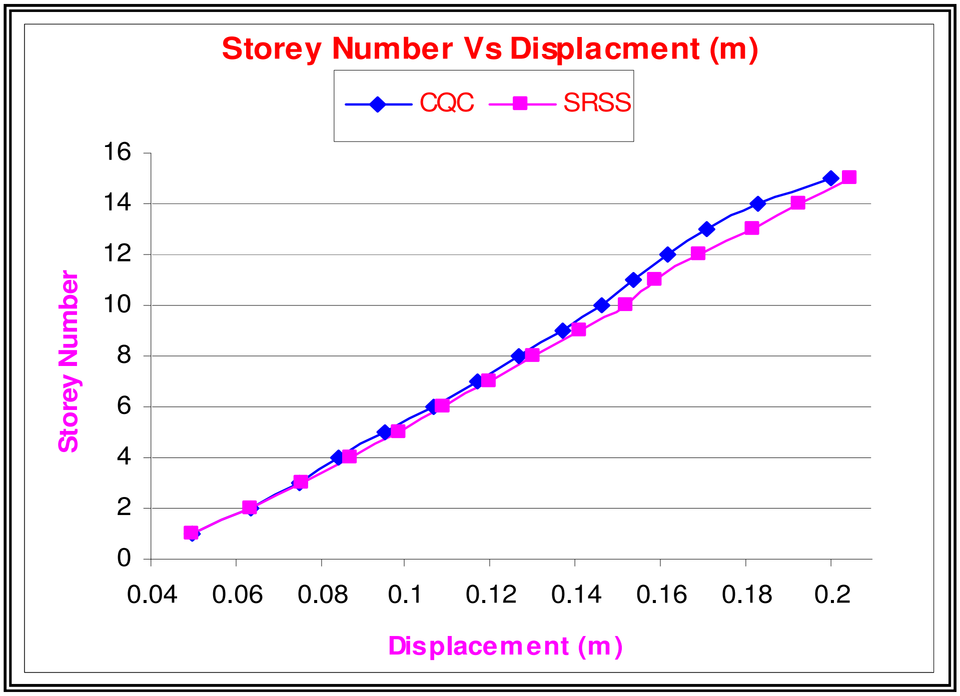
Table 7.9

Maximum displacement result of system approach for case-3 for Bhuj E.Q data given as forcing function in Z-direction

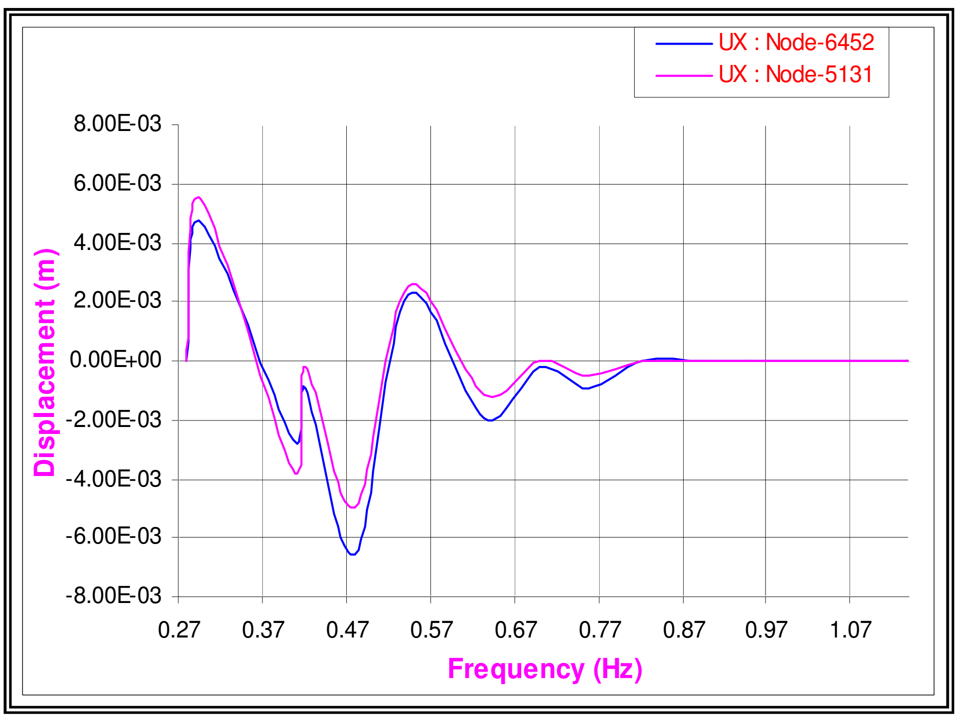
Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.205	0.200
Top of Raft	0.417E-02	0.412E-02
Top of Soil	0.390E-02	0.383E-02



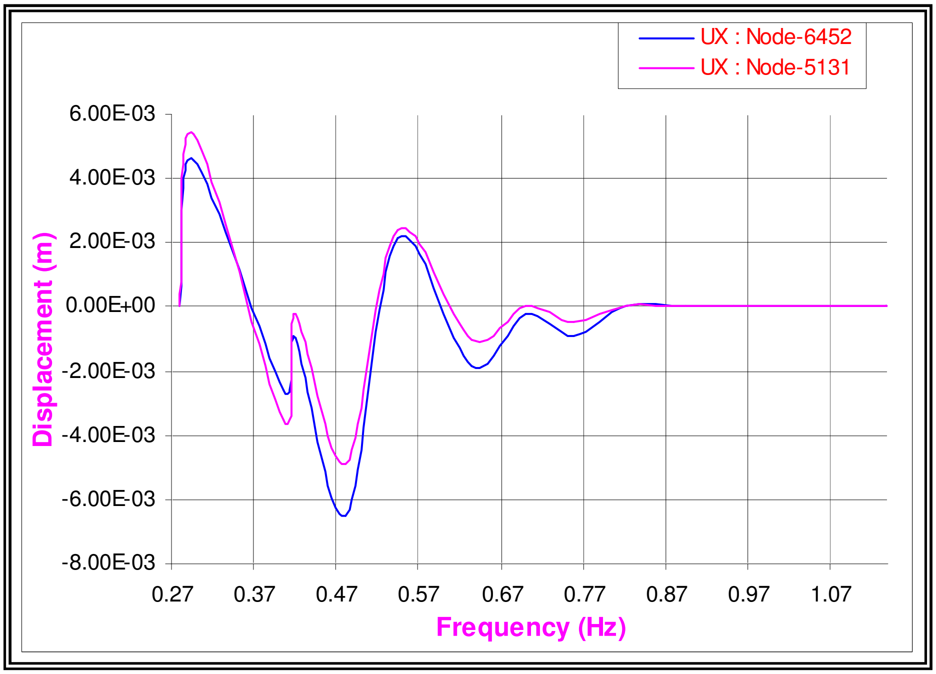
Plot 7.22
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in X-direction for system approach (Case-3)



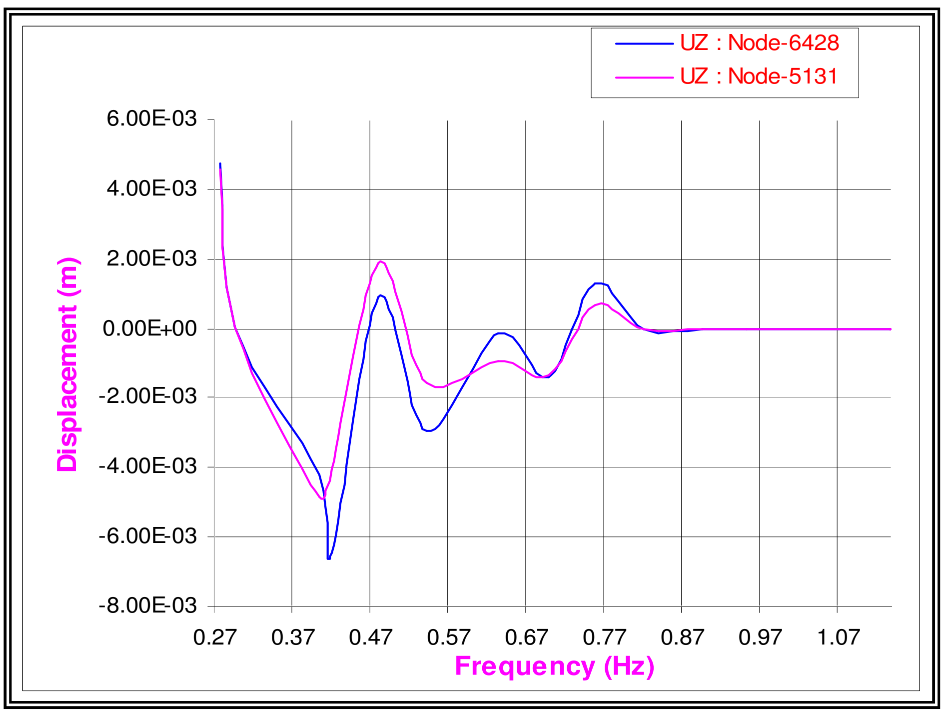
Plot 7.23
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in Z-direction for system approach (Case-3)



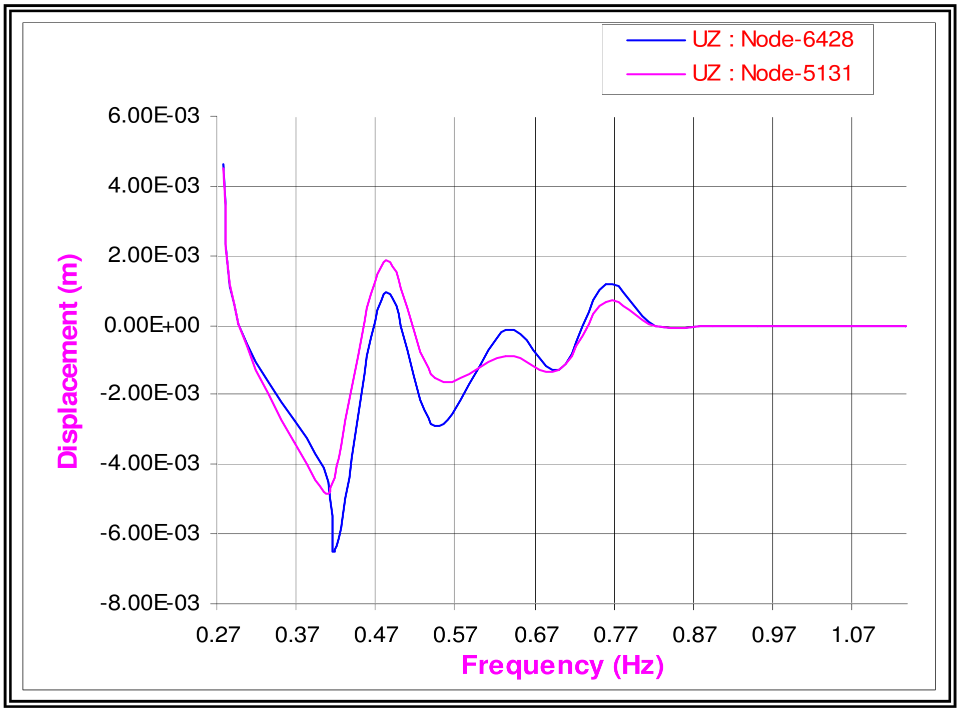
Plot-7.24
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach (Case-3)



Plot-7.25
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach (Case-3)



Plot-7.26
Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach (Case-3)



Plot-7.27
Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach (Case-3)

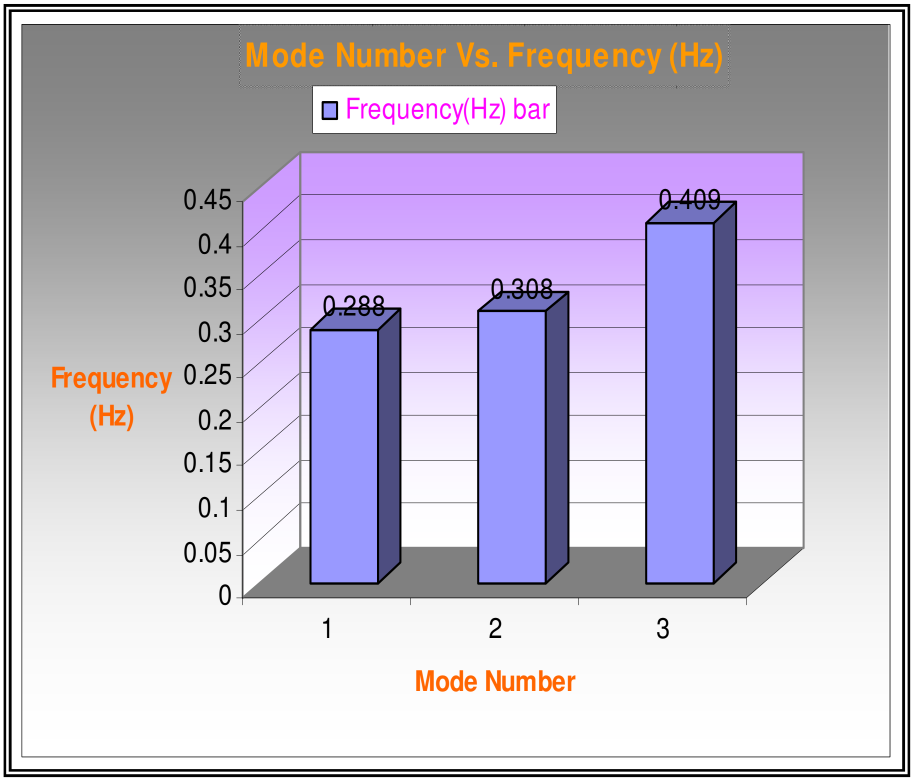
7.6.4 CASE:-4 : FOR SOIL MATERIAL PROPERTIES ARE MODIFIED UP TO 33.5%

7.6.4.1 MODAL ANALYSIS OF CASE-4

As per the advice of IIT-R this case is also studied. The soil properties considered for this case are modified up to 33.5% for carrying out the response spectrum analysis. As mentioned in standard design codes, earthquake and wind loads are short duration loads. It is observed that, when earthquake strikes structural response for the entire structural system takes time to build up. So, In order to more realistically estimate the behavior of the holistic model, as per the IS 1893 the soil properties have been jacked up by 33.5% Boundary condition used in the modeling of an antenna supporting structure with raft and soil mass in this case are kept same as explained in chapter 5. For finding out the response of structural system, modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.288 Hz. Table 7.10 shows the free vibration result of an antenna supporting structure. Plot 7.28 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

TABLE 7.10
Standard frequency results of
System Approach for Case 4 [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.288	3.472
2	0.308	3.246
3	0.409	2.445



Plot 7.28
Mode Number vs. Frequency (Hz) for modal analysis result for system approach for case-4

7.6.4.2 RESPONSE SPECTRUM ANALYSIS OF CASE-4

Using modal analysis result response spectrum analysis is carried out for Bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.11 and Table 7.12 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.29 and plot 7.30 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.31 and plot 7.32 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.33 and 7.34 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

Table 7.11

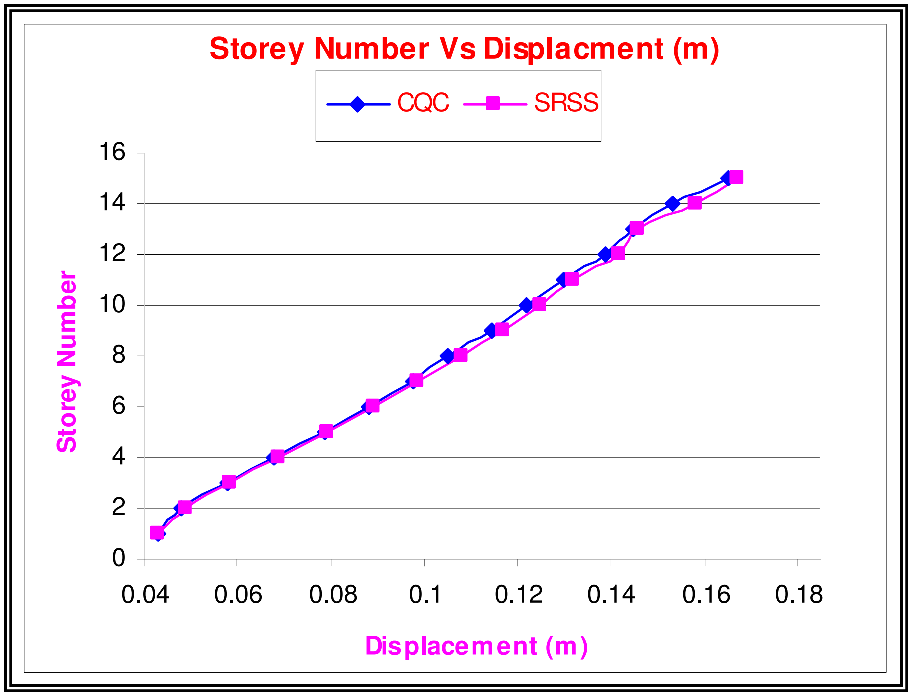
Maximum displacement result of system approach for case-4 for Bhuj E.Q data given as forcing function in X-direction

Maximum Displacement at	**Displacement(m)**	
	SRSS Method	**CQC Method**
Top of an Antenna supporting frame	0.167	0.163
Top of Raft	0.467E-02	0.464E-02
Top of Soil	0.416E-02	0.411E-02

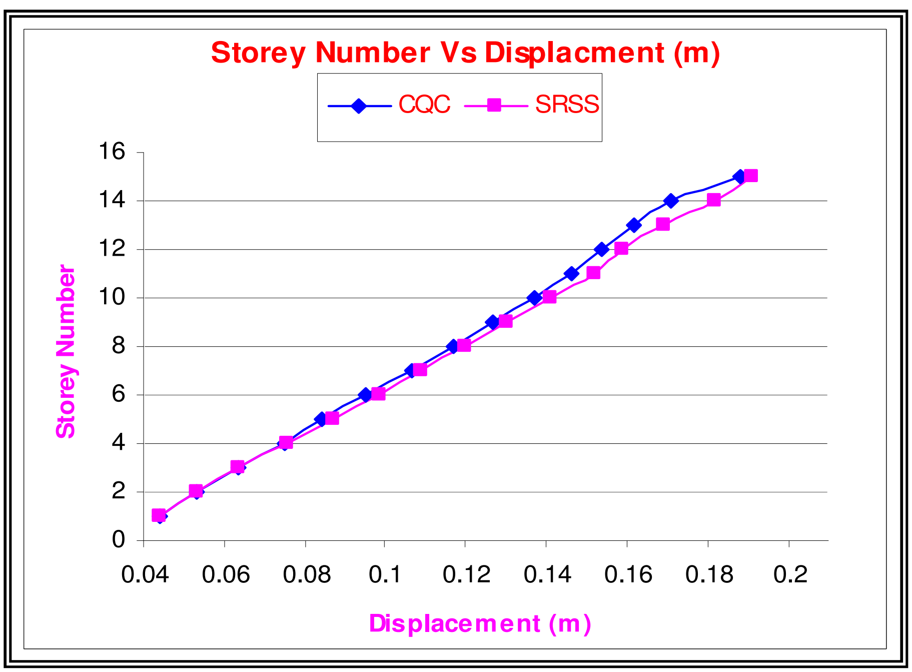
Table 7.12

Maximum displacement result of system approach for case-4 for Bhuj E.Q data given as forcing function in Z-direction

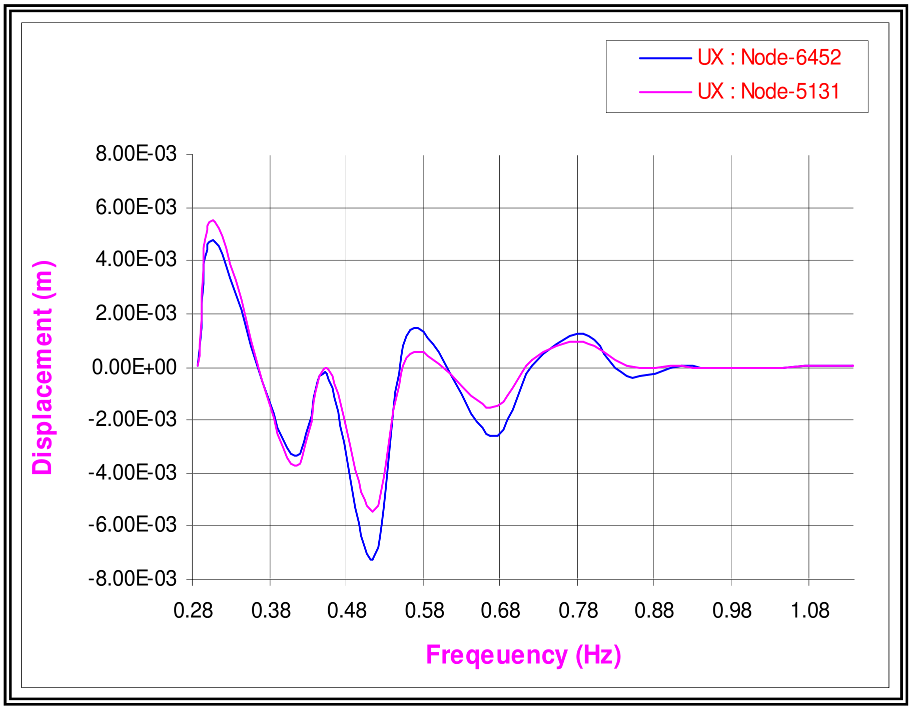
Maximum Displacement at	**Displacement(m)**	
	SRSS Method	**CQC Method**
Top of an Antenna supporting frame	0.191	0.188
Top of Raft	0.402E-02	0.399E-02
Top of Soil	0.377E-02	0.373E-02



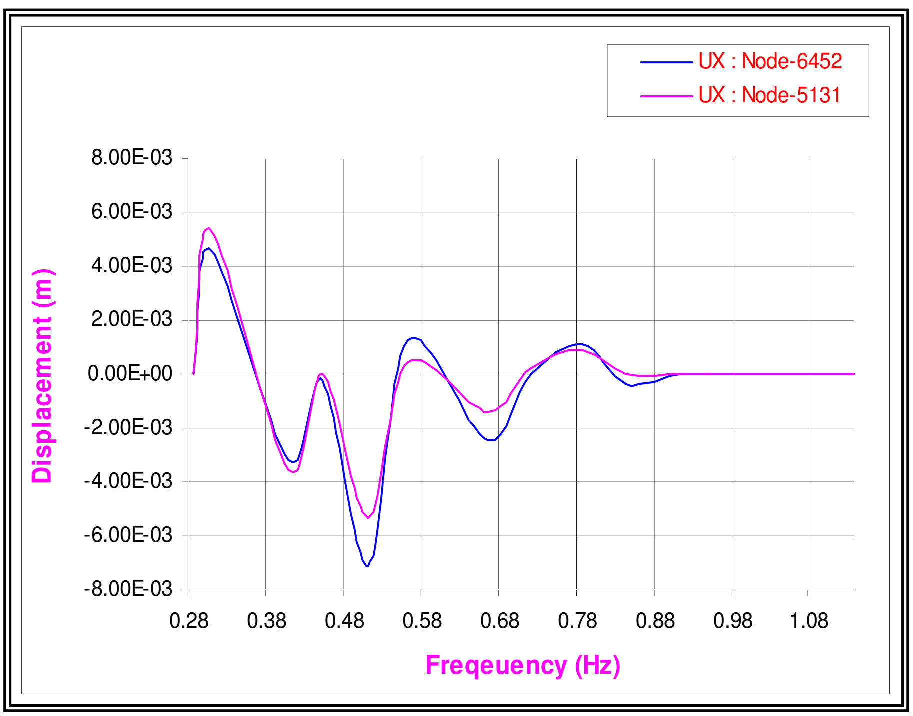
Plot 7.29
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in X-direction for system approach (Case-4)



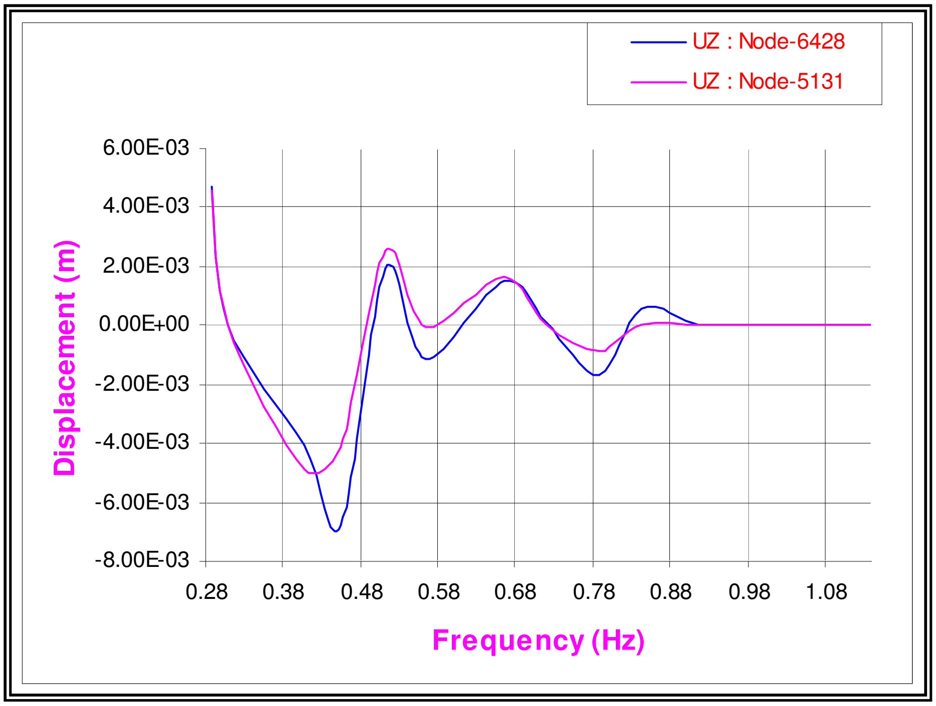
Plot 7.30
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in Z-direction for system approach (Case-4)



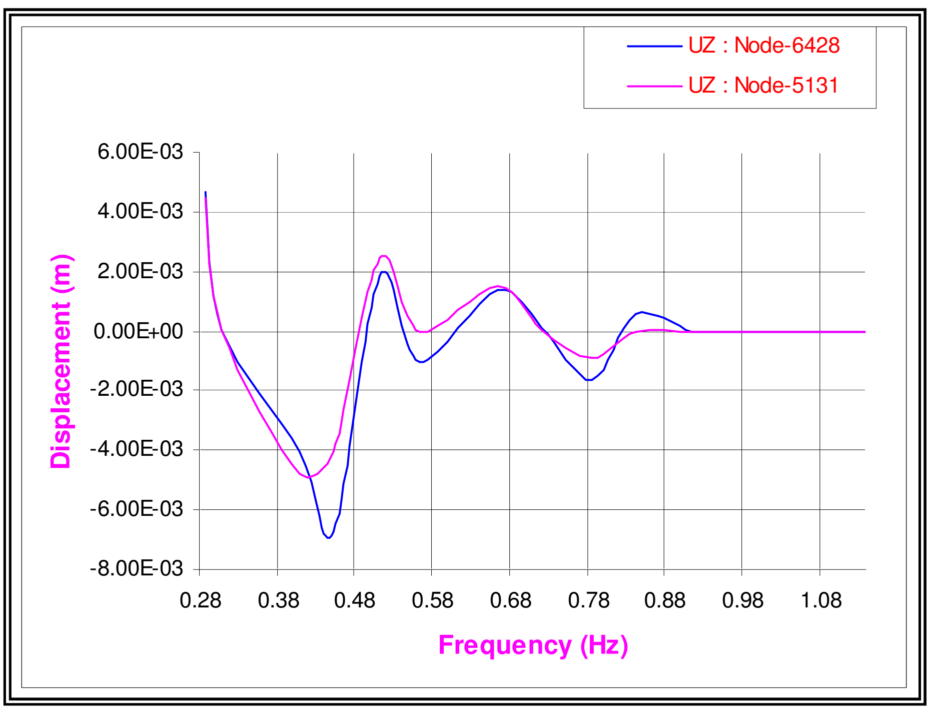
Plot-7.31
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach (Case-4)



Plot-7.32
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach (Case-4)



Plot-7.33
Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach (Case-4)



Plot-7.34
Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach (Case-4)

7.7 HOLISTIC APPROACH FOR 10% DAMPING VALUE OF CONCRETE

As per IIT-R suggestion response spectrum analysis was carried out for all above cases for actual bhuj earthquake data for 10% damping of concrete in both x-direction and z-direction

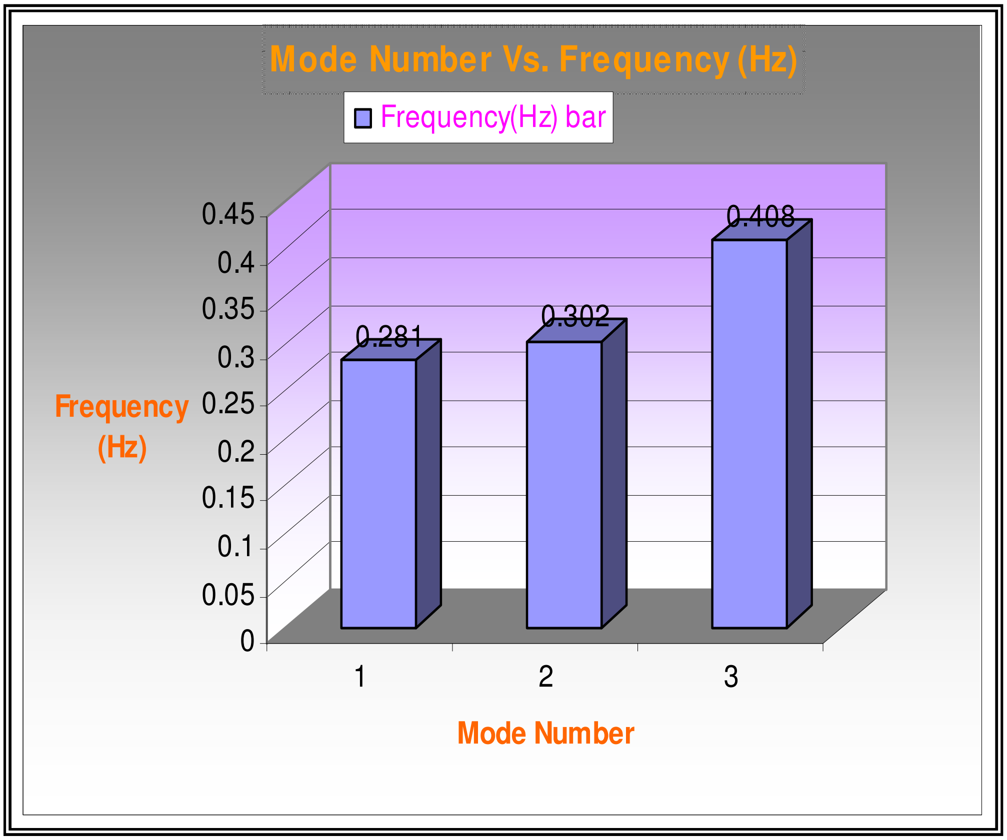
7.7.1 CASE:-1 : WITHOUT CONSIDERING CENTER ELASTIC EFFECT IN SOIL MASS

7.7.1.1 MODAL ANALYSIS OF CASE-1

For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.281 Hz. Table 7.13 shows the free vibration result of an antenna supporting structure. Plot 7.35 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

TABLE 7.13
Standard frequency results of System Approach without considering center elastic effect [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.281	3.559
2	0.302	3.311
3	0.408	2.450



Plot 7.35
Mode Number vs. Frequency (Hz) for system approach without considering center elastic effect for modal analysis result.

7.7.1.2 RESPONSE SPECTRUM ANALYSIS OF CASE-1

Using modal analysis result response spectrum analysis is carried out for Bhuj earthquake data. For combining modes two different method SRSS method and CQC method is used. Table 7.14 and Table 7.15 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to bhuj earthquake data for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.36 and plot 7.37 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for Bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.38 and 7.39 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in x-direction for SRSS method and CQC method respectively. Plot 7.40 and 7.41 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in z-direction for SRSS method and CQC method respectively.

Table 7.14

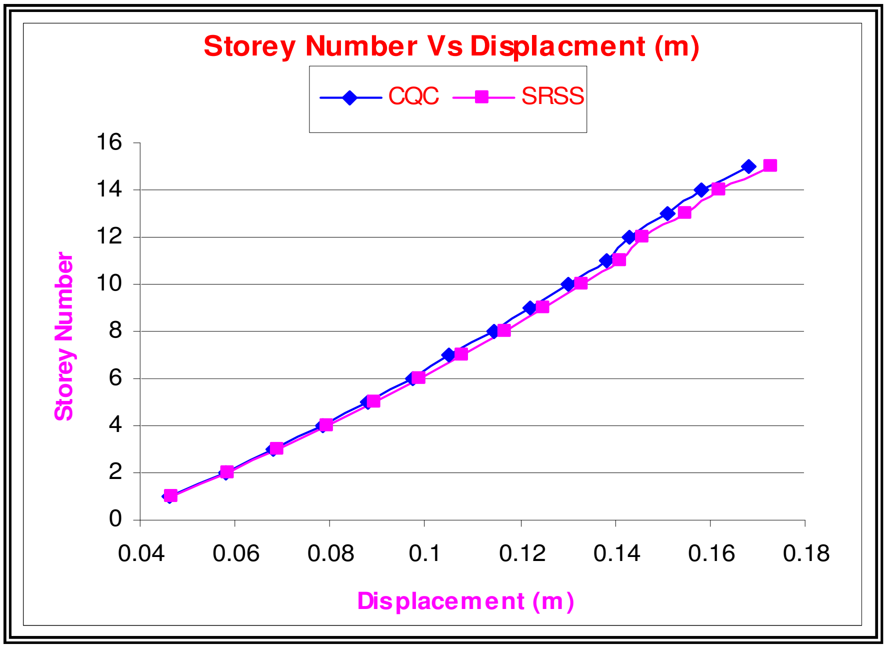
Maximum displacement result of system approach without considering center elastic effect in soil for Bhuj E.Q data given as forcing function in X-direction

Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.173	0.168
Top of Raft	0.473E-02	0.470E-02
Top of Soil	0.424E-02	0.419E-02

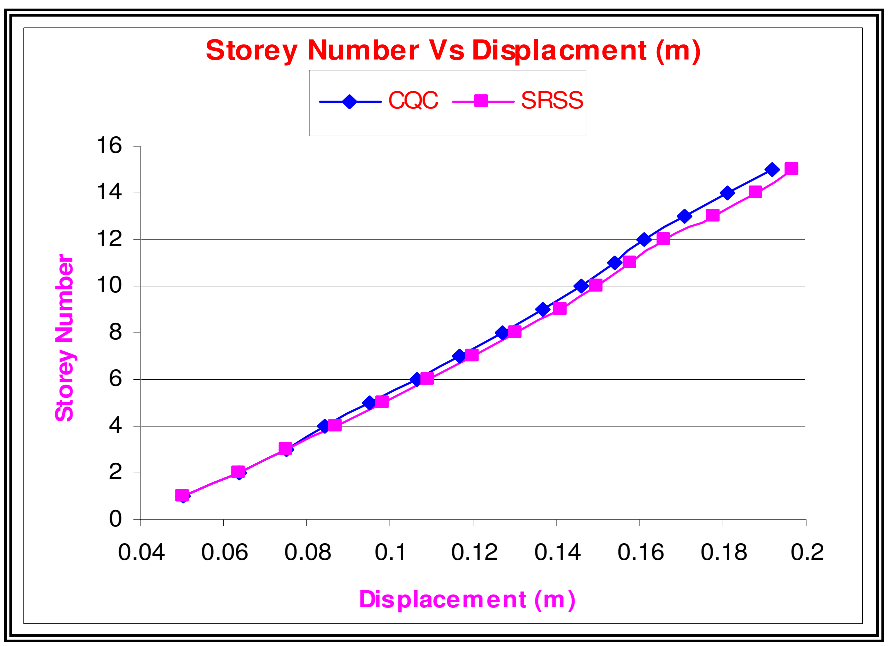
Table 7.15

Maximum displacement result of system approach without considering center elastic effect in soil for Bhuj E.Q data given as forcing function in Z-direction

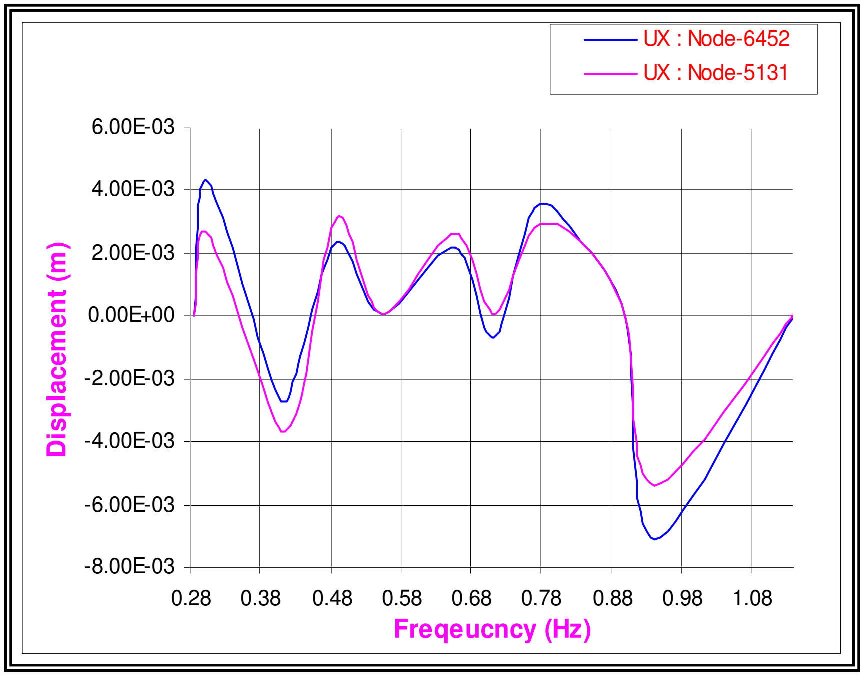
Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.197	0.192
Top of Raft	0.408E-02	0.403E-02
Top of Soil	0.381E-02	0.380E-02



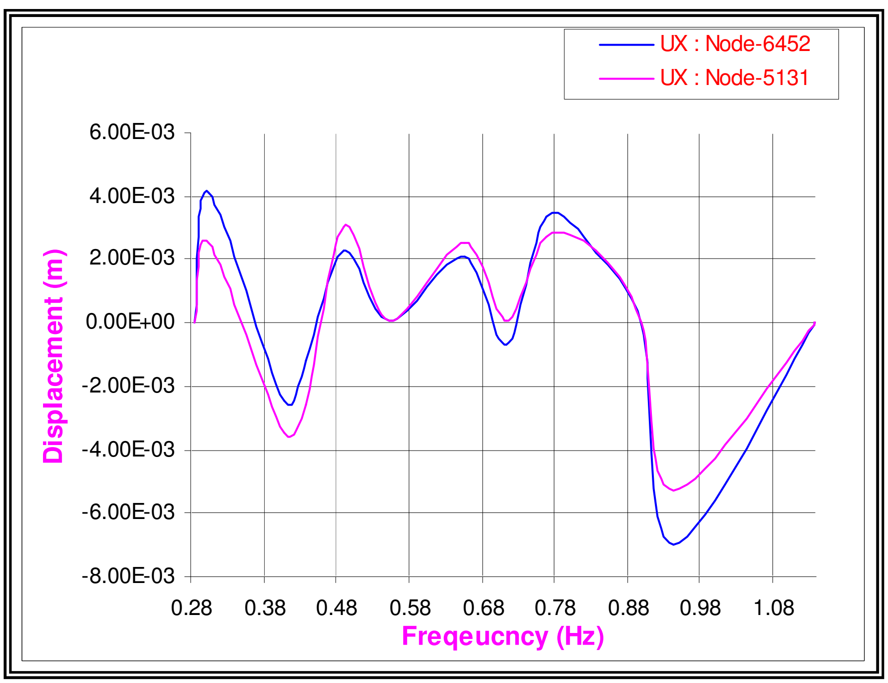
Plot 7.36
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach without considering center elastic effect for Bhuj E.Q data given in X-direction



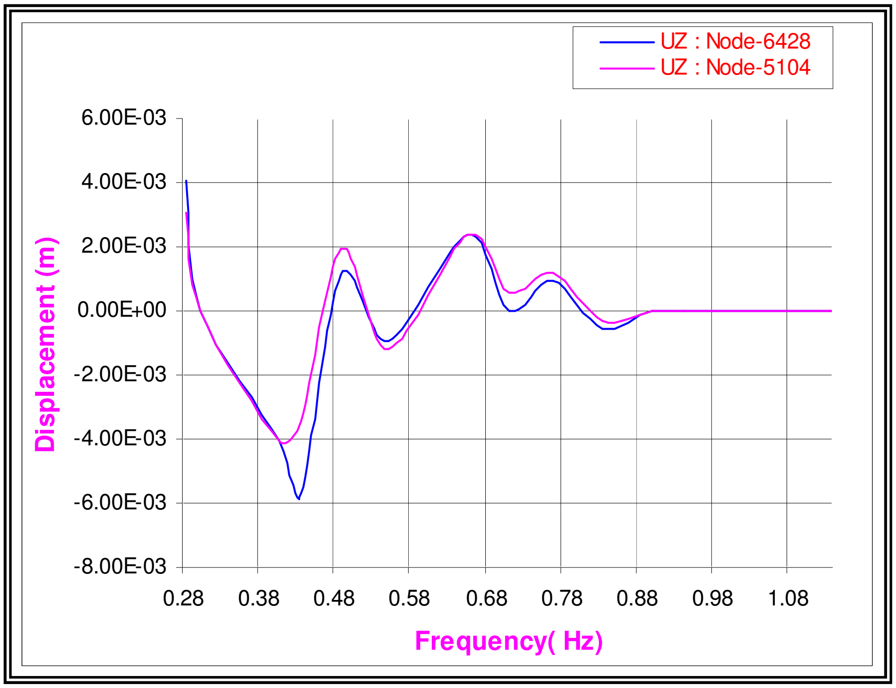
Plot 7.37
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach without considering center elastic effect for Bhuj E.Q data given in Z-direction



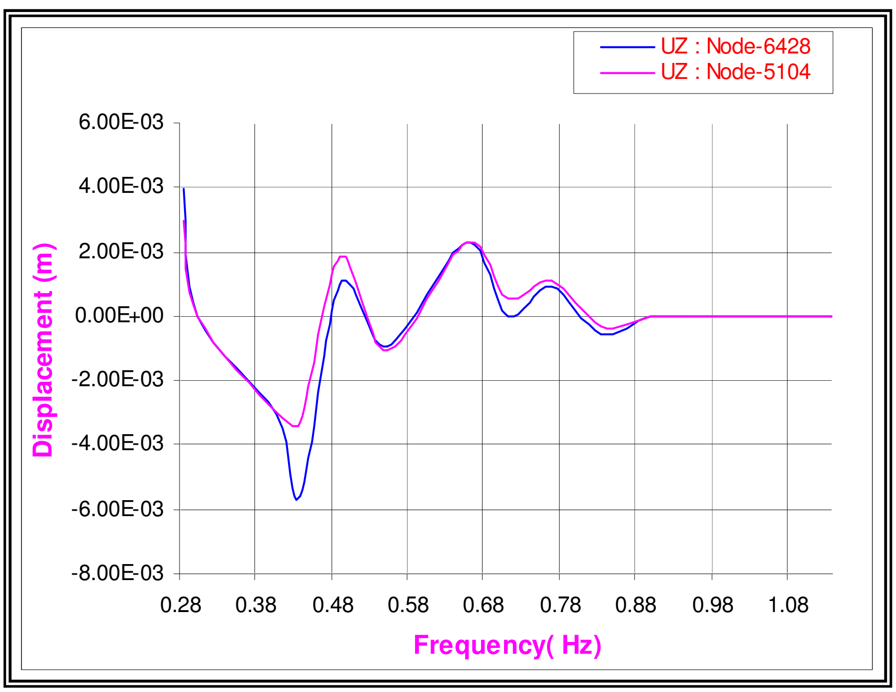
Plot-7.38
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach without considering center elastic effect in soil



Plot-7.39
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach without considering center elastic effect in soil



Plot-7.40
Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach without considering center elastic effect in soil



Plot-7.41
Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach without considering center elastic effect in soil

7.7.2 CASE:-2 : CONSIDERING CENTER ELASTIC EFFECT IN SOIL MASS

7.7.2.1 MODAL ANALYSIS OF CASE-2

As per the interaction with IIT-R, it was suggested that the flexibility of the soil mass can be incorporated in to FE model by increasing the density of solid element in the center of soil mass system. Therefore for precise understanding of the displacement pattern, finer mess was incorporated in the middle portion of the soil model in both directions. Material properties and boundary condition used in the modeling of an antenna supporting structure with raft and soil mass in this case are kept same as explained in chapter 5. For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.281 Hz. Table 7.16 shows the free vibration result of an antenna supporting structure. Plot 7.42 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

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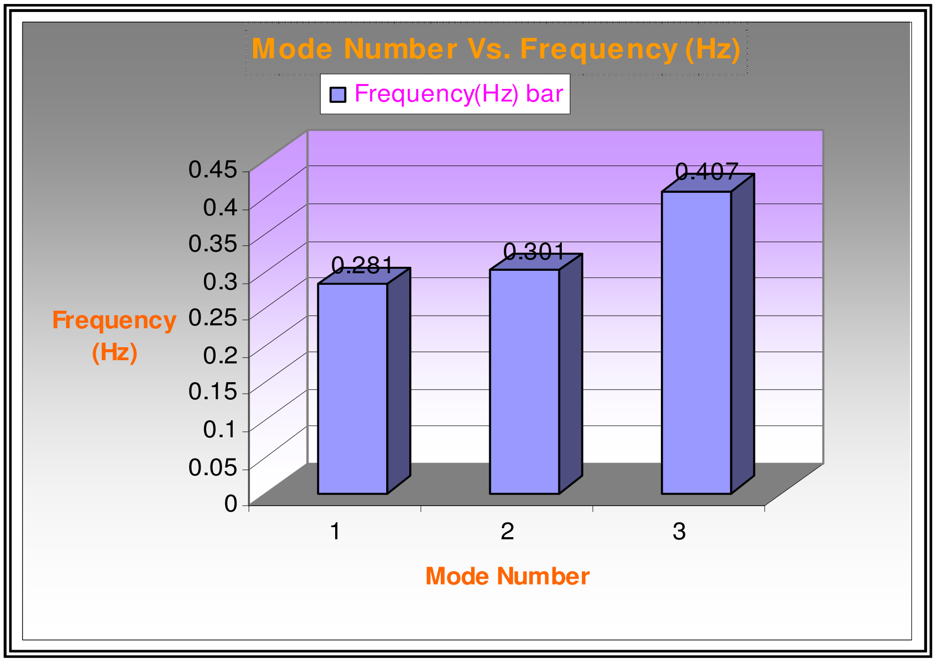
TABLE 7.16
Standard frequency results of System Approach considering center elastic effect [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.281	3.559
2	0.301	3.31
3	0.401	2.449



Plot 7.42
Mode Number vs. Frequency (Hz) for modal analysis result for system approach considering center elastic effect in soil

7.7.2.2 RESPONSE SPECTRUM ANALYSIS OF CASE-2

Using modal analysis result response spectrum analysis is carried out for bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.17 and Table 7.18 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.43 and plot 7.44 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.45 and plot 7.46 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in x-direction for SRSS method and CQC method respectively. Plot 7.47 and 7.48 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

Table 7.17

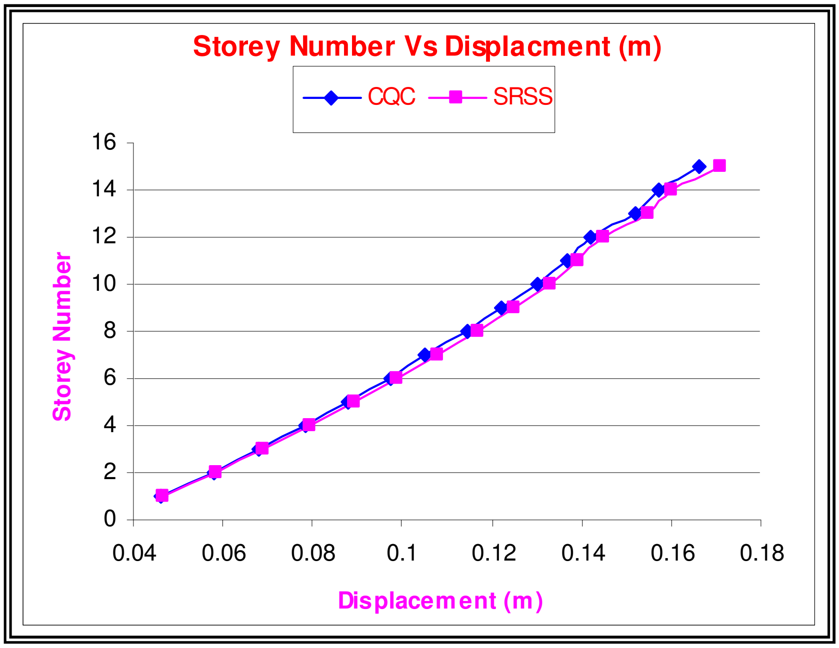
Maximum displacement result of system approach considering center elastic effect in soil for Bhuj E.Q data given as forcing function in X-direction

Maximum Displacement at	**Displacement(m)**	
	SRSS Method	**CQC Method**
Top of an Antenna supporting frame	0.171	0.166
Top of Raft	0.480E-02	0.478E-02
Top of Soil	0.429E-02	0.428E-02

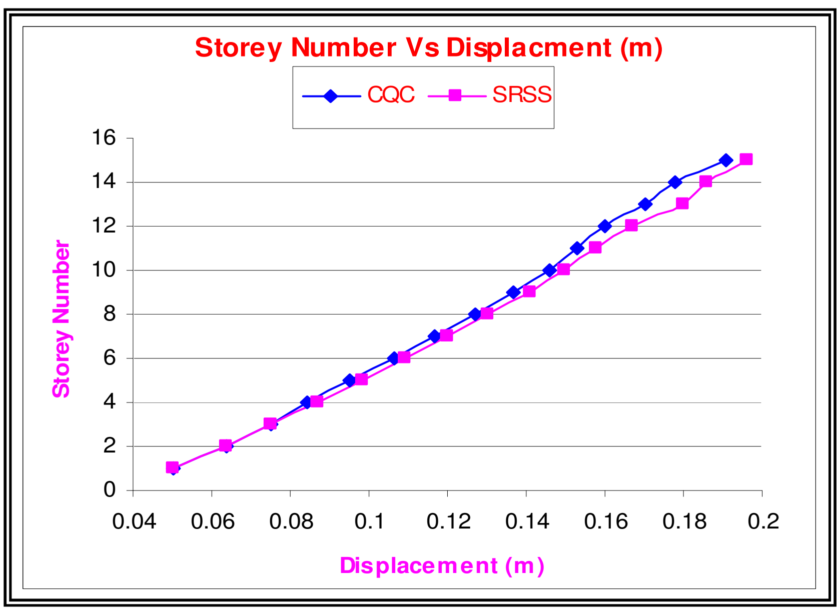
Table 7.18

Maximum displacement result of system approach considering center elastic effect in soil for Bhuj E.Q data given as forcing function in Z-direction

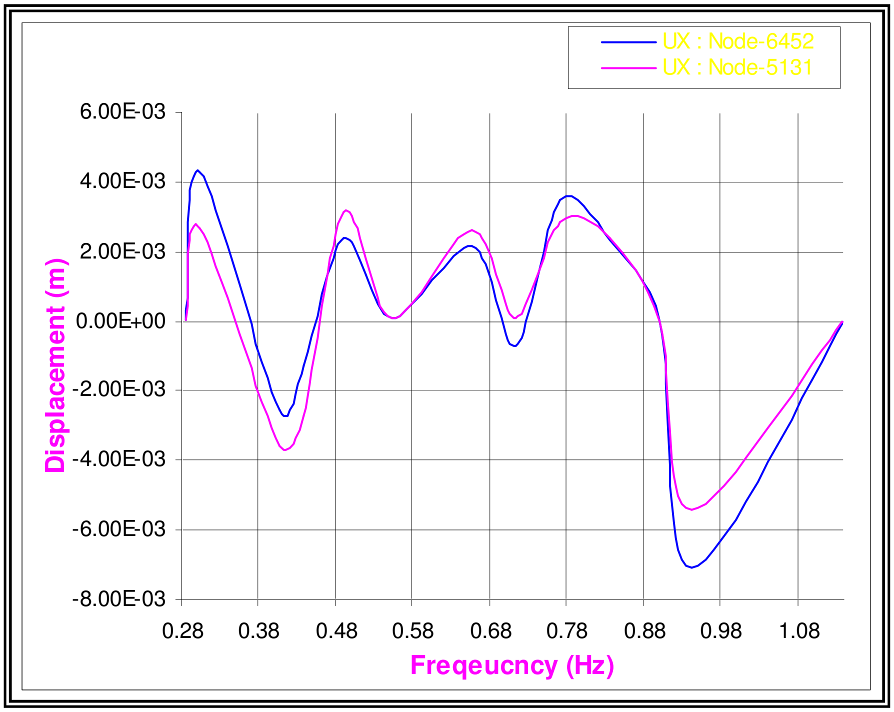
Maximum Displacement at	**Displacement(m)**	
	SRSS Method	**CQC Method**
Top of an Antenna supporting frame	0.196	0.191
Top of Raft	0.407E-02	0.403E-02
Top of Soil	0.381E-02	0.374E-02



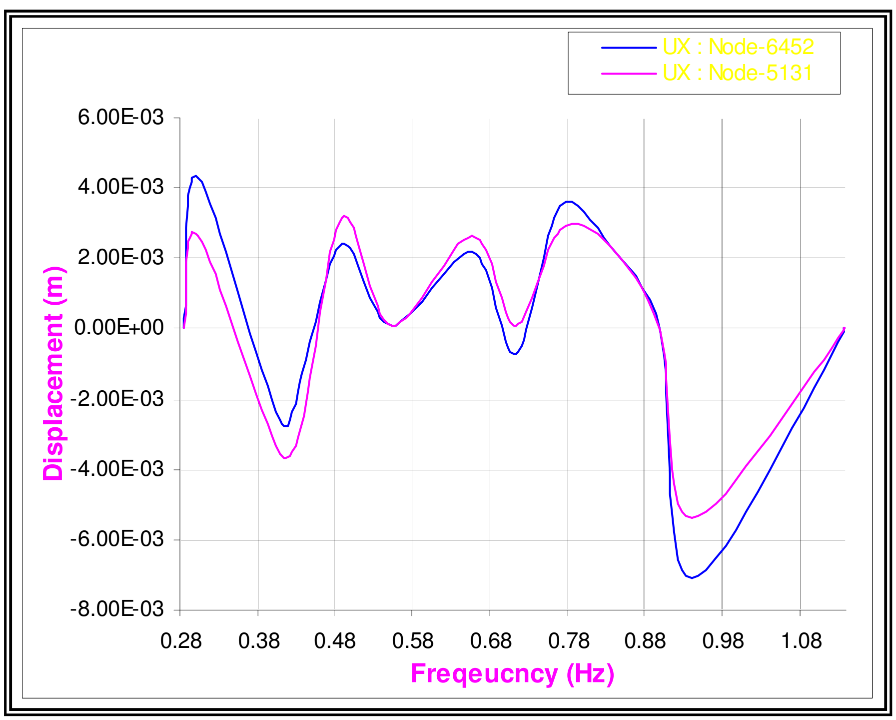
Plot 7.43
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach considering center elastic effect for Bhuj E.Q data given in X-direction



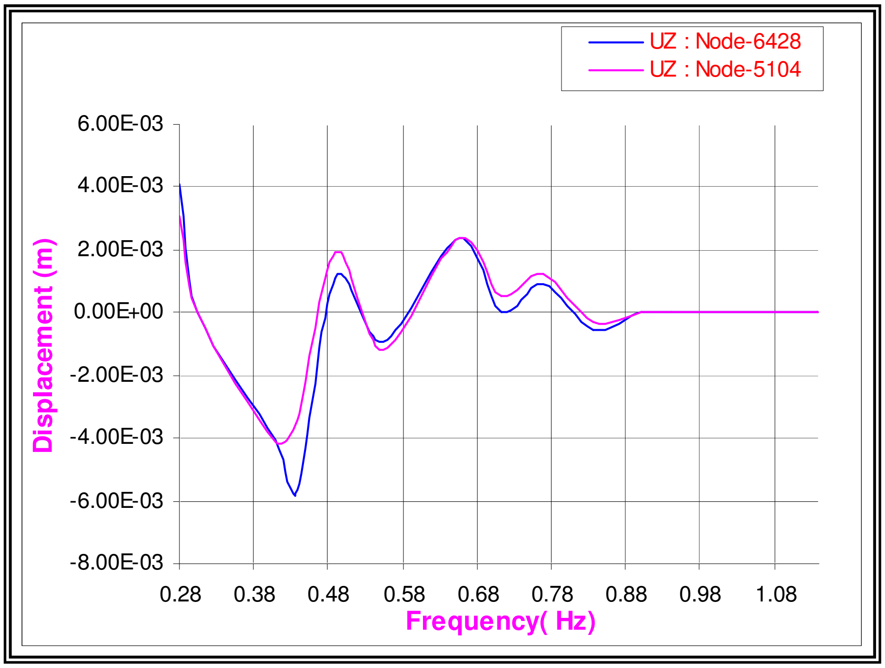
Plot 7.44
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for system approach considering center elastic effect for Bhuj E.Q data given in Z-direction



Plot-7.45
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach with considering center elastic effect in soil

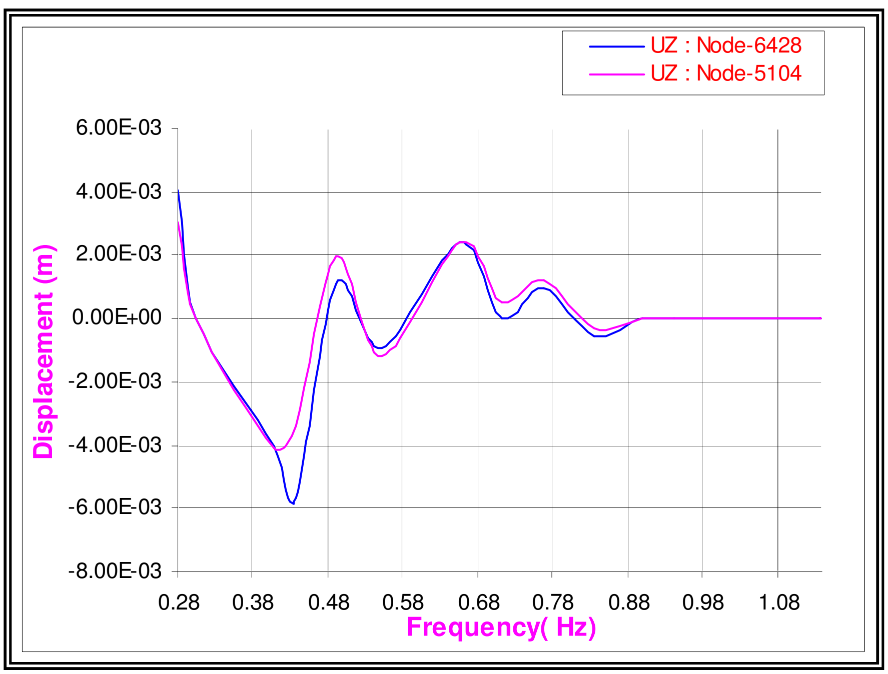


Plot-7.45
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach with considering center elastic effect in soil



Plot-7.46

Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach with considering center elastic effect in soil



Plot-7.47

Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach with considering center elastic effect in soil

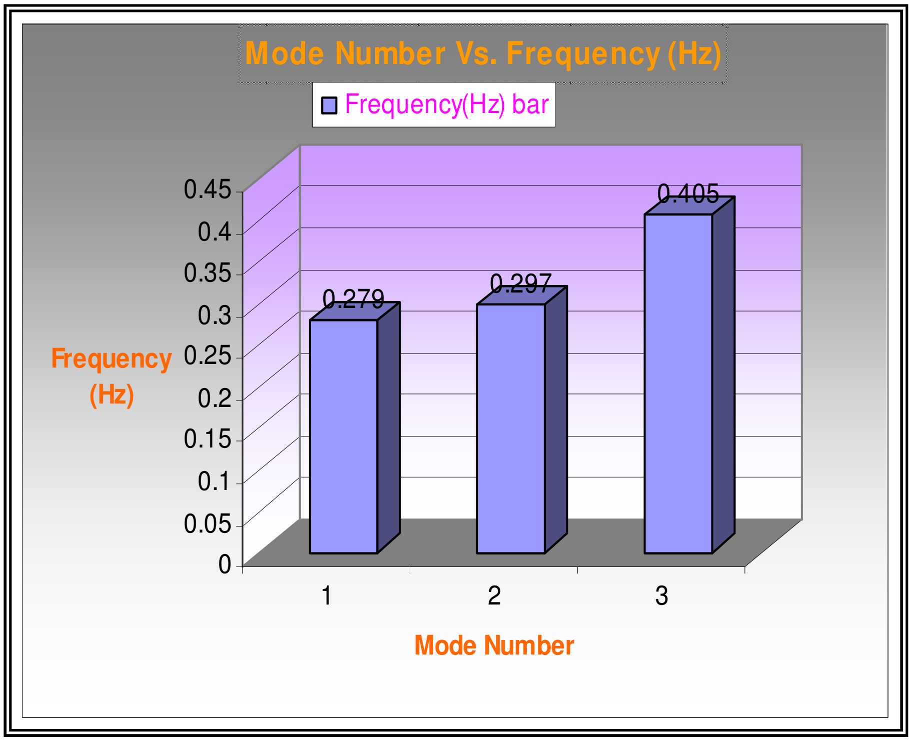
7.7.3 CASE:-3 : FOR SOIL MODULUS OF ELASTICITY OF HORIZONTAL PLANE IS ABOUT 2/3 OF VERTICAL PLANE

7.7.3.1 MODAL ANALYSIS OF CASE-3

As per the advice of IIT-R this case is also studied Modulus of Elasticity of soil in vertical plane is depends upon the shear wave velocity values. This approach of modeling the E of soil in horizontal plane is 2/3rd of its value in vertical plane is adopted to estimate the upper bound in displacement domains in the horizontal plane. Material properties of other component and boundary condition used in the modeling are kept same as explained in chapter 5. For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as .0.279 Hz. Table 7.19 shows the free vibration result of an antenna supporting structure. Plot 7.48 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

TABLE 7.19
Standard frequency results of
System Approach for Case-3 [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.279	3.584
2	0.297	3.367
3	0.405	2.469



Plot 7.48
Mode Number vs. Frequency (Hz) for modal analysis result for system approach for case-3

7.7.3.2 RESPONSE SPECTRUM ANALYSIS OF CASE-3

Using modal analysis result response spectrum analysis is carried out for bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.20 and Table 7.21 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.49 and plot 7.50 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for Bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.51 and plot 7.52 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.53 and 7.55 shows the response history plot for two different extreme node at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

Table 7.20

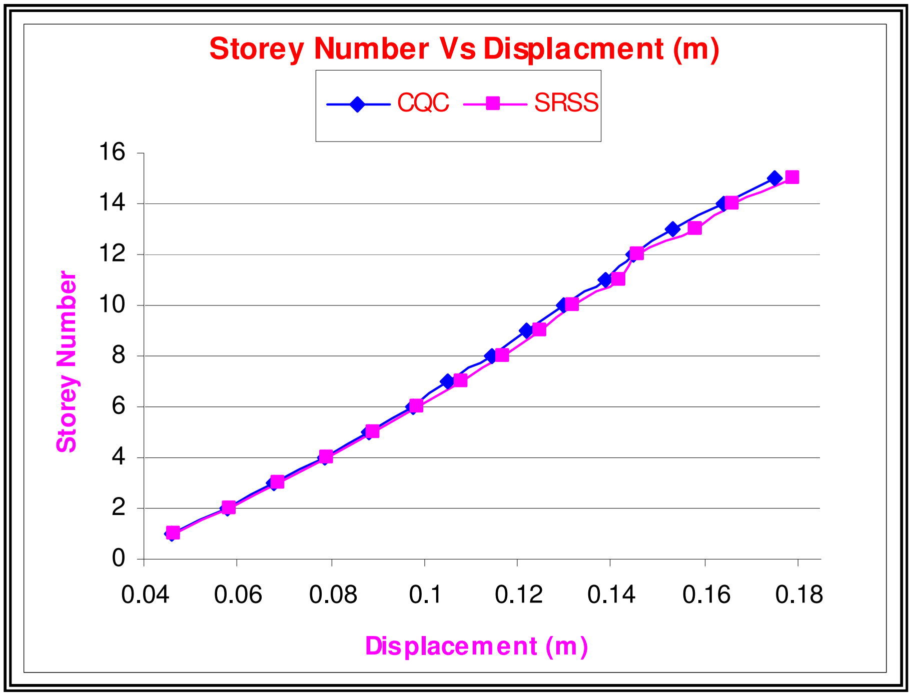
Maximum displacement result of system approach for case-3 for Bhuj E.Q data given as forcing function in X-direction

Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.179	0.175
Top of Raft	0.473E-02	0.467E-02
Top of Soil	0.422E-02	0.416E-02

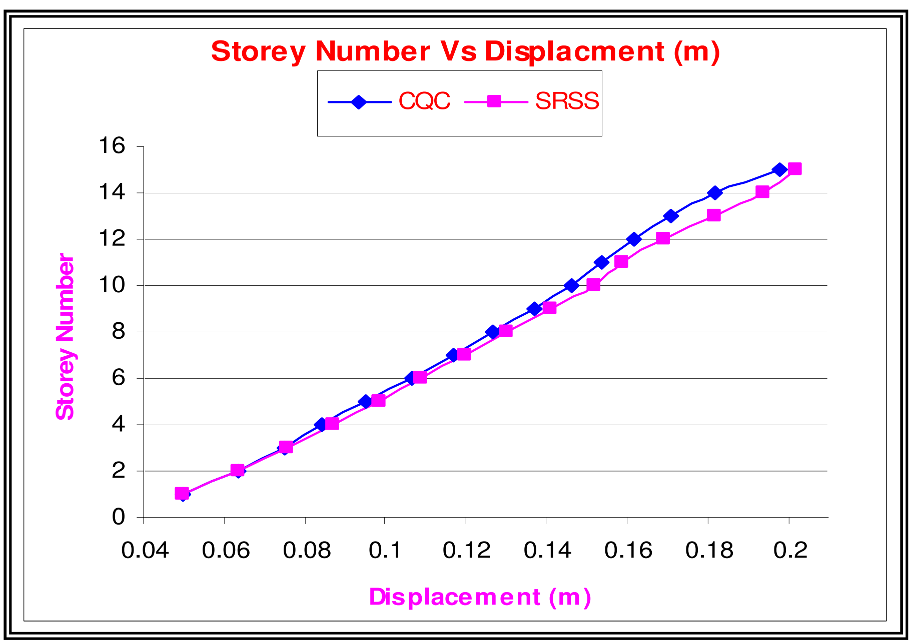
Table 7.21

Maximum displacement result of system approach for case-3 for Bhuj E.Q data given as forcing function in Z-direction

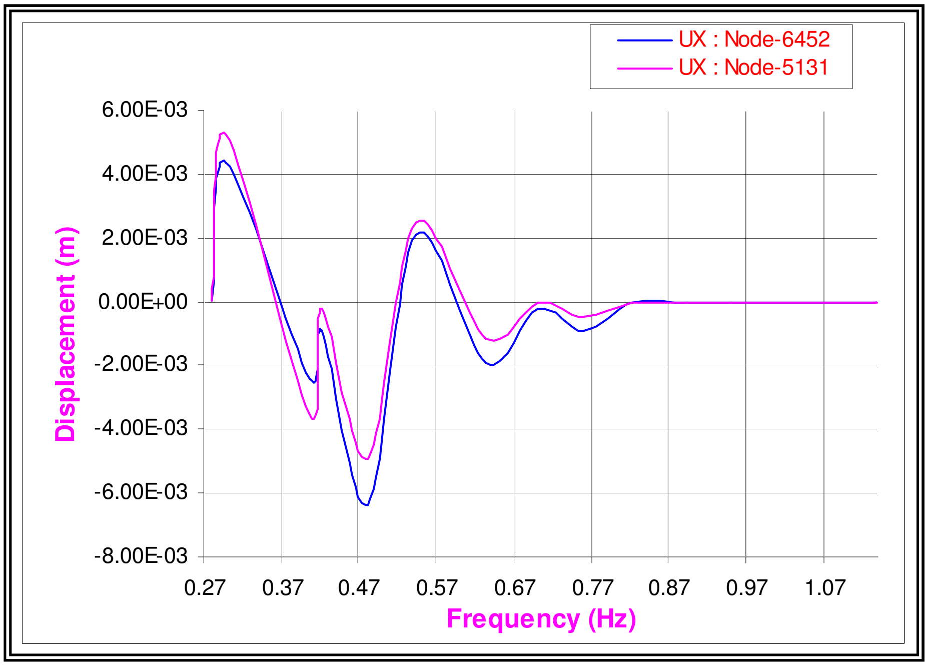
Maximum Displacement at	Displacement(m)	
	SRSS Method	CQC Method
Top of an Antenna supporting frame	0.202	0.198
Top of Raft	0.415E-02	0.410E-02
Top of Soil	0.388E-02	0.381E-02



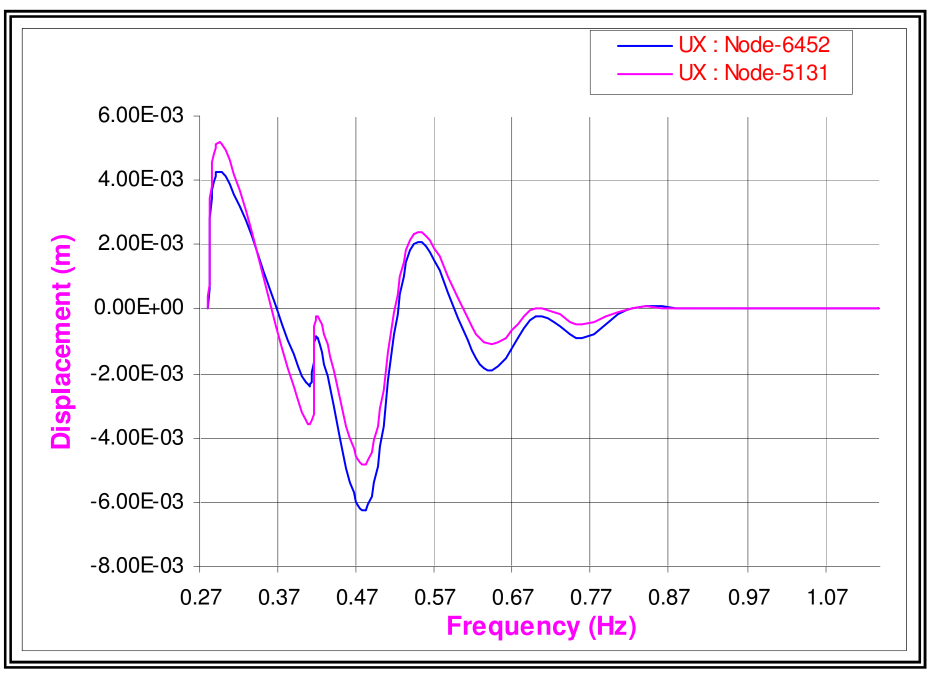
Plot 7.49
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in X-direction for system approach (Case-3)



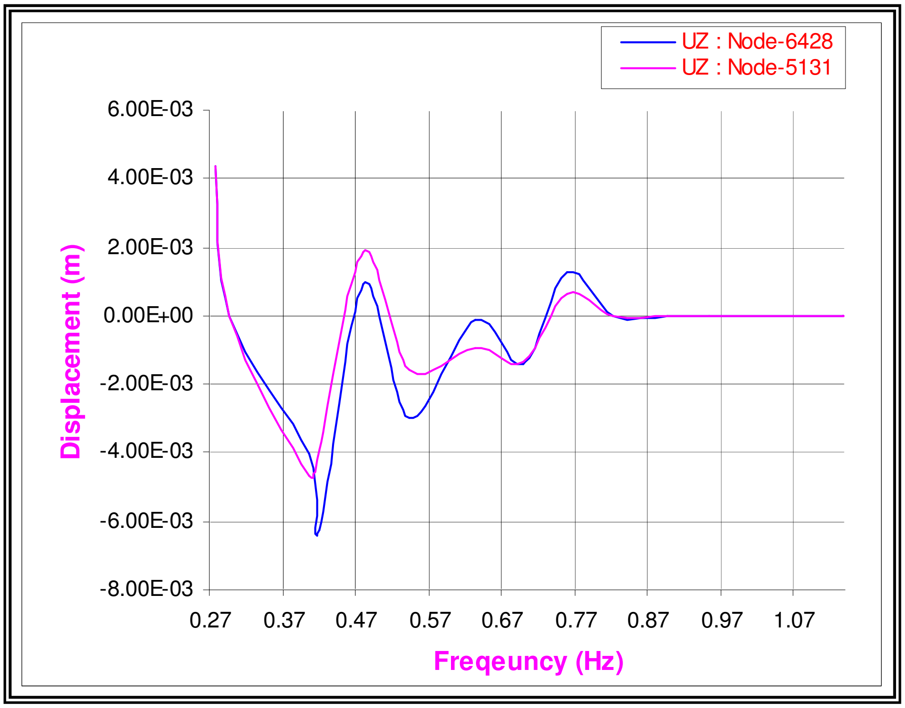
Plot 7.50
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in Z-direction for system approach (Case-3)



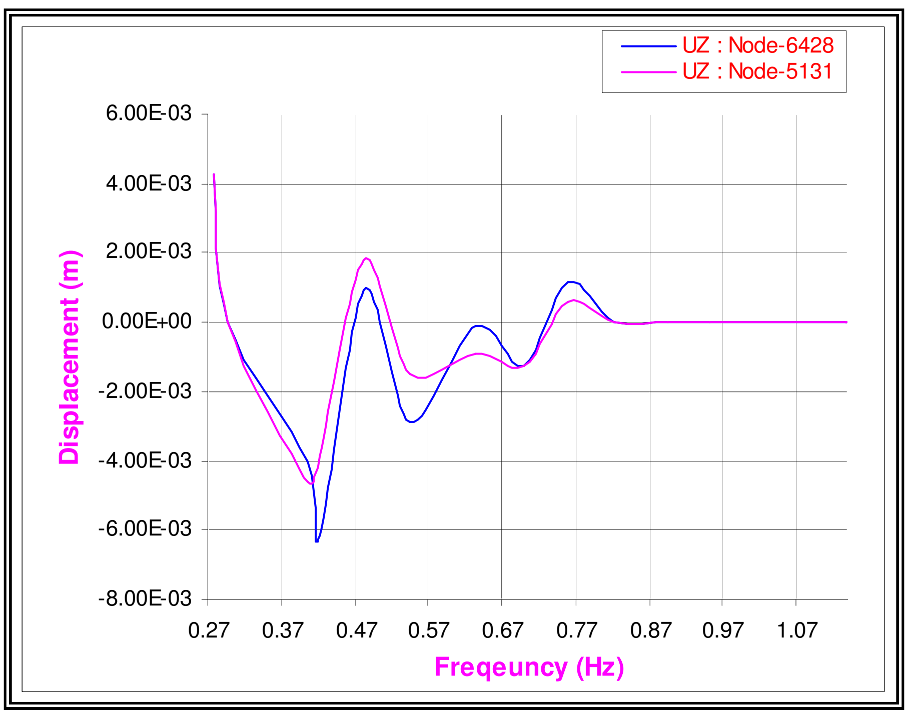
Plot-7.51
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach (Case-3)



Plot-7.52
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach (Case-3)



Plot-7.53
Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach (Case-3)



Plot-7.54
Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach (Case-3)

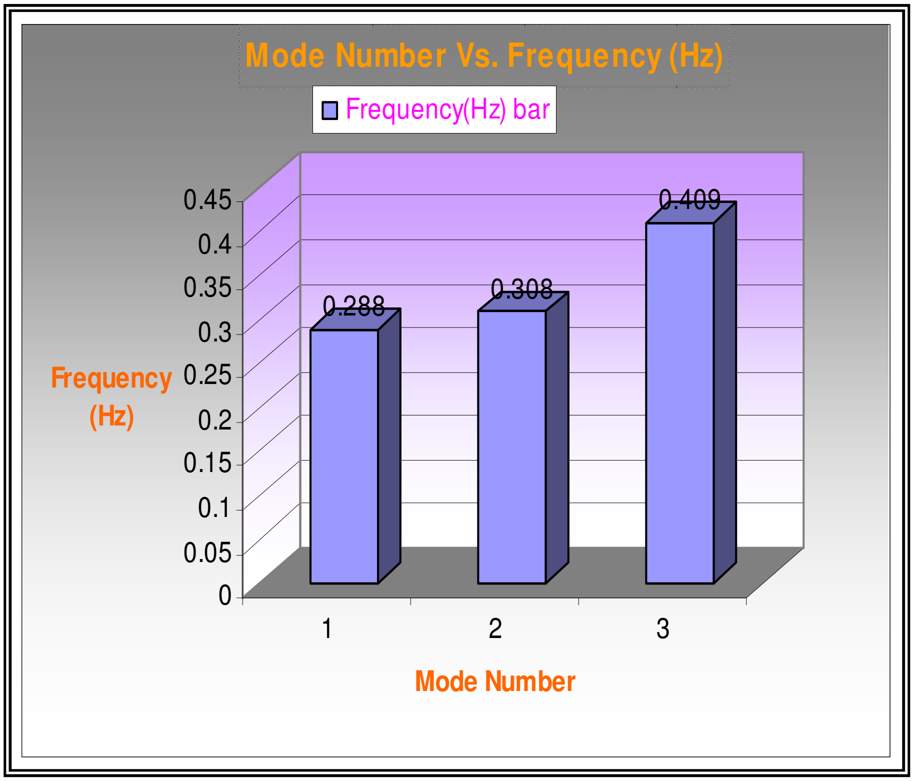
7.7.4 CASE:-4 : FOR SOIL MATERIAL PROPERTIES ARE MODIFIED UP TO 33.5%

7.7.4.1 MODAL ANALYSIS OF CASE-4

As per the advice of IIT-R this case is also studied. The soil properties considered for this case are modified up to 33.5% for carrying out the response spectrum analysis. As mentioned in standard design codes, earthquake and wind loads are short duration loads. It is observed that, when earthquake strikes structural response for the entire structural system takes time to build up. So, In order to more realistically estimate the behavior of the holistic model, as per the IS 1893 the soil properties have been jacked up by 33.5%. Boundary condition used in the modeling of an antenna supporting structure with raft and soil mass in this case are kept same as explained in chapter 5. For finding out the response of structural system modal analysis is carried out using block lanczos method. From the analysis the fundamental frequency of this model is observed as 0.0.279 Hz. Table 7.22 shows the free vibration result of an antenna supporting structure. Plot 7.55 shows the Mode Number vs. Frequency (Hz) for modal analysis result.

TABLE 7.22
Standard frequency results of
System Approach for Case-4 [ANSYS 8.0]

Mode No.	Frequency [Hz]	Period [sec]
1	0.288	3.472
2	0.308	3.246
3	0.409	2.445



Plot 7.55
Mode Number vs. Frequency (Hz) for modal analysis result for system approach for case-4

7.7.4.2 RESPONSE SPECTRUM ANALYSIS OF CASE-4

Using modal analysis result response spectrum analysis is carried out for bhuj earthquake spectrum. For combining modes two different method SRSS method and CQC method is used. Table 7.23 and Table 7.24 shows the maximum displacement at the top of an antenna supporting structure, raft and soil due to Bhuj earthquake spectrum for SRSS method and CQC method in forcing function given in X- direction and Z–direction respectively. Plot 7.56 and plot 7.57 shows the comparison between Storey Number vs. Displacement (m) for SRSS method and CQC method for Bhuj E.Q data given as forcing function in X-direction and Z-direction respectively.

Plot 7.58 and plot 7.59 shows the response history plot for two different extreme nodes at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in X-direction for SRSS method and CQC method respectively. Plot 7.60 and 7.61 shows the response history plot for two different extreme node at top of an antenna supporting structure due to Bhuj earthquake data given as forcing function in Z-direction for SRSS method and CQC method respectively.

Table 7.23

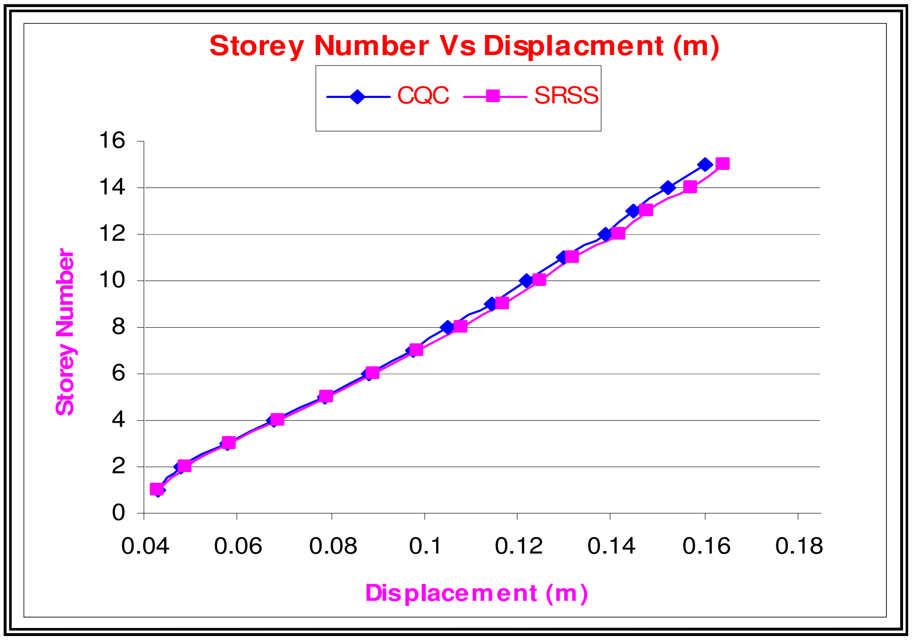
Maximum displacement result of system approach for case-4 for Bhuj E.Q data given as forcing function in X-direction

Maximum Displacement at	**Displacement(m)**	
	SRSS Method	**CQC Method**
Top of an Antenna supporting frame	0.164	0.160
Top of Raft	0.463E-02	0.460E-02
Top of Soil	0.413E-02	0.407E-02

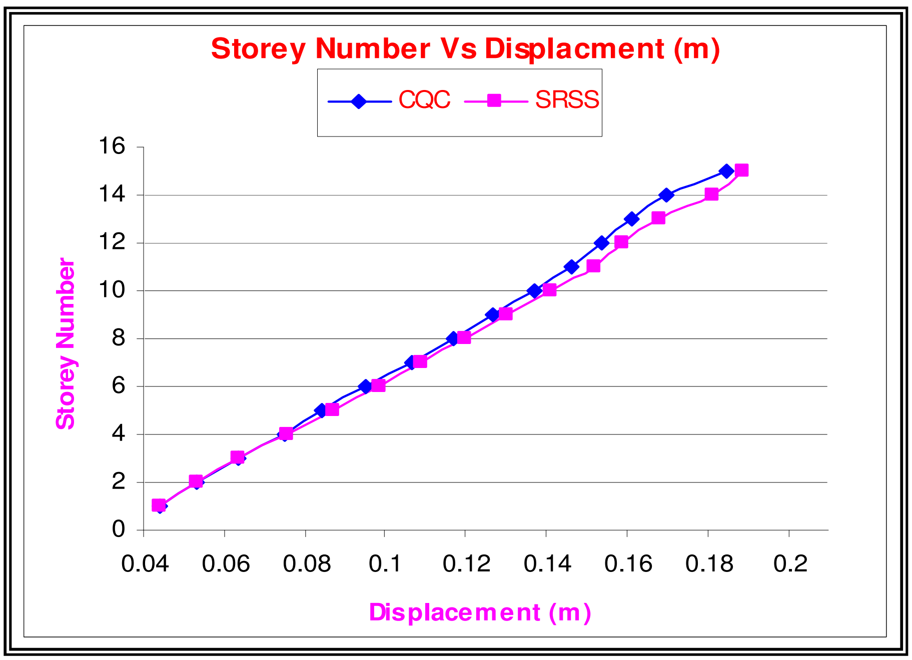
Table 7.24

Maximum displacement result of system approach for case-4 for Bhuj E.Q data given as forcing function in Z-direction

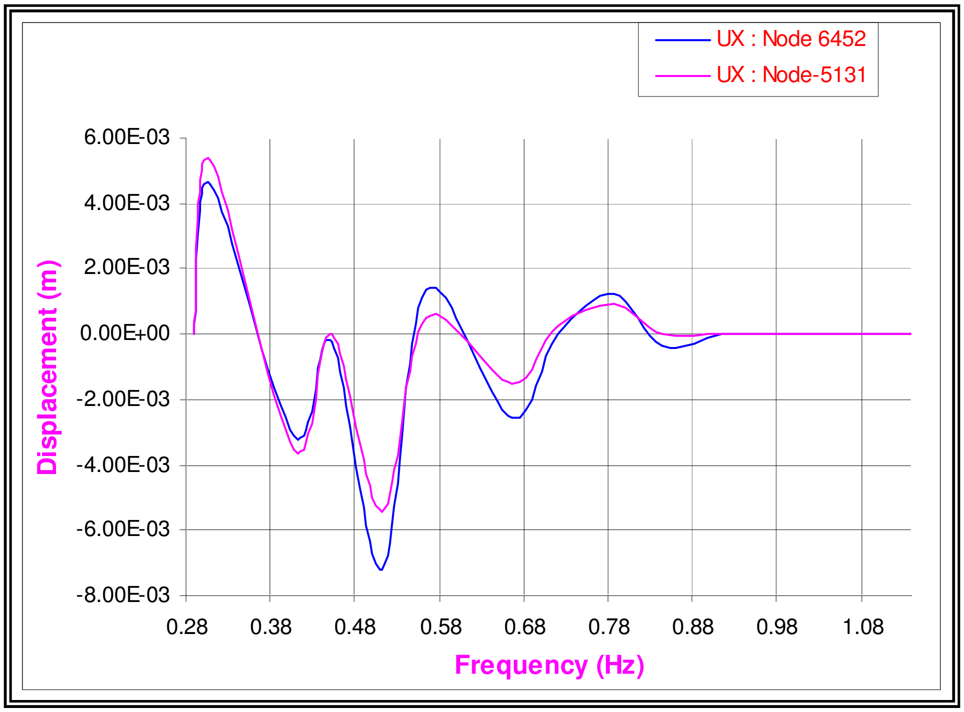
Maximum Displacement at	**Displacement(m)**	
	SRSS Method	**CQC Method**
Top of an Antenna supporting frame	0.189	0.185
Top of Raft	0.399E-02	0.396E-02
Top of Soil	0.374E-02	0.370E-02



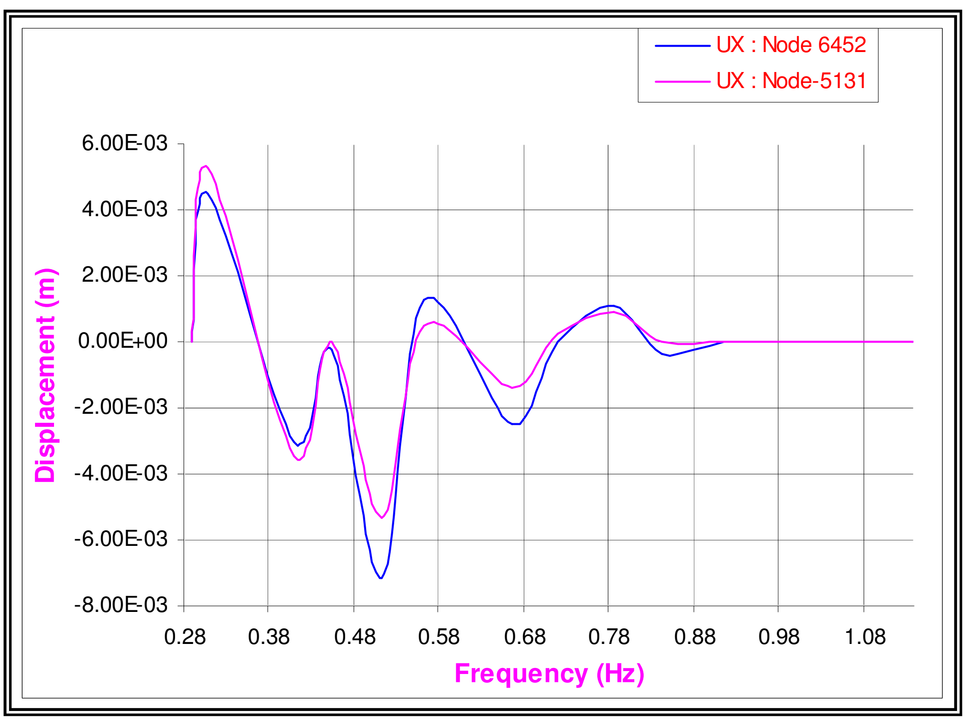
Plot 7.56
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in X-direction for system approach (Case-4)



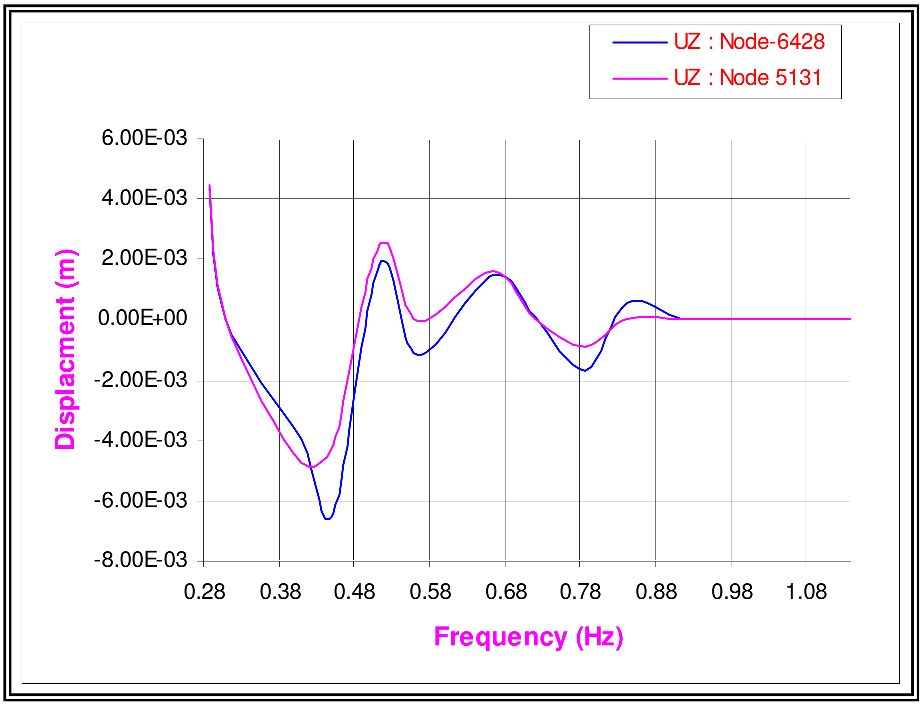
Plot 7.57
Comparison between Storey Number vs. Displacement (m) for CQC method and SRSS method for Bhuj E.Q data given in Z-direction for system approach (Case-4)



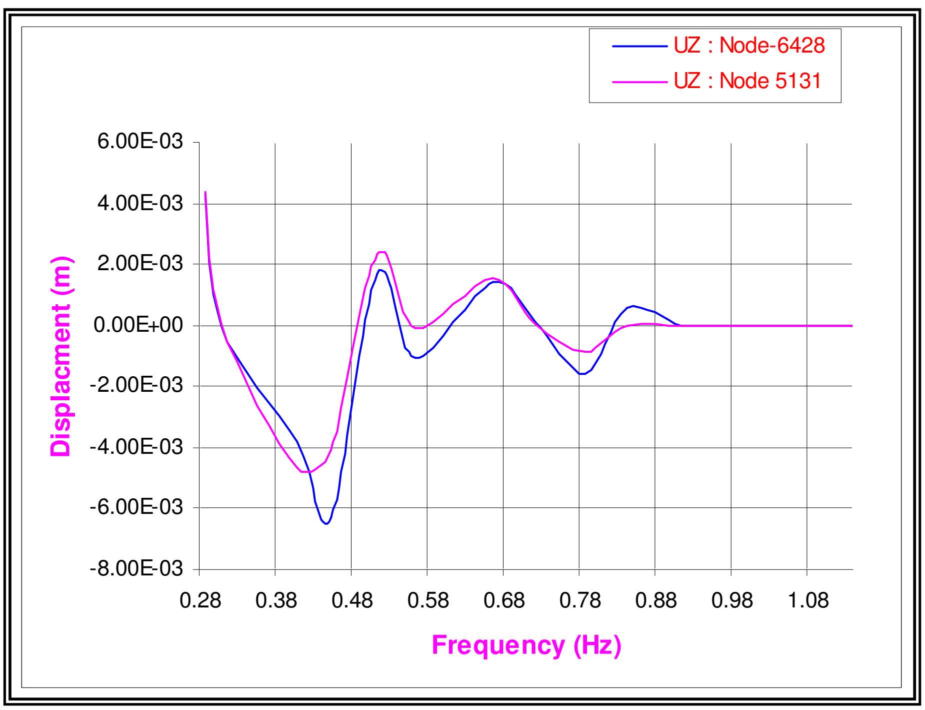
Plot-7.58
Time History plot for SRSS method for Bhuj E.Q data in X-Direction for system approach (Case-4)



Plot-7.59
Time History plot for CQC method for Bhuj E.Q data in X-Direction for system approach (Case-4)



Plot-7.60
Time History plot for SRSS method for Bhuj E.Q data in Z-Direction for system approach (Case-4)



Plot-7.61
Time History plot for CQC method for Bhuj E.Q data in Z-Direction for system approach (Case-4)

7.8 Estimate of the pointing error

Pointing error for the antenna can be estimated as per equation given below,

$$P.E = \tan^{-1}(\delta/F) + \text{Translational and rotational Value of sub reflector} + \text{Translational and rotational value of Reflector} \quad \textbf{7.1}$$

Where,

δ = Displacement

F = Focal length

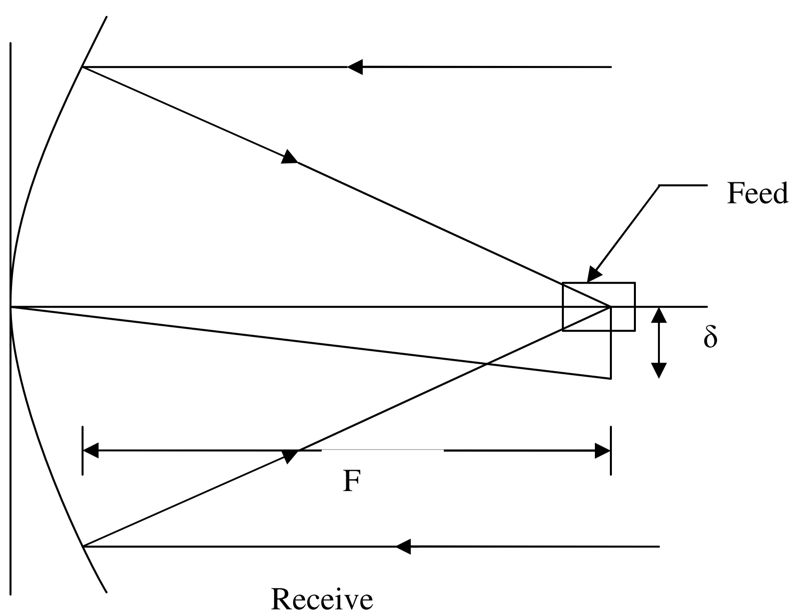


Figure 7.4 Feed system for the Antenna

Calculation of pointing error for the typical 7.5m diameter earth station antenna as given below

Diameter of antenna (D) = 7.5m

Focal length = F/D = 0.4 **7.2**

F = 0.4 X D

F = 0.4 X 7500

= 3000 mm

Pointing error can also be estimated as 1/5th of beam width and beam width can be calculated as per below,

Beam Width = 70λ / D **7.3**

Where,

λ = wave length

$$= \frac{\text{Velocity of light}}{\text{Freq. of light}} \quad \textbf{7.4}$$

$$= \frac{186000 \text{X } 1.6 \text{ X } 1000 \text{ X } 1000}{4.6 \text{ X } 1000 \text{ X } 1000 \text{ X } 1000}$$

= 64.6 mm

Therefore,

$$\text{Beam Width} = \frac{70 \text{ X } 64.6}{7500}$$

$= 0.60^0$

Now,

P.E = 1/5 (Beam Width) **7.5**

$= 1/5 \text{ X } (0.60^0)$

$= 0.12^0$

Now, as per equation 7.1

$$P.E = \tan^{-1}(\delta/F)$$

Therefore,

$$\delta = \tan(P.E) \text{ X } F$$
$$= \tan 12^0 \text{ X } 3000$$
$$= 6.28 \text{ mm} < 173 \text{ mm},$$

7.9 SUMMARY

As per the suggestion of IIT-R all the above cases was studied for holistic structural system. This attempt was made to predict the conservative value of structural response. However, response studies for the Bhuj earthquake was studied for forcing function in both X-direction and Z-direction for two different damping cases. It was observed that with increases in damping in both X and Z direction (Horizontal Plane) structural response at the top of the building dropped.

CHAPTER 8

SUMMARY, CONCLUSION AND DISCUSSION

8.1 CONCLUSION AND DISCUSSION

After interaction with Indian Institute of Technology, Roorkee, this piece of work was divided into two parts; first one was to study the structural response in component approach and then take all the components together for holistic approach. As mentioned earlier in the chapter-1 regarding the need of study, it is definitely indispensable to go ahead with such detailed parametric studies for roof mounted high-speed tracking antennas.

As per the approach synthesis, analysis data was generated for component approach as well as system approach and response spectrum analysis has been studied systematically for all cases. In component approach each component of the main system was handled separately and analysis was carried out by varying each parameter as per chapter six and seven.

Some of the important conclusions have been carried out as per given below

- No semi-resonance issues are expected in the holistic system as the system frequency of entire model (0.281 Hz) is decoupled w.r.t the antenna locked rotor frequency of 3 Hz.
- When compared with the frequency of the SP-22 frame, which was modeled without foundation, it is observed that there is significant drop in the frequency of the total system, when antenna mass is also considered on the frame along with the foundation soil mass.
- Response Spectrum Analysis is carried in component approach and holistic approach for actual Earthquake spectra (Bhuj Earthquake-2001) and spectrum given in IS: 1893 for hard soil in both X- Direction and Z-Direction. It is observed that in component approach as well as in holistic approach structural responses are prominent in actual Earthquake Spectra.
- From the Structural Response graph, it is observed that for antenna supporting frame, damping take place at higher frequency in the Z-direction

- From Structural Response graph, it is observed that for raft, damping take place at higher frequencies in X-Direction. It becomes almost straight line beyond 12.1Hz, because of massive concrete mass behavior.
- From Structural Response graph, it is observed that for soil, damping take place at higher frequency in X-Direction. It becomes almost straight line beyond 7.8Hz, because of massive large soil mass block behavior.
- A response study for the Bhuj Earthquake is studied for forcing function in both X-Direction and Z-Direction for two damping cases for the Holistic Approach. It is observed that with increase in damping in both X and Z direction (Horizontal Plane) structural response at the top of the building dropped
- From Structural Response graph it is observed that for holistic model in case of the run for, “Without considering center elastic effect”, damping takes place at higher frequencies in Z-Direction for both 5% damping and 10% damping cases. It becomes almost straight line beyond 0.94Hz for 5% damping and 0.88Hz for 10% damping respectively.
- Similar observation is made for holistic model in case of the run for, “Considering center elastic effect”, damping takes place at higher frequencies in Z-Direction for both 5% damping and 10% damping case. It becomes almost straight line beyond 0.94Hz for 5% damping and 0.88Hz for 10% damping respectively..
- From Structural Response graph it is observed that for holistic model in case when E of Horizontal Plane is 2/3rd of Vertical Plane for soil damping takes place at higher frequencies in both X and Z Direction for both 5% damping and 10% damping case. It becomes almost straight line beyond 0.79Hz for 5% damping and 0.8Hz for 10% damping respectively.
- Pointing error calculations are also done for the structure. Peak displacement of 6.28mm is obtained for typical 7.5m diameter Earth station antenna. Top most point is used to estimate the allowable pointing error of the antenna. For the actual earthquake case dynamic displacement obtained is compared with the allowable pointing error of the antenna and it is found that the design specification are not met with.

- Hence, the pointing specifications are not met with for actual Bhuj earthquake spectra therefore, during the earthquake time the signals are likely to get disturbed as the antenna performance may get attenuated.
- It is concluded that for high frequency transmit/receive antennae of tracking type and for Radars, it is not advisable to mount them on the multistoried buildings. The dedicated massive concrete pedestal is therefore recommended in such cases.

CHAPTER 9

FURTHER SCOPE

9.1 FURTHER SCOPE

- Detailed studies can still be carried out for different configurations of massive concrete pedestals, from the optimum design point of view
- For the bad soil, the raft should be replaced by piles and holistic model should be studied along with the pile cap and pile group.
- The entire holistic model can be further made finer for detailed study by mounting the antenna along with supporting frame, raft and soil.
- Computer program can be generated to customize the response studies for the holistic model using Matlab.

References

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APPENDIX A

CODAL PROVISION OF IS: 1893 [PART-1] 2002

In this article codal provisions of IS 1893 (Part 1) 2002, regarding dynamic analysis are discussed using an example. The data for the example has been taken from SP22 – Explanatory Handbook for IS 1893.

Dynamic Analysis

Dynamic analysis shall be performed to obtain the design seismic forces and its distribution to different levels along the height of building and to the various lateral load resisting elements in following cases:

(1) Regular Building – Greater than 40 m height in zone IV and V and those greater than 90 m in height in zone II and III.
(2) Irregular building – All framed buildings higher than 12 m in zone IV and V, and those greater than 40 m height in zone II and III.
(3) For irregular building lesser than 40 m in height in zone II and III, dynamic analysis even though not mandatory, is recommended.

Method of Dynamic Analysis:

Buildings with regular, or nominally irregular plan configuration may be modeled as a system of masses lumped at floor levels with each mass having one degree of freedom, that of lateral displacement in the direction under consideration.

Undamped free vibration analysis of entire building modeled as spring – mass model shall be performed using appropriate masses and elastic stiffness of the structural system to obtain natural periods (T) and mode shapes $\{\Phi\}$ of those of its modes of vibration that needs to be considered. The number of modes to be used should be such that the sum of total of modal masses of all modes considered is at least 90% of total seismic mass.
In dynamic analysis following expressions shall be used for the computation of various quantities:

(a) Modal mass (Mk) – Modal mass of the structure subjected to horizontal or vertical as the case may be, ground motion is a part of the total seismic mass of the structure that is effective in mode k of vibration. The modal mass for a given mode has a unique value, irrespective of scaling of the mode shape.

$$M_k = (\Sigma W_i\phi_{ik})^2/(g\,\Sigma W_i\phi_{ik}^2)$$

Where

g = acceleration due to gravity,

ϕ_{ik} = mode shape coefficient at floor i in mode k

W_i = Seismic weight of floor i.

(b) Modal Participation factor (Pk) – Modal participation factor of mode k of vibration is the amount by which mode k contributes to the overall vibration of the structure under horizontal or vertical earthquake ground motions. Since the amplitudes of 95 percent mode shape can be scaled arbitrarily, the value of this factor depends on the scaling used for the mode shape.

$$P_k = (\Sigma W_i\phi_{ik})/(\Sigma W_i\phi_{ik}^2)$$

(c) Design lateral force at each floor in each mode – The peak lateral force (Qik) at floor i in mode k is given by

$$Q_{ik} = A_k\phi_{ik} P_k W_i$$

Where

A_k = Design horizontal spectrum value using natural period of vibration (T_k) of mode k.
$= (Z\,I\,S_a)/(2\,R\,g)$

(d) Storey shear forces in each mode – The peak shear force (Vik) acting in storey i in mode k is given by

$$V_{ik} = \Sigma Q_{ik}$$

(e) Storey shear force due to all modes considered – The peak storey shear force(Vi) in storey i due to all modes considered is obtained by combining those due to each mode as per following rules:

(i) CQC method: The peak response quantities shall be combined as per Complete Quadratic Combination (CQC) method.

$$\lambda = \sqrt{\sum_{1}^{r} \sum_{1}^{r} \lambda_i \rho_{ij} \lambda_j}$$

Where,

r = Number of modes being considered,
ρ_{ij} = Cross-modal coefficient
λ_i = Response quantity in mode i including sign
λ_j = Response quantity in mode j including sign

$$\rho_{ij} = \frac{8\,\zeta^2\,(1+\beta)\,\beta^{1.5}}{(1-\beta^2)^2 + 4\,\zeta^2\,\beta\,(1+\beta)^2}$$

ζ = Modal damping ratio (in fraction) 2% and 5% for steel and reinforced concrete building respectively
β = Frequency ratio = ω_i/ω_j
ω_i = Circular frequency in i^{th} mode and
ω_j = Circular frequency in j^{th} mode

(ii) SRSS method : If the building does not have closely spaced modes, than the peak response quantity (□) due to all modes considered shall be obtained as per Square Root of Sum of Square method.

$$\lambda = \sqrt{\sum_{1}^{r} (\lambda_k)^2}$$

Where
λ_k = Absolute value of quantity in mode k and
r = Number of modes being considered

Closely spaced modes of a structure are those of its natural modes of vibration whose natural frequencies differ from each other by 10 percent or less of the lower frequency.

(iii) SAV: If the building has a few closely spaced modes, then the peak response quantity (□*) due to these modes shall be obtained as

$$\lambda^* = \sum_{c}^{r} (\lambda_k)$$

Where the summation is for the closely spaced modes only. This peak response quantity due to the closely spaced modes (□*) is then combined with those of the remaining well separated modes by the method of SRSS.

The analytical model for dynamic analysis with unusual configuration should be such that it adequately models the types of irregularities present in the building configuration. Building with plan irregularities like torsion irregularities, re-entrant corners, diaphragm discontinuity, out-of plane offset, non parallel systems as defined in IS 1893 can not be modeled for dynamic analysis as discussed above.

The design base shear (VB) shall be compared with base shear (VB) calculated using a fundamental period Ta, as given by empirical formula of clause 7.6 of IS 1893. Where VB is less than VB, all the response quantities shall be multiplied by VB/VB.

APPENDIX B

DETAILS OF AN EARTH STATION ANTENNA

TABLE B.1
SPECIFICATION OF A TYPICAL ANTENNA [7.5 m DIA.]

Serial No.	Description of the Item	Size
1	Main Dish	7.5 m dia. Solid parabolic
2	F/D	0.37
3	Focal Length	2775 mm
4	Feed Type	Cassegrain
5	Dia. of Reflector	Dia : 1224 mm Surface Accuracy : 0.25 R.M.S
6	Overall R.M.S (a) Main Dish	 1 mm RMS
7	Sky Coverage	X-Axis : 45 to 90 degrees
8	Tracking	High Speed Track
9	Pointing Error	0.1 Degrees R.S.S Peak
10	Wind Speed -- Operation -- Gusting -- Drive to Slow -- Survival to Slow	 60 KMPH Gusting to 80 KMPH 200 KMPH 200 KMPH

TABLE B.2
APPROXIMATE WEIGHT OF EACH SUB SYSTEM OF 7.5 m ANTENNA

Serial No.	Description of the Item	Total Weight in kgs
1	Reflector with Back up Structure, Panels, Quadrupods	2035
2	Reflector Mounting Ring	740
3	Mount Tubes with Stow Lock Pipes	3300
4	Jack Pipe	800
5	Screw Rods	780
6	Y Bearing Hinge Brackets	410
7	X Bearing Hinge Brackets	1050
8	Gear Box- X Axis Y Axis	250 250
9	Radicon Gear Box [2 nos.] Motor [2 nos.]	40 16
10	Shock Absorber	350
	Total Weight	10021 kg