"Soil Structure Interaction of Framed Structure Supported on Soils of Different Stiffness"

A Report

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **“Soil Structure Interaction of Framed Structure Supported on Soils of Different Stiffness”** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by **GAGAN PRATAP SINGH SENGER** (Enrolment no. 131623) and **ABHISHEK MAHAJAN** (Enrolment no. 131610) during a period from July 2016 to June 2017 under the supervision of **Mr. Abhilash Shukla**, Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

Conventionally the design of a building is done considering fixed base supports. However, the supporting soil medium provides a certain degree of flexibility to the base which allows some movement of the foundation. When this happens, due to the flexibility provided by the soil, the natural period of the building frame will increase. An increase in the natural time period of the building may lead to increase in spectral acceleration. This is found to be true particularly for low rise buildings. In the present study we have considered building frames with isolated footing to check the changes in response when seismic loading is acting upon it. For this soil of different stiffness has been considered and different heights of buildings has been taken. The soil structure interaction (SSI) is an interaction between the soil and the structure which can used to study the response of the structure under seismic loads. The graphs between spectral acceleration and time period have been generated artificially using simulations on software. Our study shows that the effect of the soil structure interaction (SSI) will have a detrimental effect for low rise buildings, although for high rise buildings SSI will have beneficial effect. Therefore SSI has to be considered on case to case basis and no direct relation can be drawn. Still it can be concluded that for low rise buildings i.e. for buildings having stories less than ten, SSI should be carefully taken into consideration during design and it may be neglected for high rise building i.e. for buildings having stories greater than twenty.

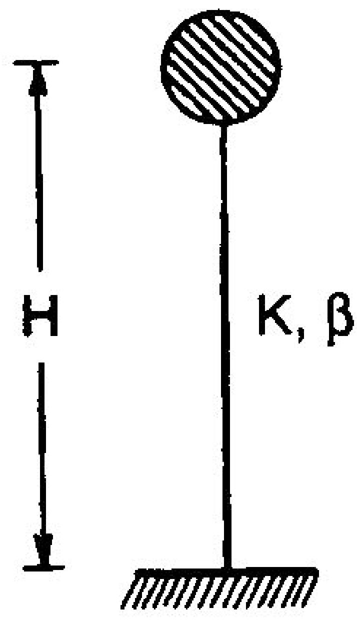
Chapter 1.

1.1. Introduction

The conventional design usually talks about dynamic loads assuming the build base of the building frame to be fixed. In actuality, thesoil as a supporting medium allows some movement due to the natural tendency of the soil to deform when the load is acting on it. This may however, result in reduction ofthe overall stiffness of the structure and hence, may lead to enhanced natural period of the structure. Such an influence of soil stiffness leads to medium rigidityat foundation level of the structure and therefore alters the response. Also,the amount of fixity soil offered at the foundation level of the structural systemwill depend on the load acting on the structure and which is transferred to the soil as it can be used to decide the foundation type and size to be provided. Such a mutually dependent behaviour between soil and structure controlling the overall response is called as soil structure interaction (SSI). It is a strong belief that the common practice of ignoring this effect in designing may lead to a conservative one. Many studies have shown that the SSI effect may enhance such a response for low-rise stiff buildings considerably. For low rise structural system, the lateral natural time period of the building is generally less and therefore will lie in the sharply increasing zone of the response spectrum curve. Hence, an increase in the fundamental period due to the SSI effect will shift it rightwards where the spectral acceleration ordinate will be more than it previously was.Hence, the SSI effect may prove to be detrimental which is a cause of huge concern for low rise buildings. The aim of this study is to observe the effect of such changes on the seismic response of buildings under three typical kinds of fixity conditions i.e. hard, medium and soft viz,recorded earthquake time histories consistent with the design spectrum of Indian earthquake code.

1.2. SSI and Seismic Code Spectra

The presence of distorting soil as a support of a structure affects its seismic response in many different ways, as shown in Fig. 1.1 & 1.2. Firstly, a structure which is flexibly-supported has different vibrational characteristics, notably a bit longer natural period, T', than the period T of the corresponding rigidly-supported (fixed-base) structure. Secondly, a segment of the vibrating energy of this flexibly-supported structure is dissipated into the soil through wave radiation (note that this phenomenon has no counterpart in rigidly-supported structures) and hysteretic action, leading to an effective damping ratio, **β'**, larger than the damping **β** of the corresponding fixed-base structural system.



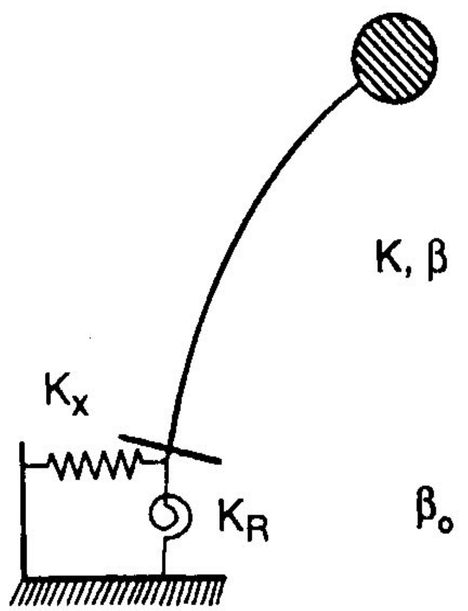


Fig. 1.1fixed base **Fig. 1.2 flexible base**

T <T’

β < β’

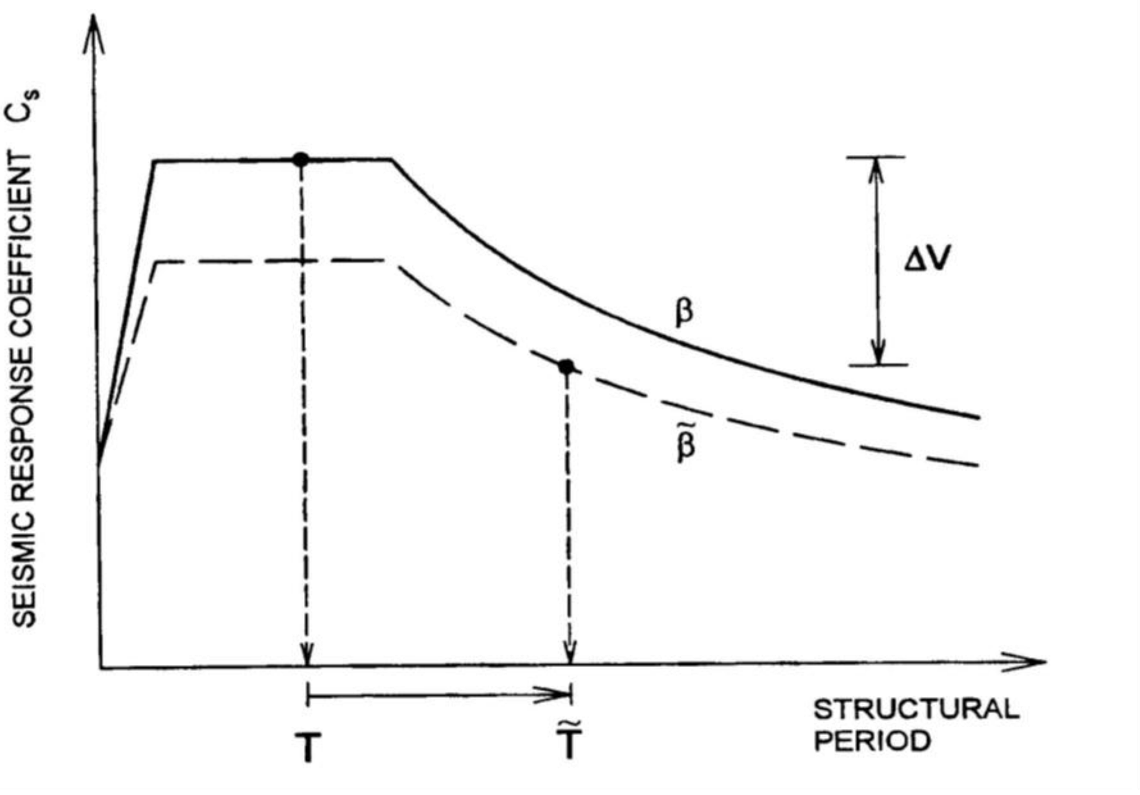


Fig. 1.3. Reduction in design base shear due to SSI according to NEHRP-97 seismic code.

Seismic codes that are mostly used today have an idealized smoothdesign spectra which attain constant acceleration up to a certain period (that is of the orderof 0.4 s to 1.0 s at most, which depends on soil the conditions). And thereafter decrease monotonically with period (usually in proportion to 1/T). Consequence of which consideration of soil structure interaction leads to smaller accelerations and stresses in the framed structure and its foundation. The reduction in base shear according to NEHRP-97 is expressed as

$$\Delta V = \left[C_s(T,\beta) - C_s(\tilde{T},\beta) \left(\frac{\beta}{\tilde{\beta}} \right)^{0.4} \right] W$$

WhereC_s is the seismic response coefficient obtained from the spectrum and $W$is the weight of the structure; the term $(\beta/\tilde{\beta})^{0.4}$on the right-hand side of Eq. (1) accounts for the difference in damping between the rigidly- and the flexibly-supported structure.

1.3. Gap in the study

General saying of many researchers is that SSI is always advantageous hence the design discarding SSI will be over safe. However practically it has been shown through examples that SSI can also have deleterious effects.The effect of soil–structure interaction on the dynamic characteristics, at least for low-rise buildings, may be of major concern.

It is a common belief that the conventional practice of discarding the effect of soil-flexibility in designingMay often leads to a conservative one. However, for low rise structural system, the lateral natural period is pretty much small and may lie within the sharply increasing range of response spectrum. Hence, an increase in lateral fundamental period due to the effect of soil–structure interaction may cause an increase in the ordinate of spectral acceleration.

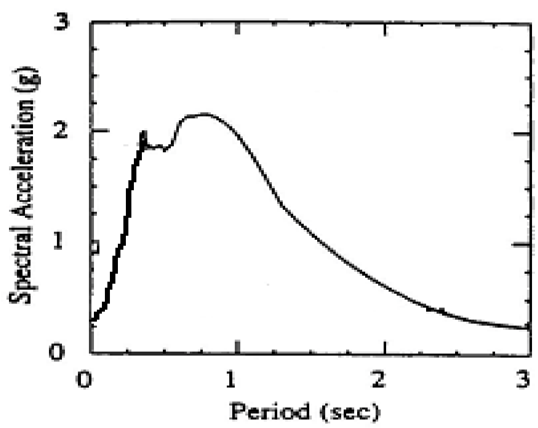


Fig.1.4. Spectral acceleration vs natural period as per NHERP-97

Chapter 2

2.1 Literature Review

1.) **Gregory L. Feneves, Stewart Jonathan. "Seismic soil-structure interaction in buildings. *I: analytical results"J. Geotech. Engrg.*, ASCE, (1999) 125:26-37:**There are two ways in which soil, structure and its foundation can interact:

Inertial Interaction: when vibrations are caused in any structure inertia developed in it which generates base shear in the foundation.

Kinematic Interaction*:* if we consider base slab and structure massless then the kinematic effects are described by a frequency dependent transfer function relating the free-field motion to the motion.

2.) **Stewart, J. P., Seed, R. B., and Fenves, G. L. (1999). ''Seismic soilstructure interaction in buildings. II: Empirical results.'' J. Geotech. Engrg., ASCE, 125(1), 38–48.**Effect of foundation type, flexibility shape, embedment depth on SSI. The flexible foundation less stiff and damping is also lesser than the rigid foundation.

3.) **George Mylonakis."Seismic soil-structure interaction: beneficial or detrimental?" Journal of Earthquake Engineering, Vol. 4, No. 3 (2000) 277–301:** there are certain misconceptions when SSI is considered. the role of SSI is still controversial when we apply the seismic loading on structural system founded on soft soil.SSI is beingconventionallyrecognised to be *advantageous* for seismic response. Discarding effect of SSI is currently being suggested in many seismic codes like ATC-3 & NEHRP-97 as a conservative factor that would help in improvising safety margins. The most important of these simplifications with reference to SSI are:

(1) Acceleration design spectra that decrease monotonically with increasing structural period;

(2) Response modification coefficients (i.e. "behaviour factors" used to derive design forces) which are either constant (period-independent) or increase with increasing structural period;

(3) Foundation impedances derived assuming homogeneous halfspace conditions for the soil, which tend to over predict the damping of structures on actual soil profiles.

4.) **Roy R, Dutta SC. "Effect of soil –structure interaction on dynamic behavior of building frames on grid foundations." Structural Engineering Convention (SEC 2001) Proceedings, Roorkee, India 2001; 579-86.**

The conventional design usually talks about dynamic loading assuming the building frame base to be fixed. In reality, soil as a supporting medium allows movement to some extent due to its natural tendency to deform when the load is acting on it. This may however, reduce the overall stiffness of the structure and hence, may enhance the natural period of the structure. Such influence of soil stiffness led to partial fixity of structural system at foundation level, in turn, alters the response.

5.) Boris Jeremic and Shashi Kannath. "Soil–Foundation–Structure Interaction Eff ects in Seismic Behavior of Bridges." 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 294 The analysis done in this paper evaluates the effect of inelastic behavior of the soil as well as the structural components during the evaluation of the seismic response of highway bridge systems. At the level of systems, the extra flexibility introduced by the soilfoundation system (SFS) results in an increased displacement demands under moderate to severe ground excitations. Moreover, it is also shown that SFS interaction can sometimes have a beneficial eff ect on the superstructure response and sometimes produce detrimental eff ects on the system behavior and is dependent on the characteristics of the earthquake motion as well as other factors. It is thus concluded that each SFS interaction problem has to be fully analyzed and it is almost impossible to carry out the conclusions about the behavior of the SFS system during seismic motions.

6.) Chen, J.C. J. Lymer, and H.B. Seed. "Analysis of Local Variations in Free Field Seismic Ground Motion." Report No. UCB/EERC–81/03. Berkeley, California: University of California. 1981

Three major factors that control SSI effect are:

(i) Geometry of soil or geologic profile geometry

(ii) The property of soil material, and

(iii) The ground motion.

Generally, the influence of the above mentioned factors is complicated. It is mostly difficult to understand the effects of one factor on the dynamic response of a structural system irrespective of the others. The seismic response of a structural system results from the soil-structure interaction analyses are measured along the two horizontal direction.

7.) Tyapin A (2011) The effects of the base mat's flexibility on the structure's seismic response. Part I: wave solution. SMiRT21. New Delhi. #85.there are certain major assumptions which are to be considered in the analysis of SSI :-

a) Linear behavior of the soil, structure and soil-structure contact;

b) Horizontal layering of the soil (except some limited volume near the structure).

There are two other minor assumptions which are not mandatory. The first assumption that the soil-structure contact surface must be rigid. Often base foundations are not completely rigid, but they are braced by either thick shear walls. Standards mentioned in the code like ASCE4-98 allow some basic treatments of bases of the NPP structures as stiff ones. However, recommendations given by SASSI can treat flexible base mats as well. Different parameters of structural seismic response show different sensitivity to the flexibility of the base mat. Some examples are presented in the author's reports in SMiRT-21.

Note that: SSI analysis requires special general tools. **FEM** software cannot treat SSI properly because of the infinite geometry of the initial problem. Specialpurpose tools like **CLASSI, SASSI**, etc. should be used.

2.2 Objectives of the project

1. To check the effect of soil structure interaction on natural time period and response of a framed structural system on soils of different stiffness.
2. To check whether SSI does have a detrimental effect or not for low rise buildings.
3. To find the range of the height of building up to which SSI has a detrimental effect.

Chapter 3:Modelling

3.1. Structural Idealisation as per Roy R, Dutta SC (2001): During action of siesmic loads,the building will experience sway in the plane of the lateral loading. The brick in-fill within the panel acts like the compressive struts and tends to resist deformation due to sway by providing enough stiffness along the diagonals. This will provide enough stiffness laterally to the building frame. In order to include this stiffness due to the brick fill struts have been placed on each story in diagonals .The struts which are placed will give stiffness just like the brick walls. But the stiffness due to brick fill is not present wherever there are openings. Still at the openings there are doors and windows present which will give some stiffness and compensate for the opening .However in reality a simple relation between them does not exist and the stiffness provided by the doors and windows will depend on several factors like size and material. Hence, to represent the action of brick in-fill walls the equivalent struts have been provided everywhere even in the openings so as to simplify the idealisation. It can assumed as fair compromise between simplicity and rigor. Such structural idealization has been shown in **Fig. 3.1.**

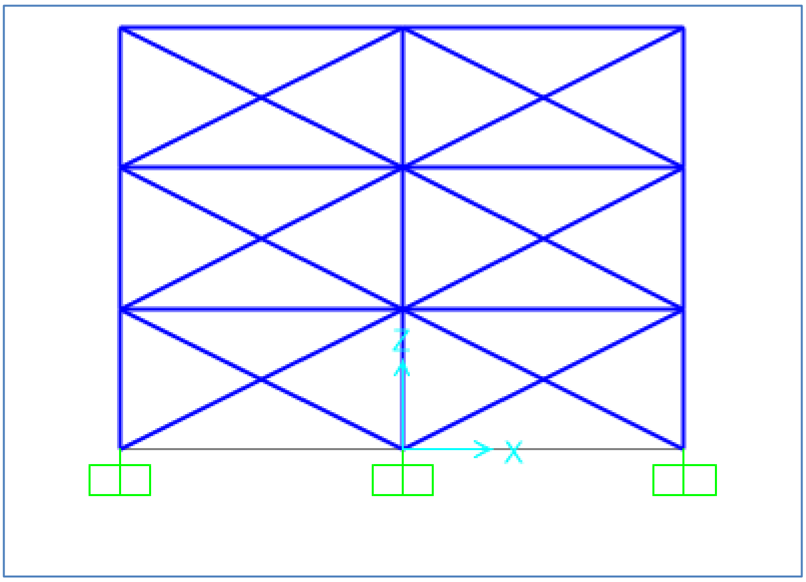


Fig. 3.1 Section showing equivalent strut approach

The tie beams present at the plinth level will also provide some resistance to movement or sway. This has been provided in the form of struts forming grids which will connect the all the columns at the plinth level. This happens because of the reduction in the effective length of the column by the provision of the tie beams in form of grids. It will also help in transfer of loads from the walls to the columns.

3.2. **Idealisation of soil as per** Roy R, Dutta SC (2001)

As given in the literature soil is being replaced by three translational springs, two of which have been placed in the global X-axis and Y-axis and also rotational springs have been placed. These springs have six degree of freedom. The idealization is being shown in the **Fig. 3.2**

Table 3.2. Details of soil parameters as per Dutta & Roy (2004)

Type of soil	N values
Soft	**3**
Medium	**6**

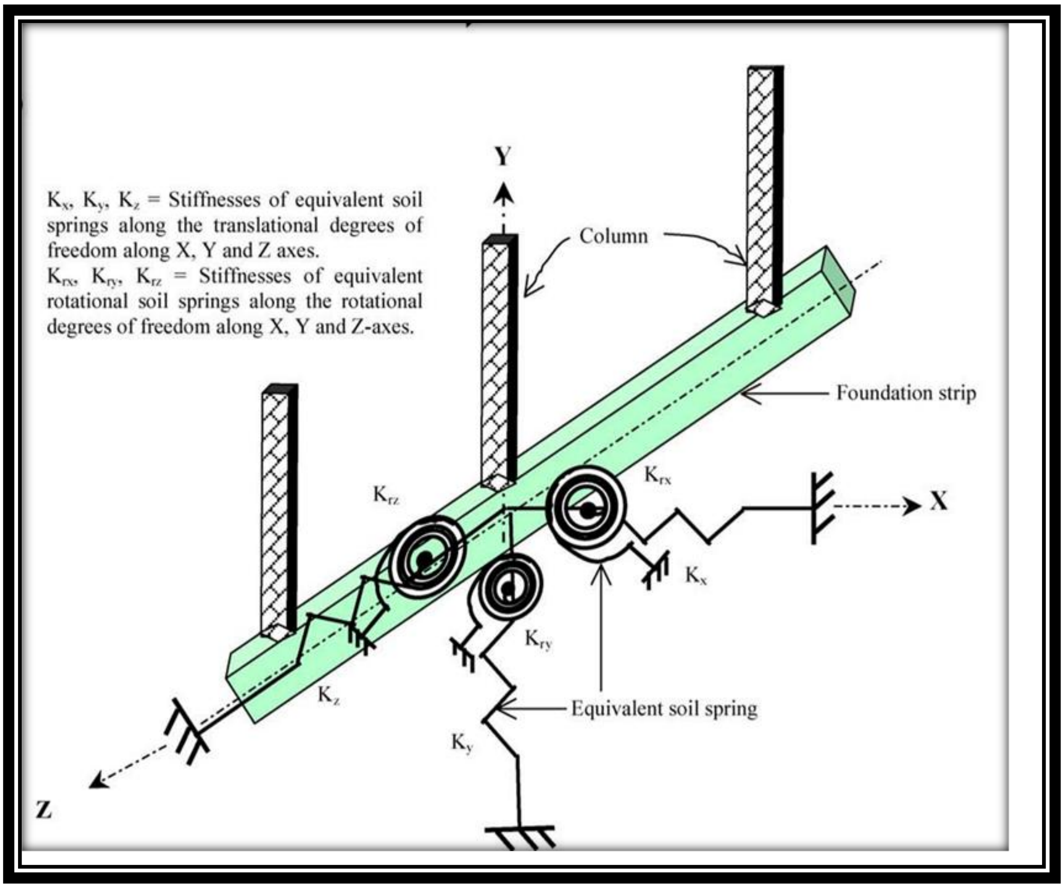


Fig.3.2.1Idealization of soil asper Dutta & Roy (2004)

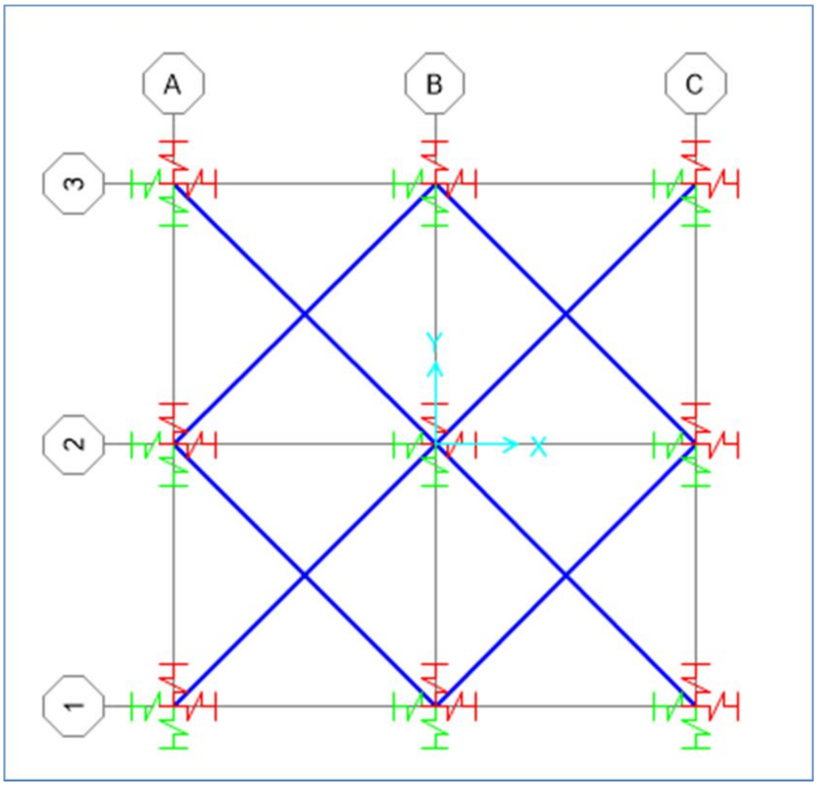


Fig. 3.2.2Section of model showing idealization of soil

Shear modulus (G) for different types of soils can be evaluated using the empirical relationship given below.

$G = 12916692.48 N^{0.8}$ MPa.

Here, **N** is the number of blows to be applied in standard penetration test (SPT) of the soil; and Poisson's ratio **(v)** of soil has been assumed to be equal to 0.5 for all types of clayto evaluate the stiffness of the equivalent soil springs.

Degrees of freedom	Stiffness of equivalent soil spring
Vertical	$[2GL/(1-\nu)](0.73+1.54\chi^{0.75})$ with $\chi = A_b/4L^2$
Horizontal (lateral direction)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})$ with $\chi = A_b/4L^2$
Horizontal (longitudinal direction)	$[2GL/(2-\nu)](2+2.50\chi^{0.85}) - [0.2/(0.75-\nu)]GL[1-(B/L)]$
Rocking (about the longitudinal)	$[G/(1-\nu)]\, I_{bx}^{0.75}\, (L/B)^{0.25}\, [2.4+0.5(B/L)]$
Rocking (about the lateral)	$[3G/(1-\nu)]\, I_{by}^{0.75}\, (L/B)^{0.15}$
Torsion	$3.5G\, I_{bz}^{0.75}\, (B/L)^{0.4} (I_{bz}/B^4)^{0.2}$

Fig.3.2.3 Formula sheet for calculation of equivalent stiffness.

$\mathbf{A_b}$, area of the foundation considered; **B** and **L**, half-width and half-length of a rectangular foundation, respectively; $\mathbf{I_{bx}}$, $\mathbf{I_{by}}$, and $\mathbf{I_{bz}}$, moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes, respectively.

Table 3.2 Equivalent values of spring stiffness constant for soft soil N=3	
Degree of freedom	Stiffness of equivalent soil spring
Vertical	1.69E+12 N/m
Horizontal(lateral direction)	1.11E+12 N/m
Horizontal(longitudinal)	1.11E+12 N/m
Rocking(about longitudinal)	4.844E+18 N/m/rad
Rocking(about lateral)	5.011E+18 N/m/rad
Torsion	30.907E+18 N/m/rad

Table 3.3 Equivalent values of spring stiffness constant for medium soil N=6	
Degree of freedom	Stiffness of equivalent soil spring
Vertical	2.95E+12 N/m
Horizontal(lateral direction)	1.94E+12 N/m
Horizontal(longitudinal)	1.94E+12 N/m
Rocking(about longitudinal)	8.419E+19 N/m/rad
Rocking(about lateral)	8.709E+19 N/m/rad
Torsion	5.679E+18 N/m/rad

3.3. Ground motion

The earthquake data taken in the study is the bhuj earthquake data which has been taken in every analysis. The Estimated acceleration Vs time graph generated from Bhuj ground motion has been shown in Fig. 3.3. Step by step integration is used to obtain the underground motion response damping of 5% has been considered in the analysis for fixed base.For an isolated footing-soil spring system. The damping is not more than 5% of the critical damping.

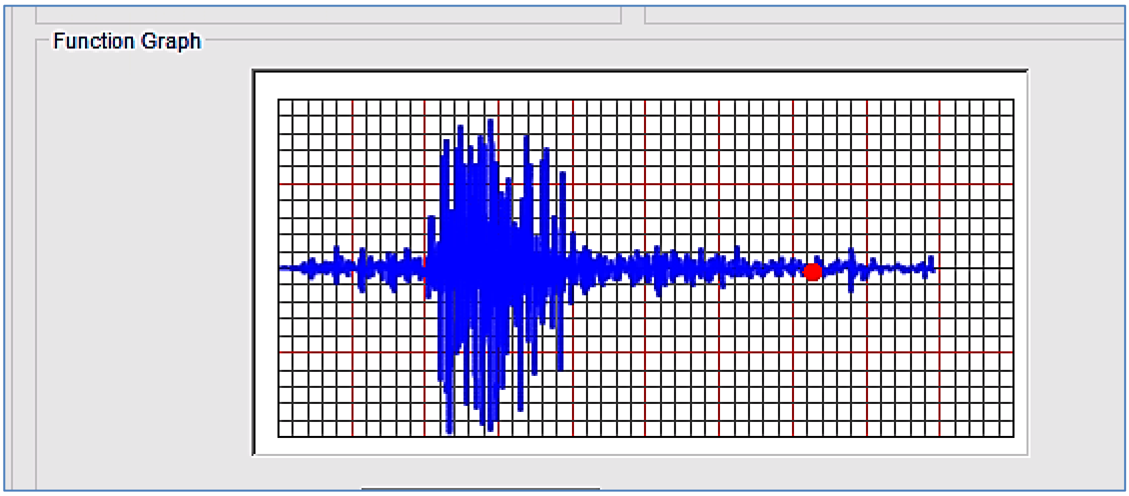


Figure 3.3 Estimated acceleration Vs time graph of Bhuj earthquake

- Bhuj Earthquake of January 26, 2001 at 08:46:42.9 I.S.T. Mag: 7.0 mb, 7.6 Ms
- Station: Ahmedabad
- Lat. & Long 23 02 N, 72 38 E Comp: N 12 W
- AccelerogramBand pass filtered between 0.07 Hz and 27.0 Hz
- Initial Velocity = -.1181E-02 m/s
- Initial Displacement = -1.006 mm
- Peak Acceleration = -0.78236 m/s/s at 34.945 sec

3.4. Method of analysis

A symmetric building has been considered in the analysis run in which a load combination of earthquake load, dead load and live load has been considered. The analysis done is modal in which spectral acceleration has been taken in X and Y directions only. The base reactions generated from the analysis in SAP 2000 has been used to validate the results. Modal analysis has been used and the response spectrum generated have been used to show the variations in different conditions of fixity in the soil. The spring stiffness has been calculated from the formulae given in Dutta and Roy (2004).

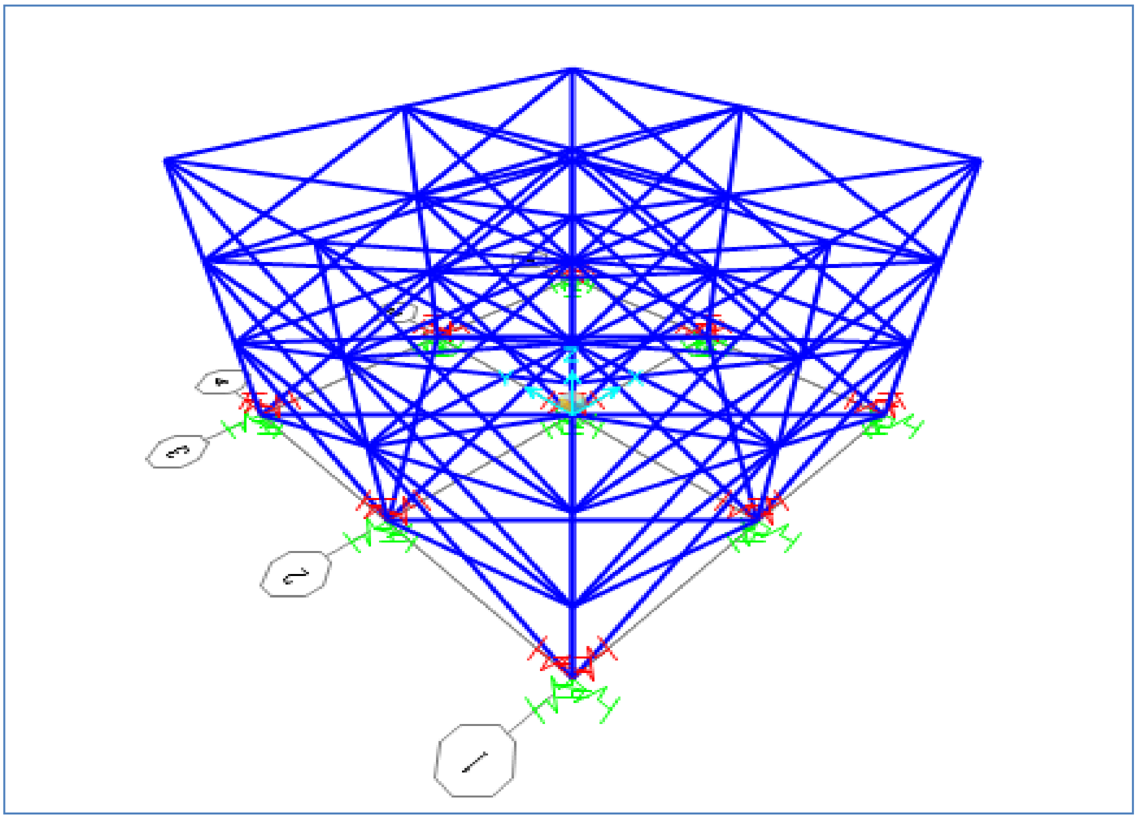


Fig.3.4. 3-D modelling of 2 bay 3 storey building

- The load combinations have been taken as per IS 1893:2002.
- Dead load value taken is 20 KN/m applied as frame load on every floor.
- Live load value is taken as 5KN/m applied as frame load on every floor.
- Fe250 I-section has been considered for the frame using suitable dimensions.

Chapter 4 Results

FOR 3 STORY BUILDING

TABLE 4.1 ForHARD SOIL

Base Reaction in X	25.85 KN
Base Reaction in Y	26.019 KN
Base Moment in X	120.161KNm
Base Moment in Y	118.839KNm

TABLE 4.2 ForMEDIUM SOIL

	.
Base Reaction in X	26.81 KN
Base Reaction in Y	26.91KN
Base Moment in X	127.25 KNm
Base Moment in Y	126.49 KNm

TABLE 4.3 For SOFT SOIL

Base Reaction in X	27.04 KN
Base Reaction in Y	27.000 KN
Base Moment in X	133.49KNm
Base Moment in Y	131.40KNm

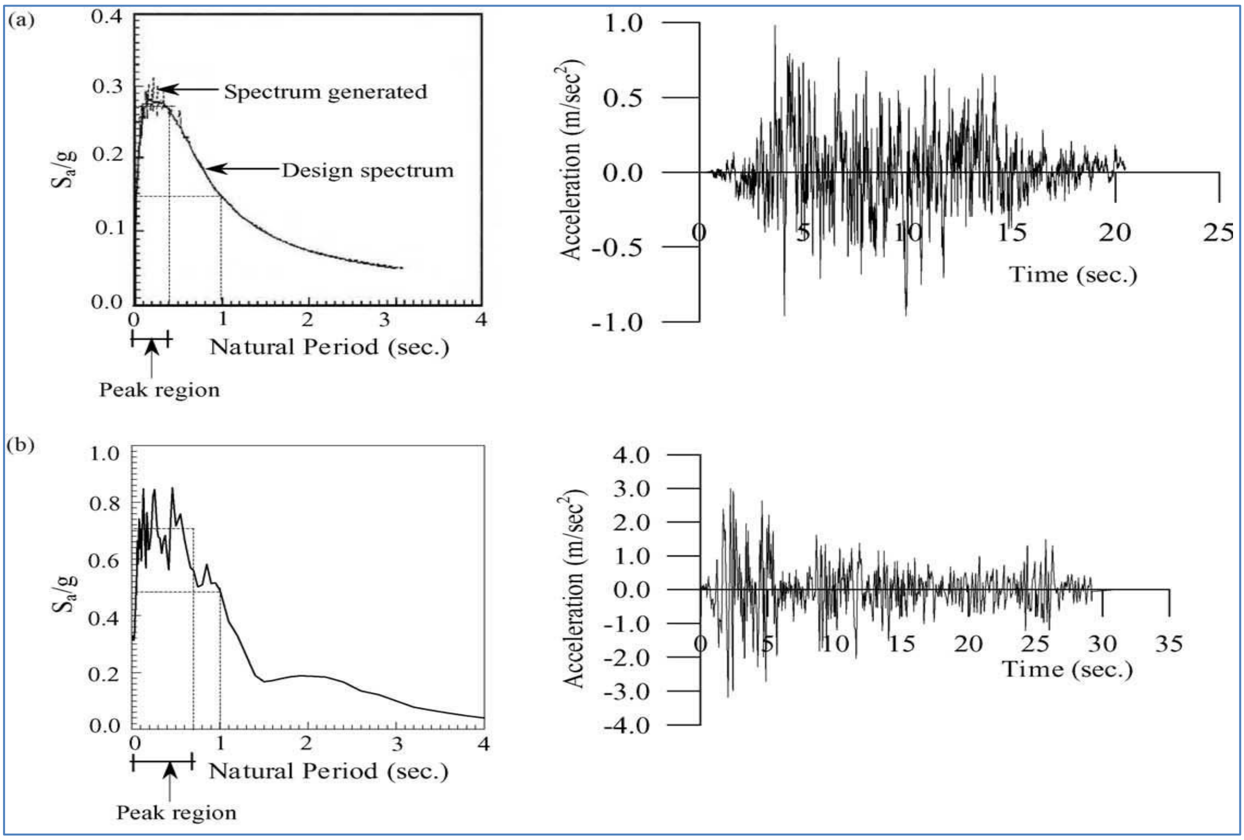


Fig.4.1. (a)Spectrum of simulated ground motion, design spectrum of IS: 1893–1984 corresponding to 5% damping and acceleration– time history. (b) Response spectrum corresponding to 5% damping and acceleration–time history of El-Centro earthquake, 1940

For fixed (hard soil) condition

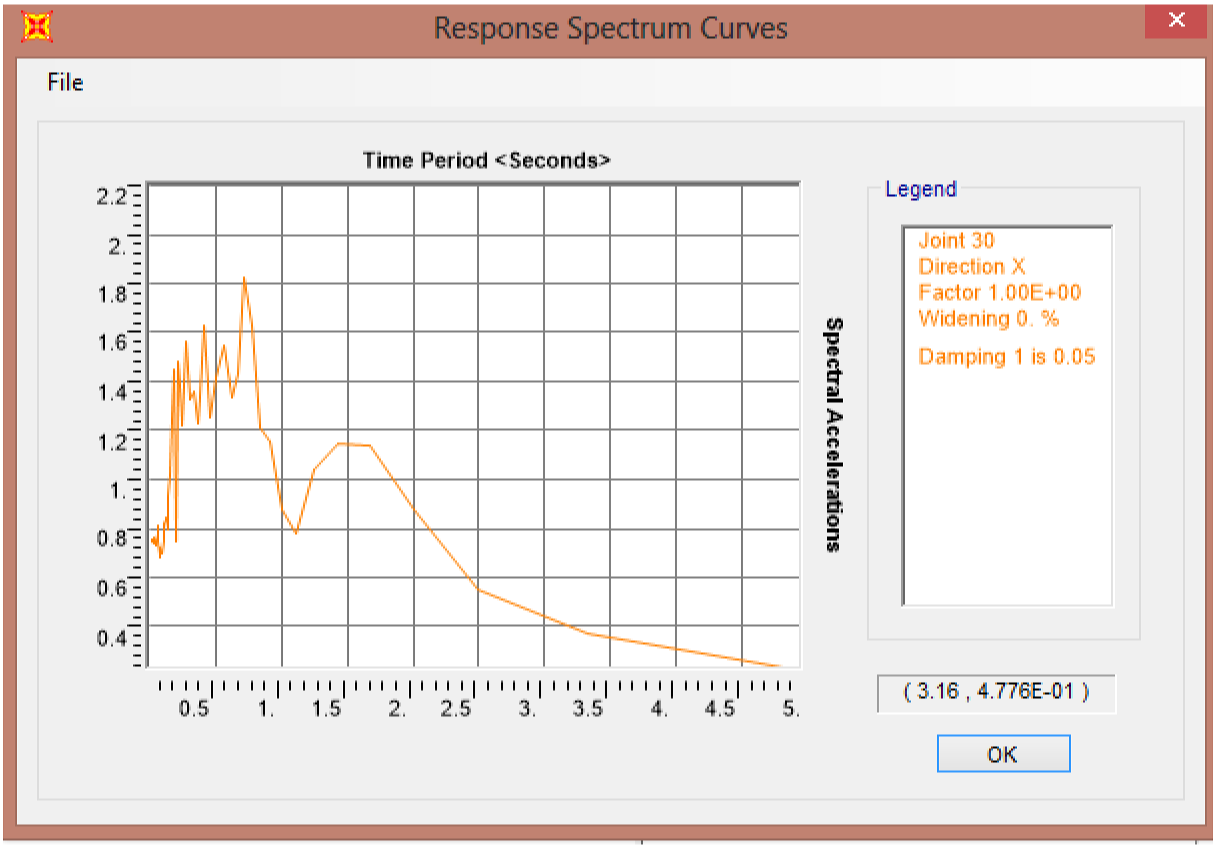


Fig. 4.2. Response spectrum corresponding to 5% damping and acceleration–time history in X of Bhuj earthquake, 2001

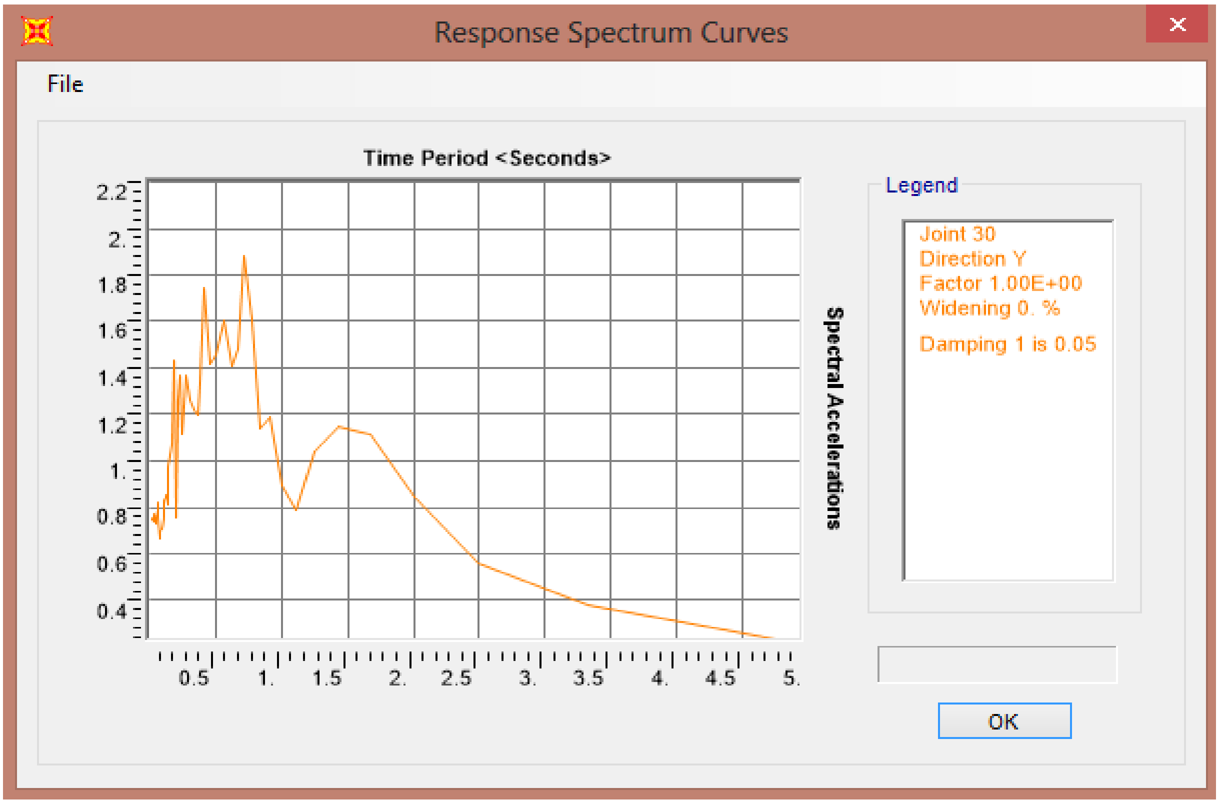


Fig. 4.3. Response spectrum corresponding to 5% damping and acceleration–time history in Y direction of Bhuj earthquake, 2001

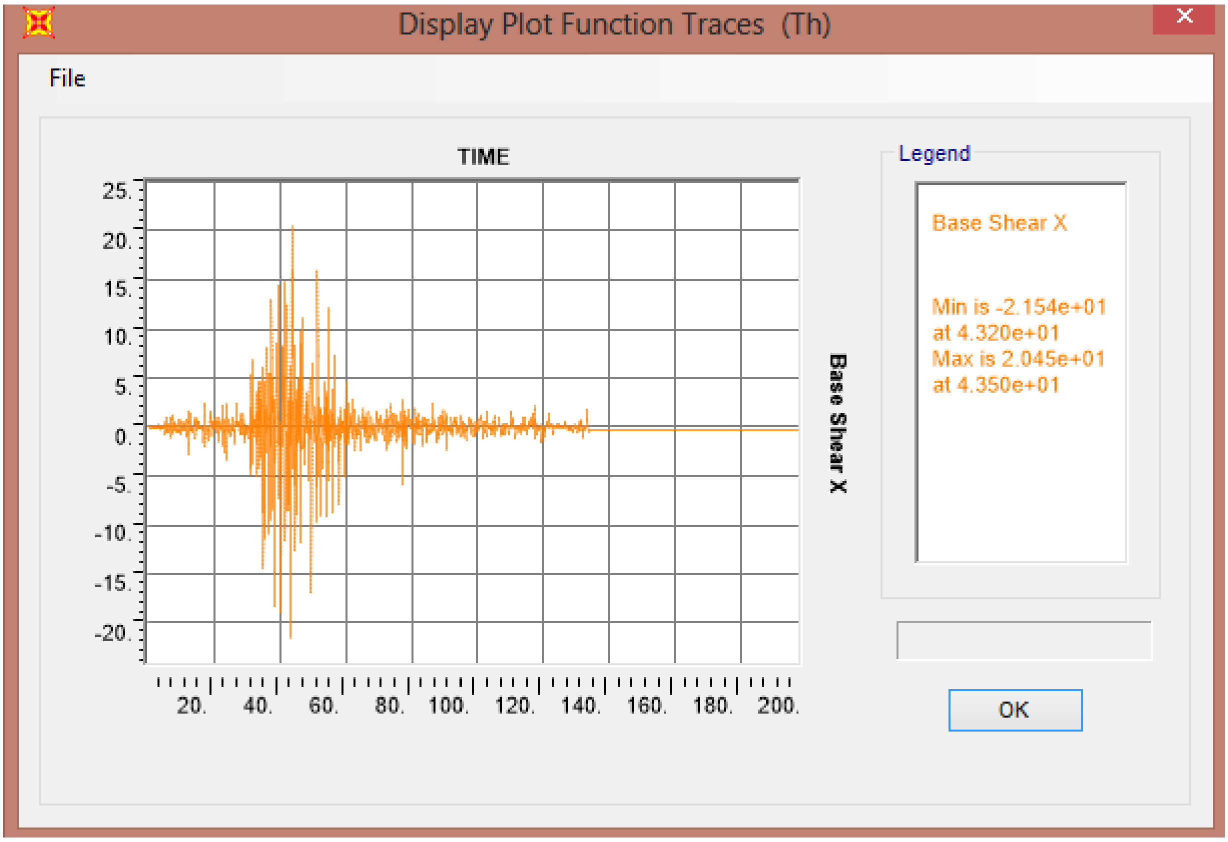


Fig. 4.4. Base Shear in X direction for Time history

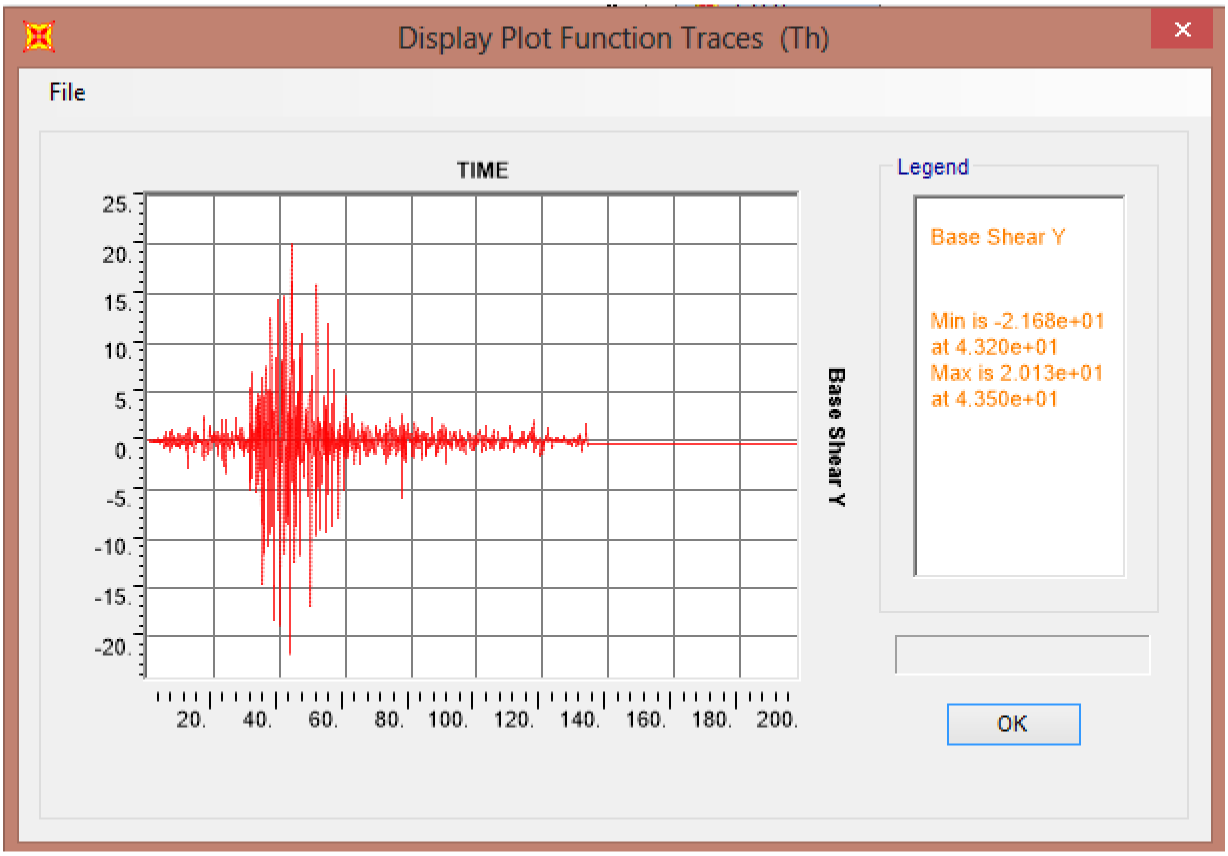


Fig. 4.5. Base Shear in Y direction for Time history

For Medium Soil

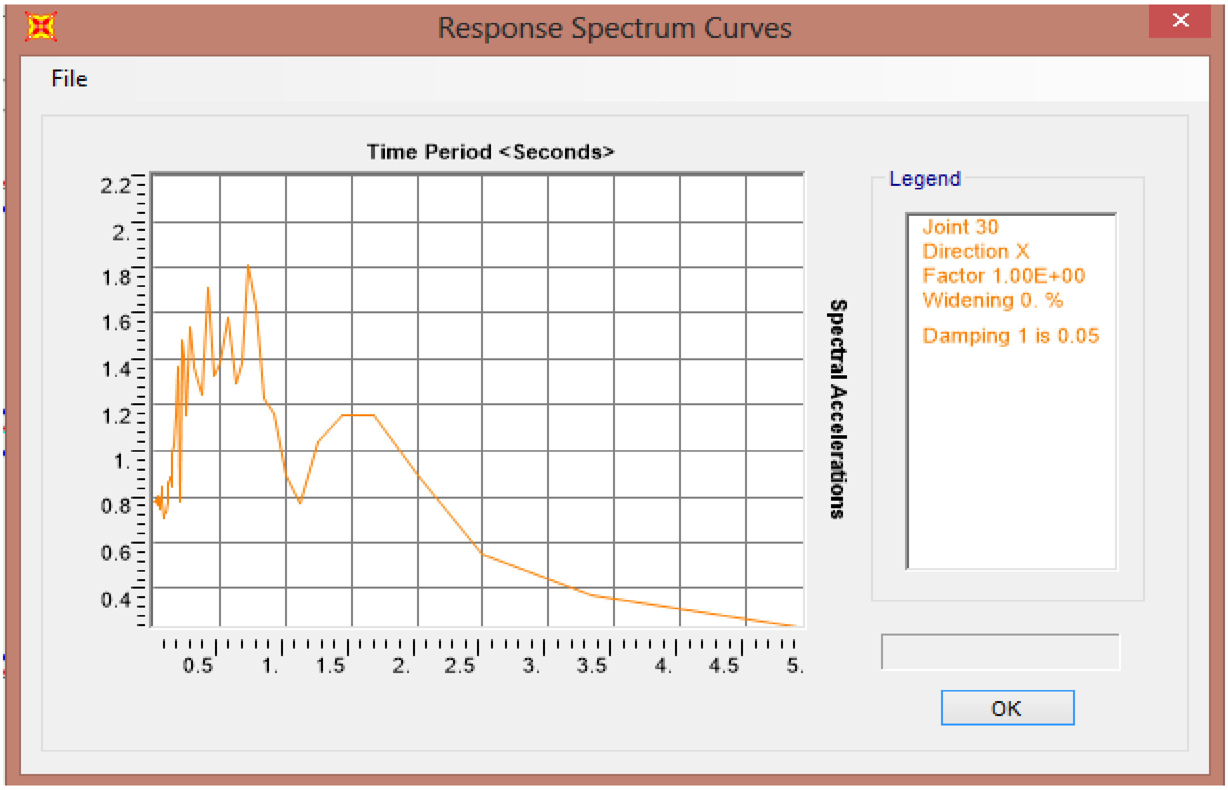


Fig. 4.6. Response spectrum corresponding to 5% damping and acceleration–time history in X of Bhuj earthquake, 2001

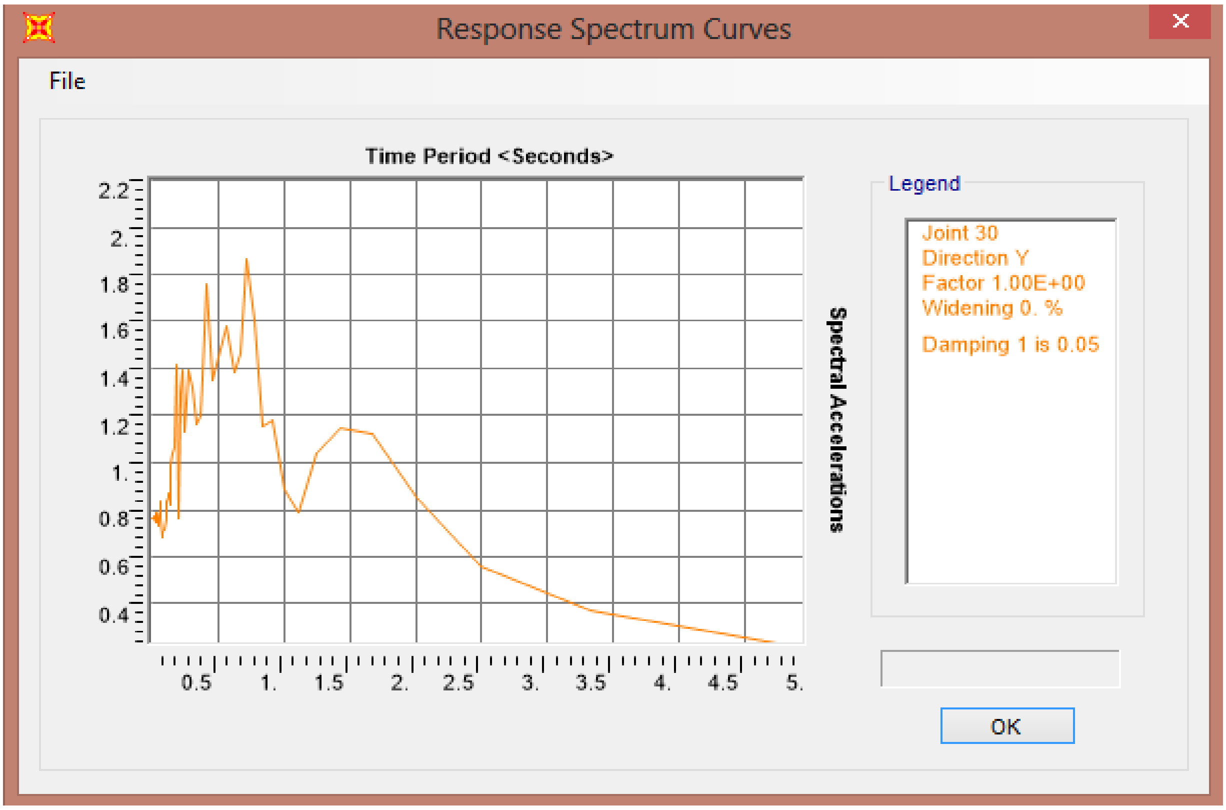


Fig. 4.7. Response spectrum corresponding to 5% damping and acceleration–time history in Y direction of Bhuj earthquake, 2001

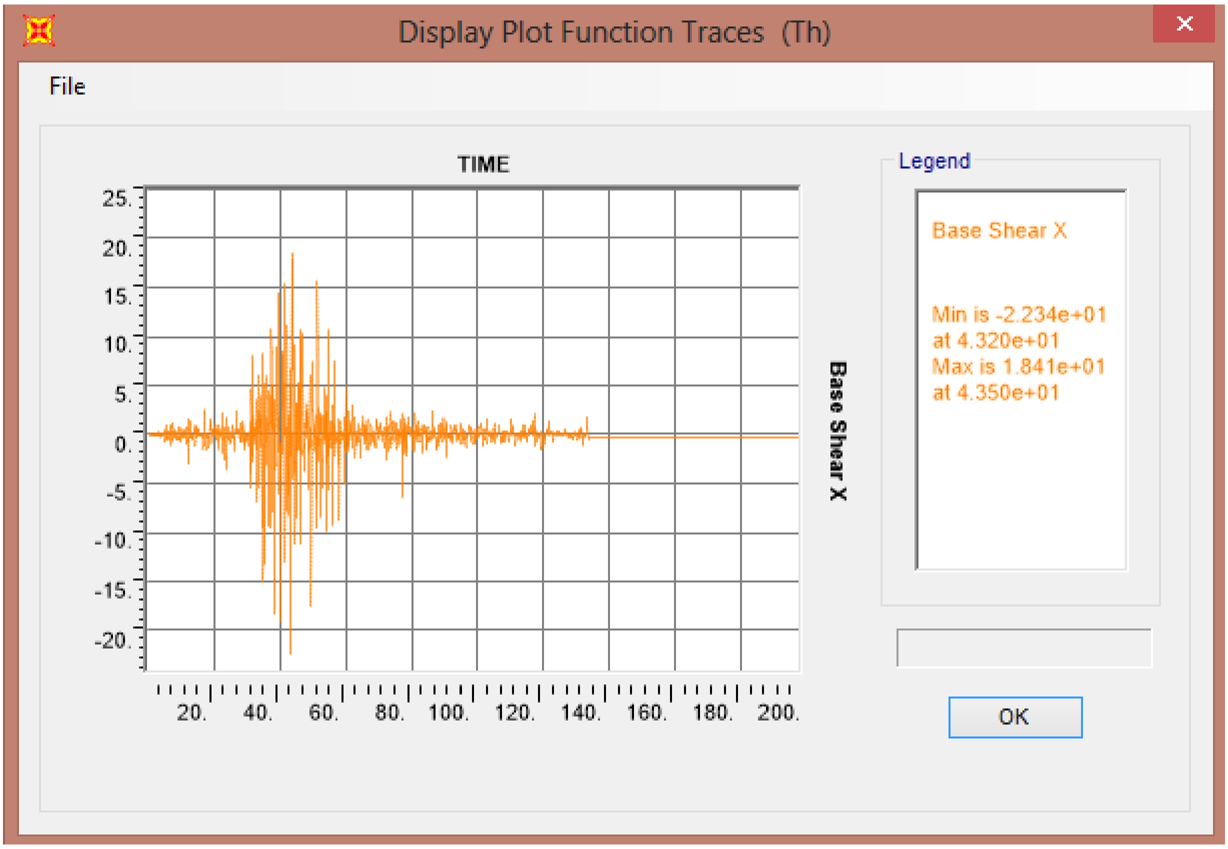


Fig. 4.8.Base shear in X direction for Time history

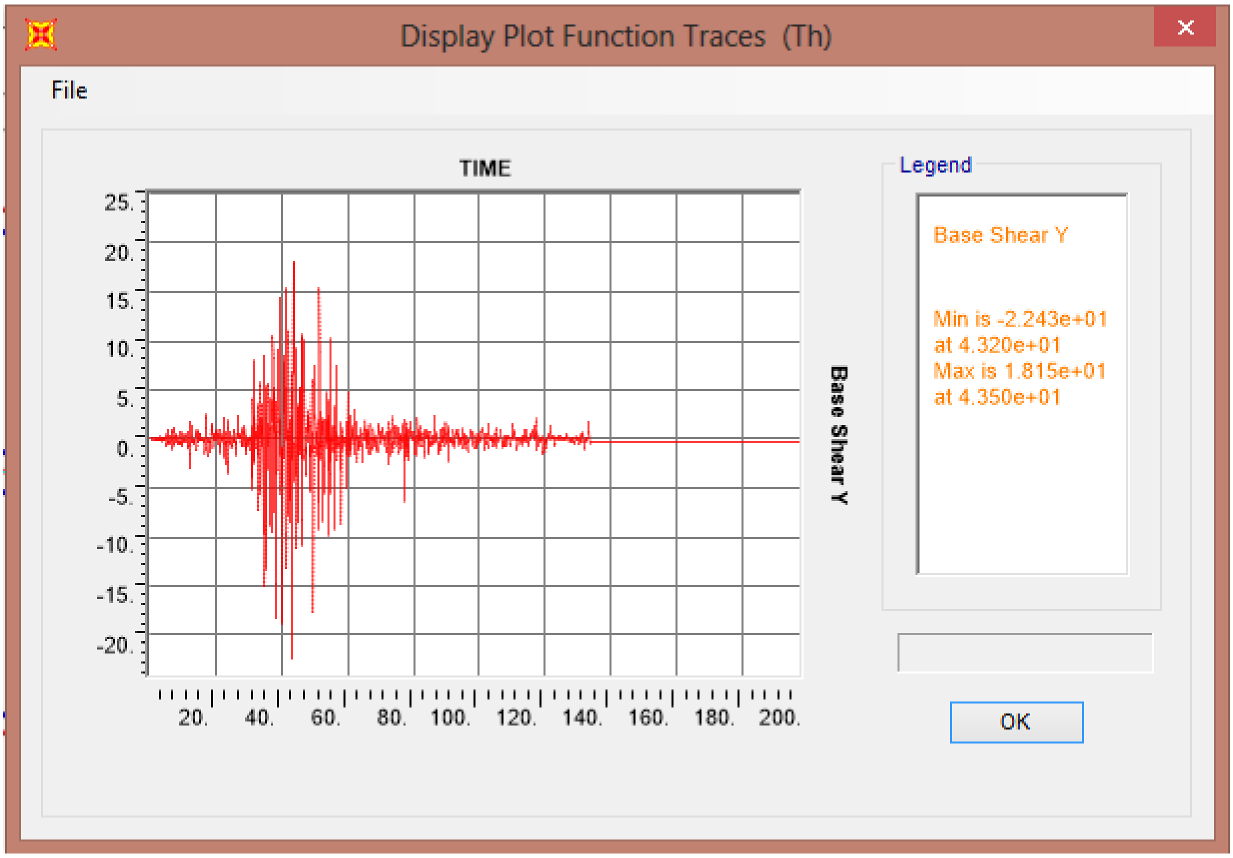


Fig. 4.9. Base shear in Y direction for Time history

For Soft Soil

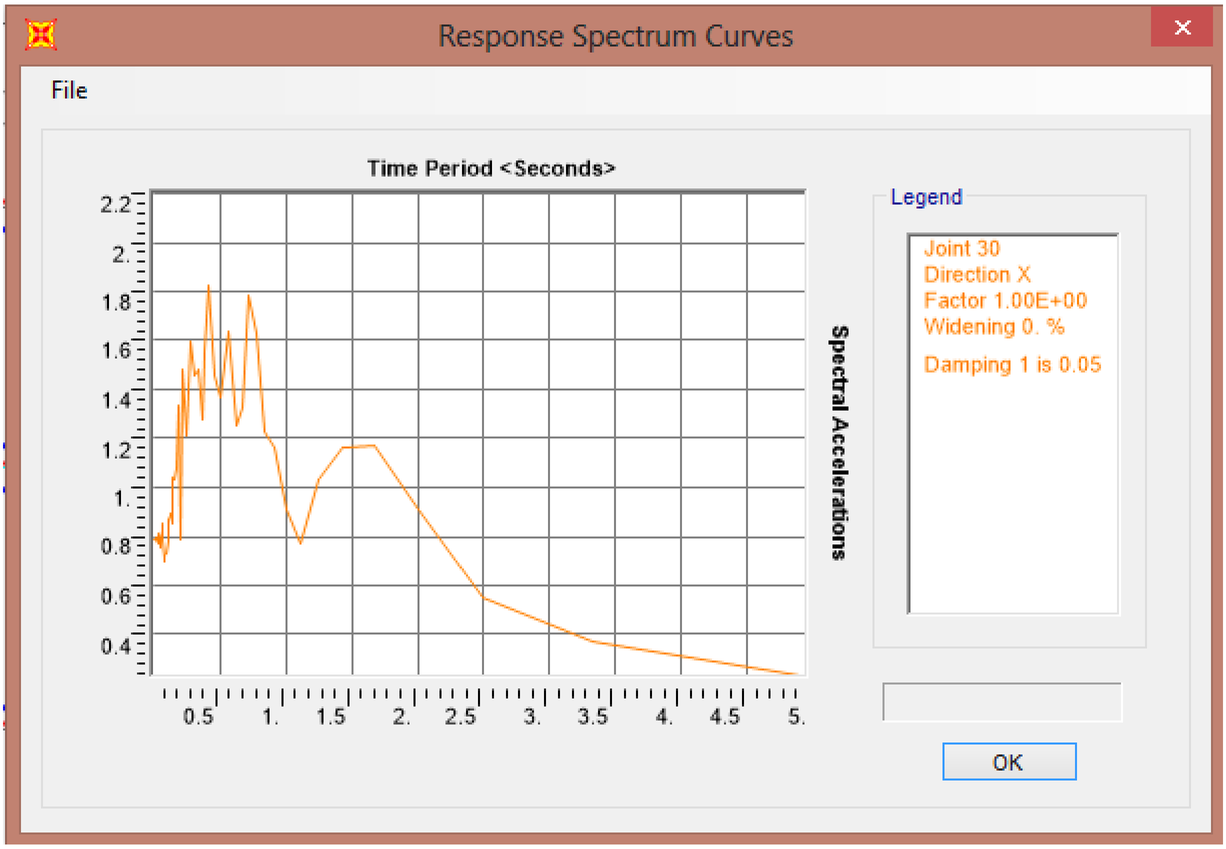


Fig. 4.10. Response spectrum corresponding to 5% damping and acceleration–time history in X of Bhuj earthquake, 2001

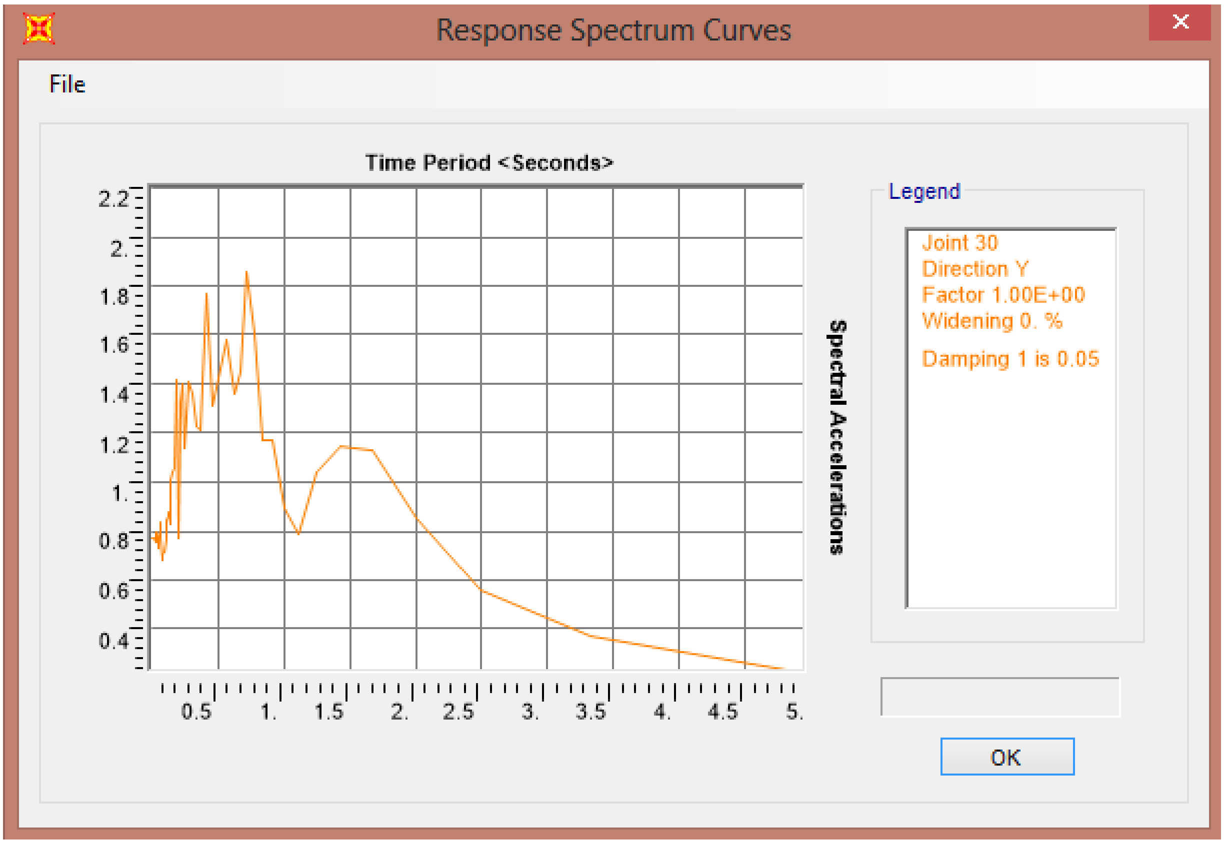


Fig. 4.11. Response spectrum corresponding to 5% damping and acceleration–time history in Y direction of Bhuj earthquake, 2001

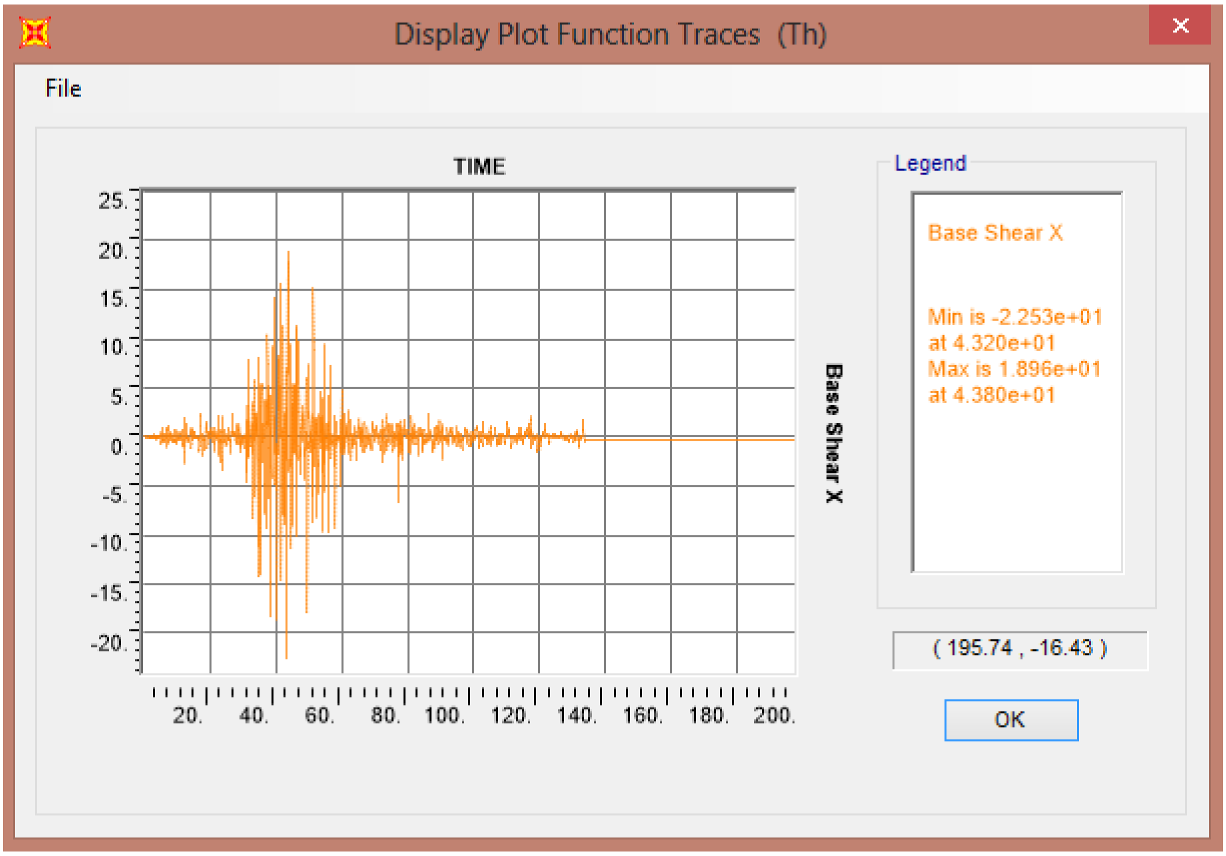


Fig. 4.12. Base shear in X direction for Time history

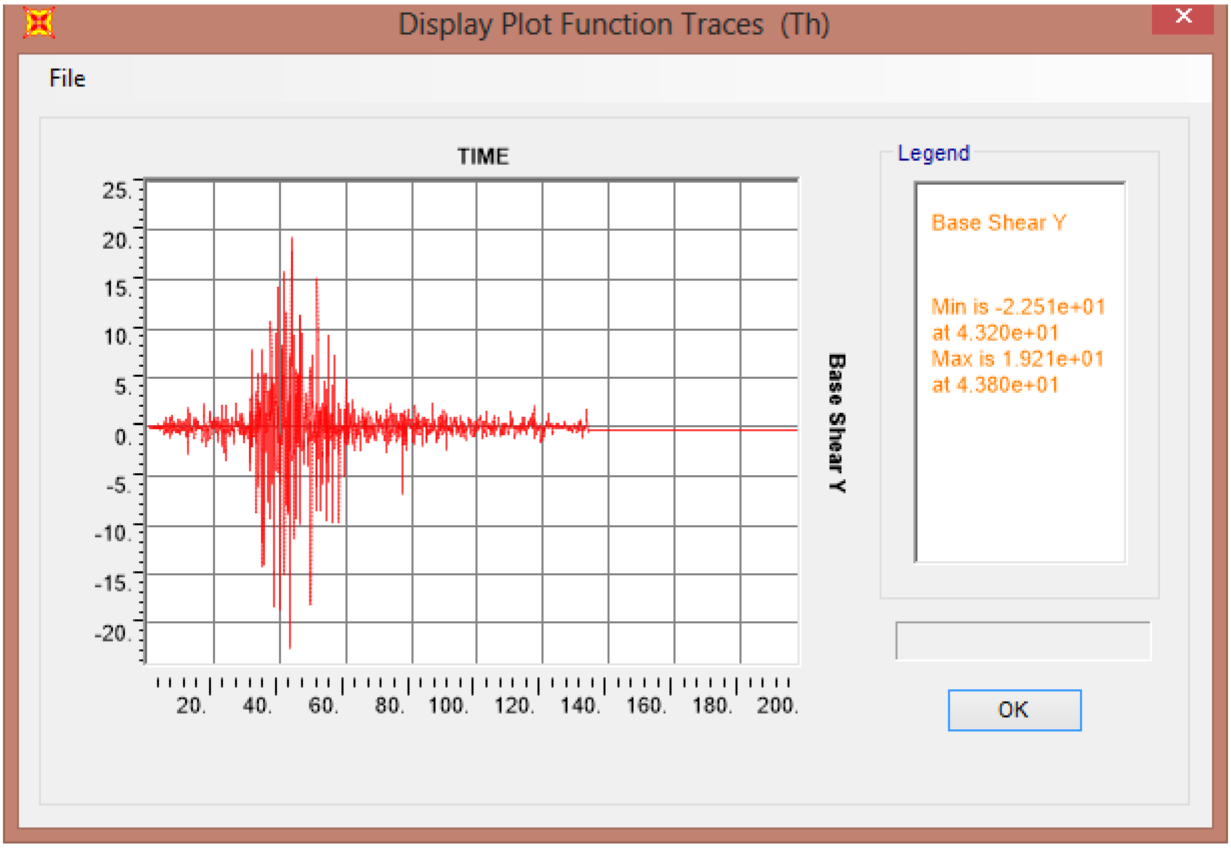


Fig. 4.13. Base shear in Y direction for Time history

4.1. SSI effect in high rise buildings

In January 2001, an earthquake hit the Gujrat and after so much of destruction took place researchers have shown their interest in considering the SSI effect in designing. It was later demonstrated in some of the research articles that strength alone is not the only sufficient criterion for the safety of structural systems. In our research simulations have been done on high rise buildings. 25 and 31 story buildings have been taken and using SAP 2000 simulations have been done for hard, medium and soft soil. The results are shown below:

I. Considering 25 storey building

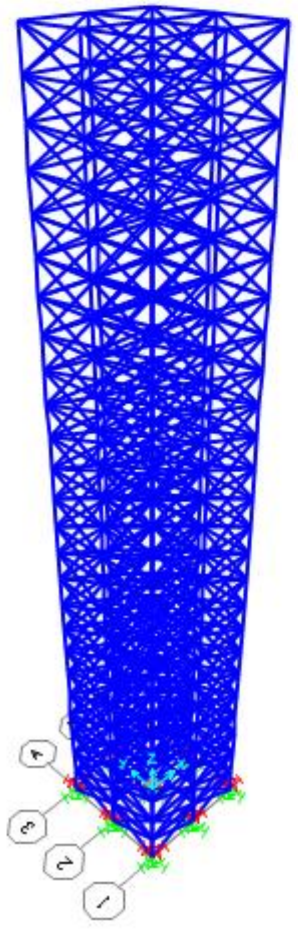


Fig.4.1.1 25 storey structural system

For hard soil

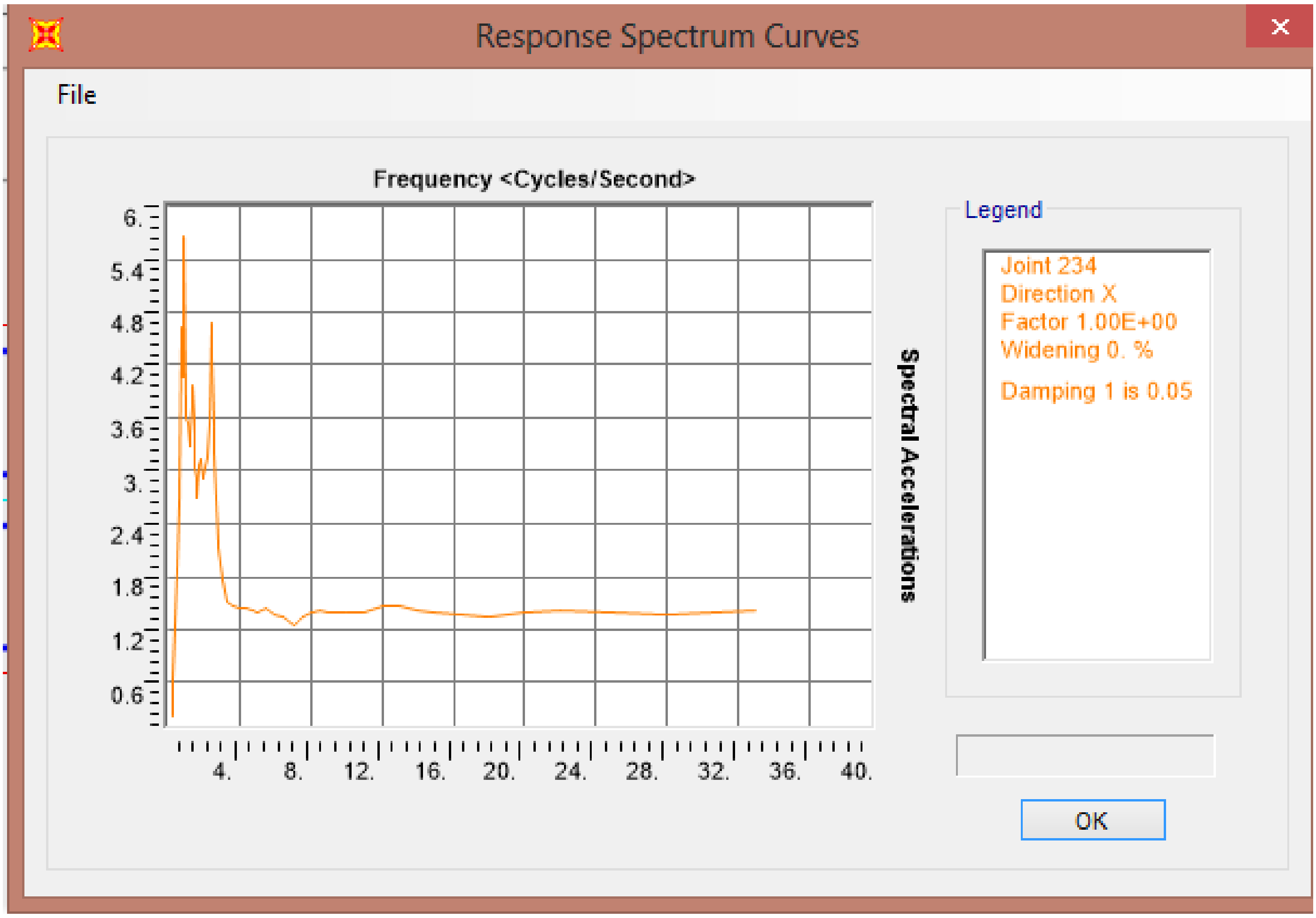


Fig.4.1.2. Response spectrum corresponding to 5% damping and acceleration–time history in X direction for high rise 25 storey building of Bhuj earthquake, 2001

For medium soil

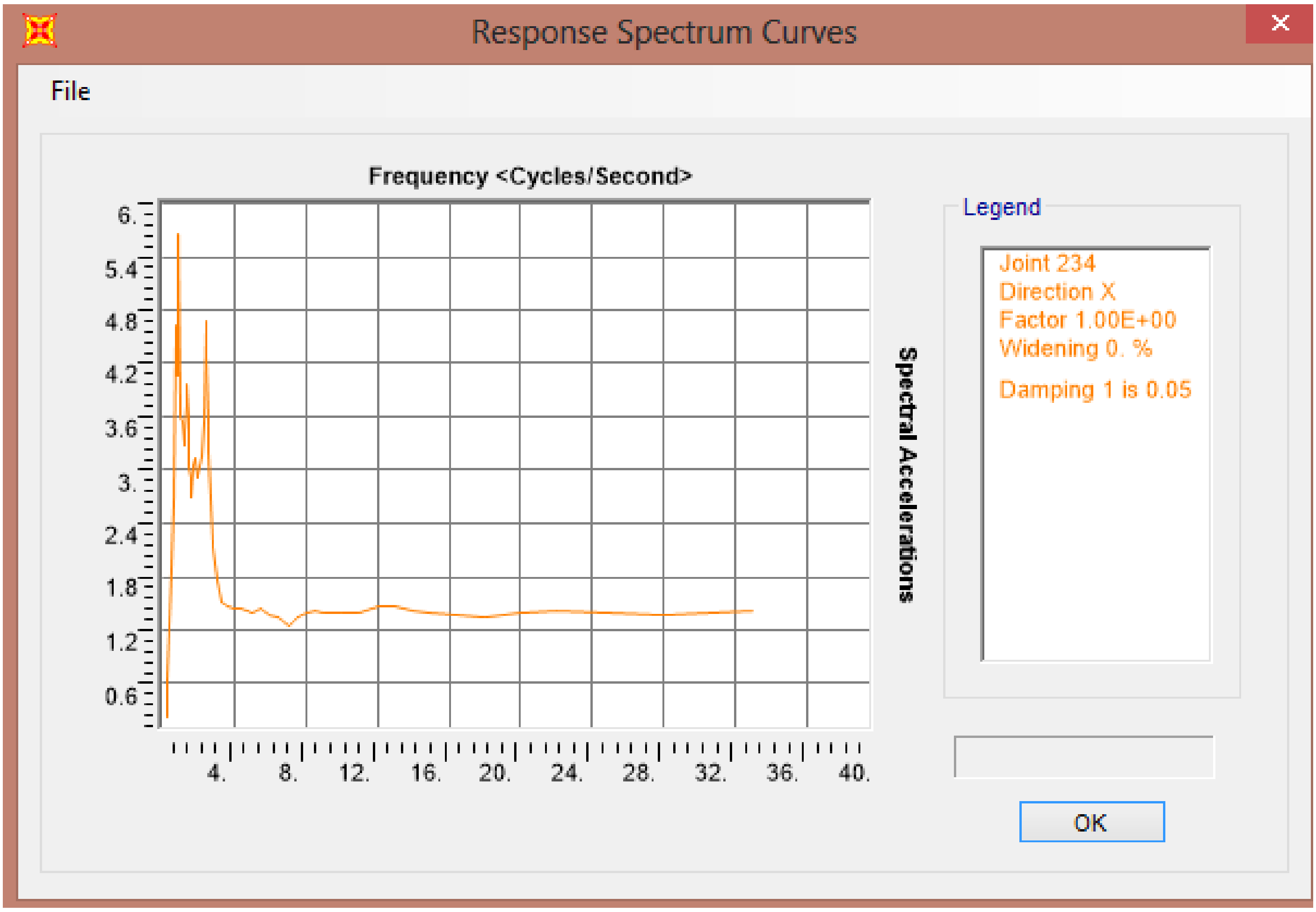


Fig.4.1.3.Response spectrum corresponding to 5% damping and acceleration–time history in X direction for high rise 25 storey building of Bhuj earthquake, 2001

For soft soil

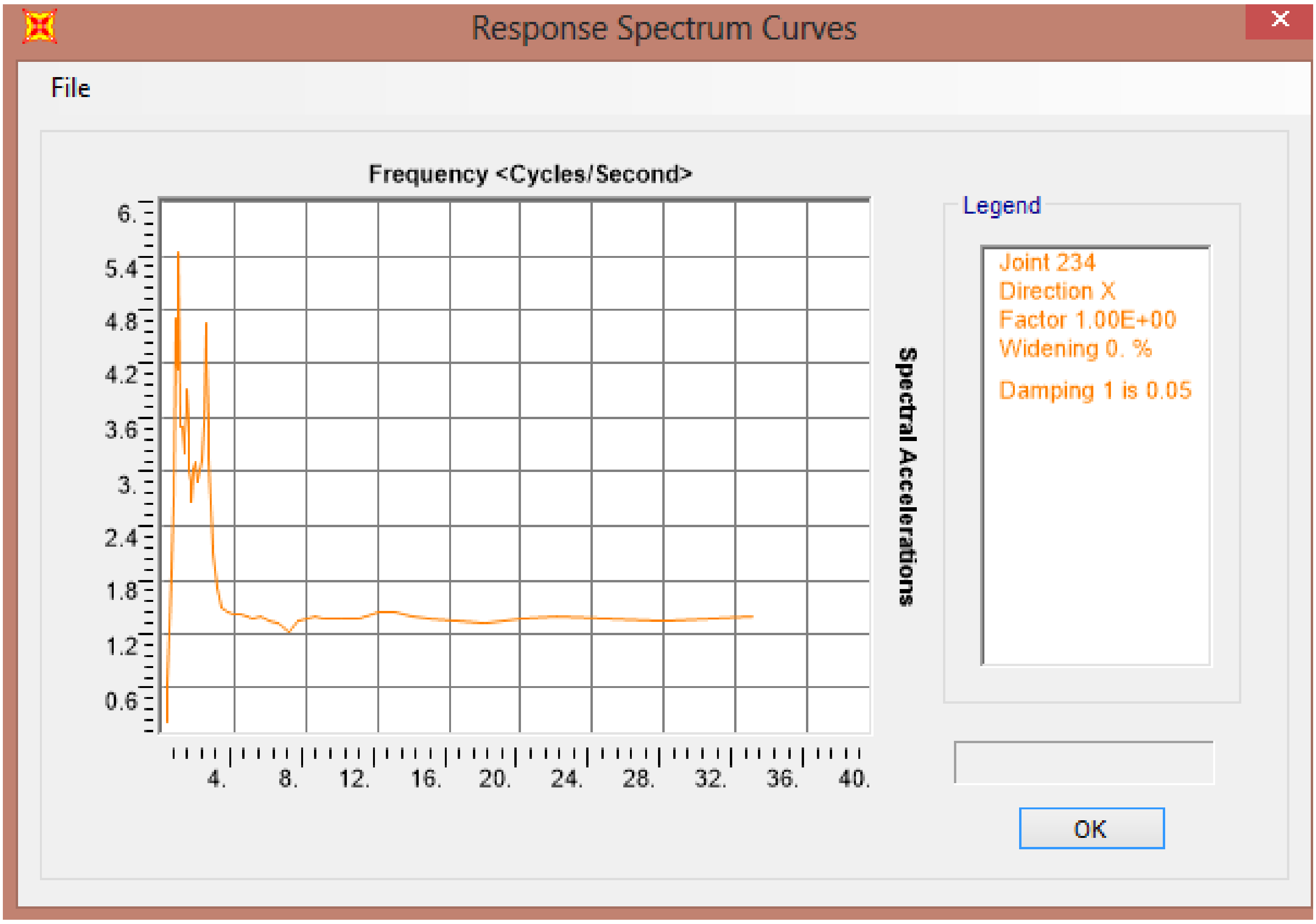


Fig.4.1.4. Response spectrum corresponding to 5% damping and acceleration–time history in X direction for high rise 25 storey building of Bhuj earthquake, 2001

TABLE 4.4 ForHARD SOIL

Base Reaction in X	157.85kN
Base Reaction in Y	151.92kN
Base Moment in X	7223.74kNm
Base Moment in Y	7902.77kNm

TABLE 4.5 ForMEDIUM SOIL

	.
Base Reaction in X	156.03kN
Base Reaction in Y	151.36kN
Base Moment in X	7383.57kNm
Base Moment in Y	7826.08KNm

TABLE 4.6 For SOFT SOIL

Base Reaction in X	154.94kN
Base Reaction in Y	152.491kN
Base Moment in X	7501.83kNm
Base Moment in Y	7760.69kNm

II. Considering 31 floors building

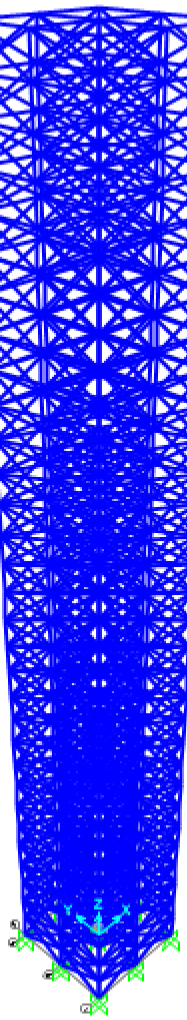


Fig. 4.1.5. 31 storey structural system

For hard soil

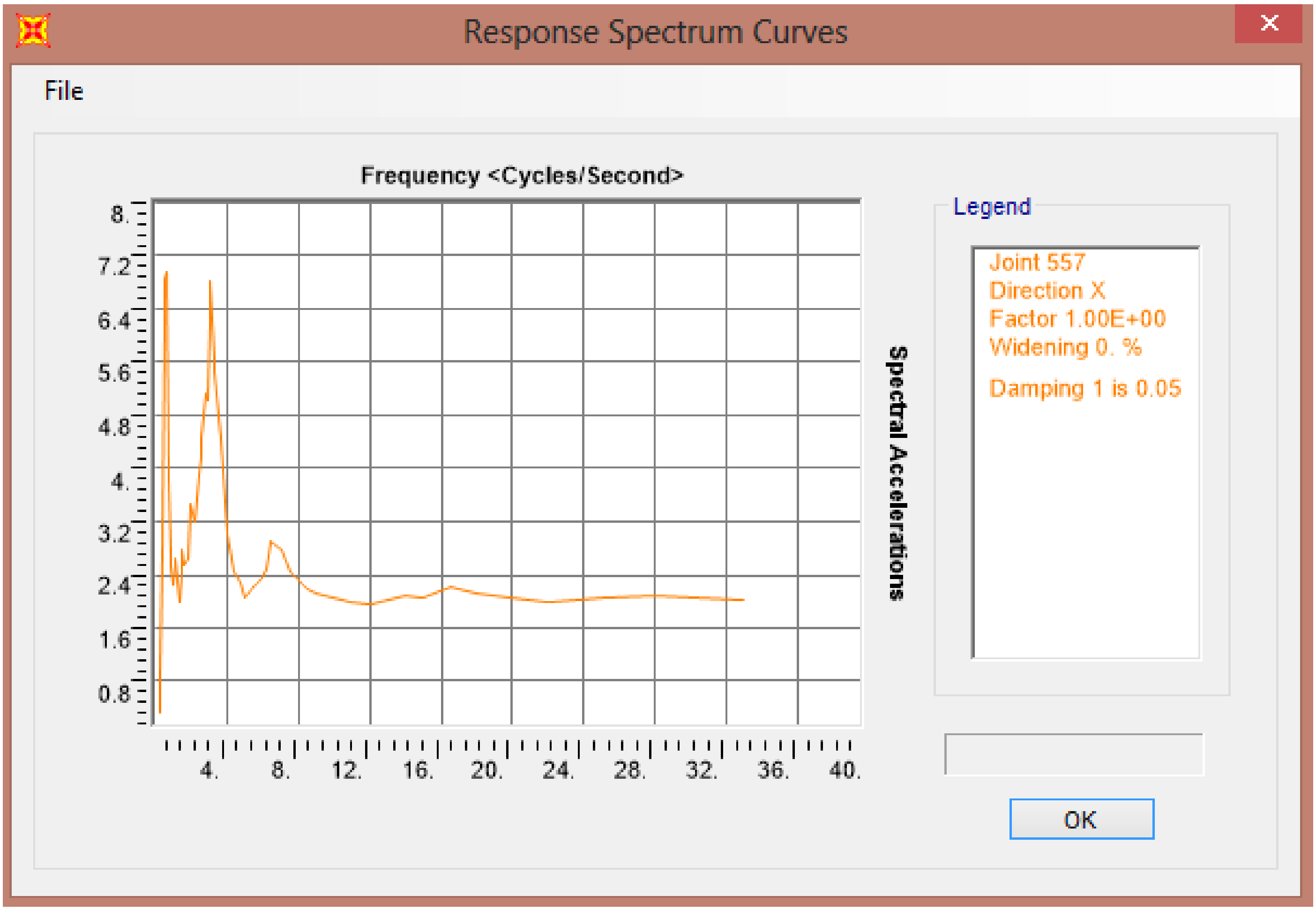


Fig.4.1.6. Response spectrum corresponding to 5% damping and acceleration–time history in X direction for high rise 31 storey building of Bhuj earthquake, 2001

For medium soil

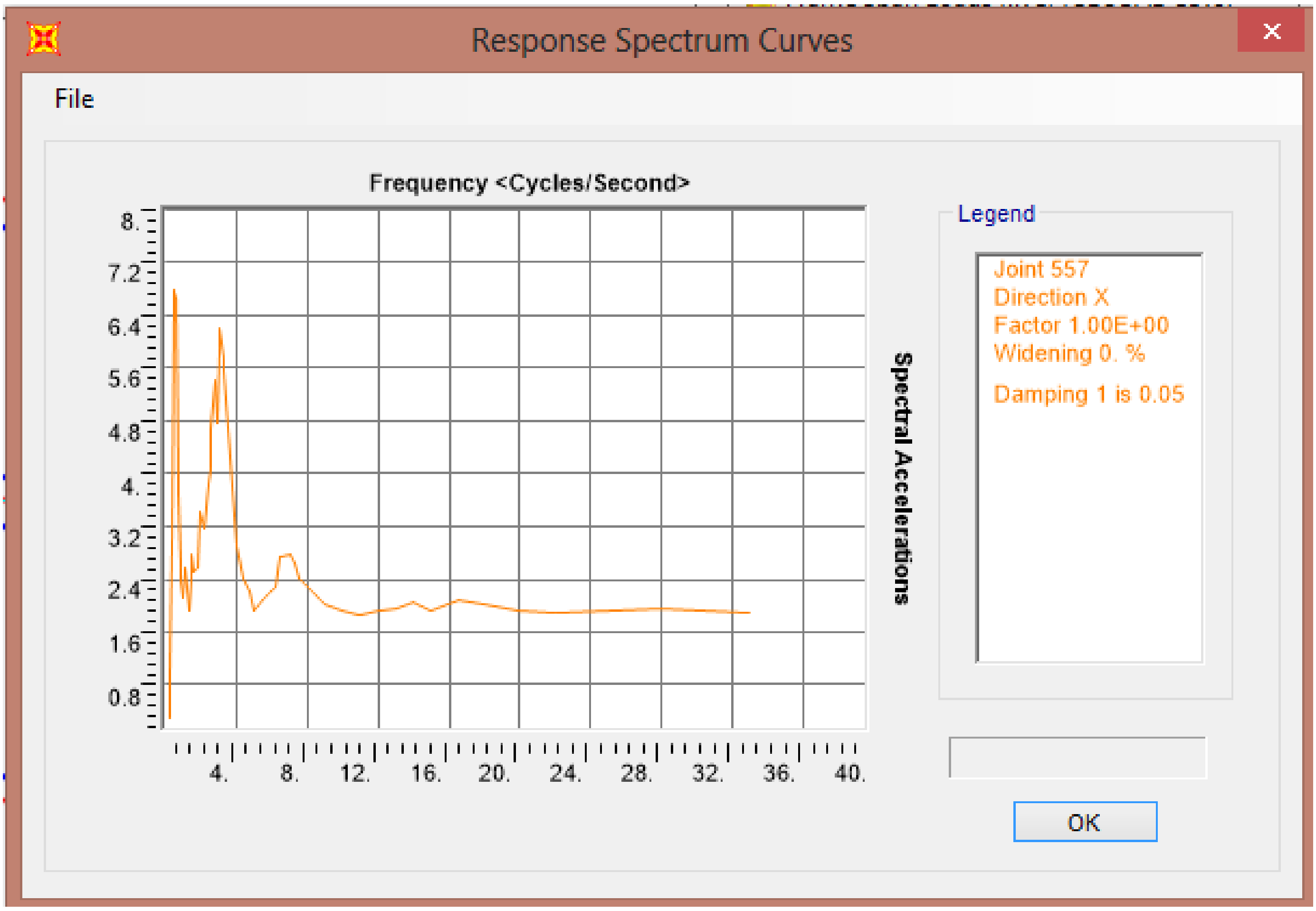


Fig.4.1.7.Response spectrum corresponding to 5% damping and acceleration–time history in X direction for high rise 31 storey building of Bhuj earthquake, 2001

For soft soil

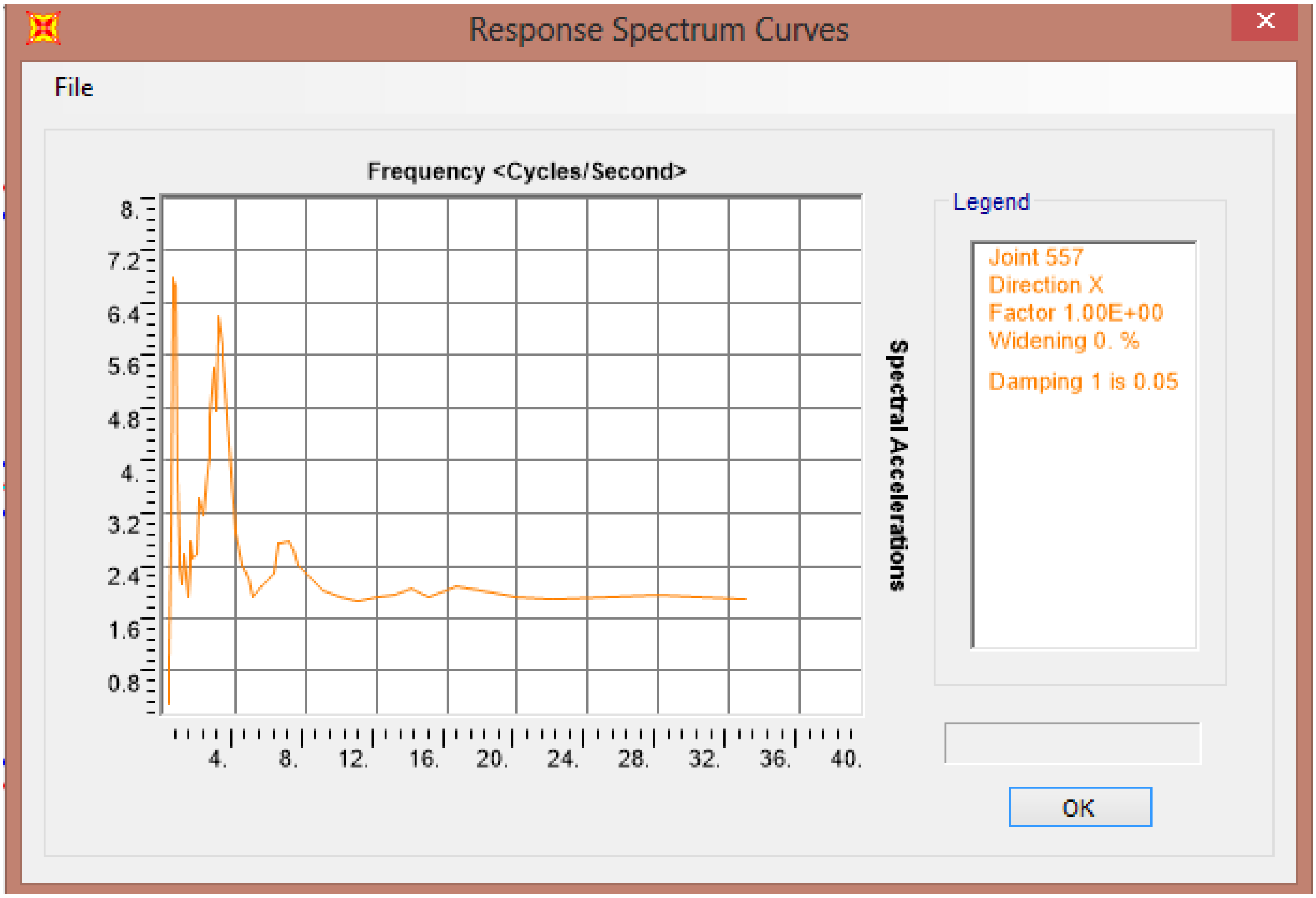


Fig.4.1.8.Response spectrum corresponding to 5% damping and acceleration–time history in X direction for high rise 31 storey building of Bhuj earthquake, 2001

TABLE 4.7 ForHARD SOIL

Base Reaction in X	215.285 KN
Base Reaction in Y	225.9 KN
Base Moment in X	11397.037KNm
Base Moment in Y	11352.469KNm

TABLE 4.8 ForMEDIUM SOIL

	.
Base Reaction in X	214.451 KN
Base Reaction in Y	224.75KN
Base Moment in X	11248.63KNm
Base Moment in Y	11246.81 KNm

TABLE 4.9 For SOFT SOIL

Base Reaction in X	213.101KN
Base Reaction in Y	223.181 KN
Base Moment in X	11197.71KNm
Base Moment in Y	11103.31 KNm

4.2 Implications of results

- By low rise building it is meant that the building frames contains five maximum number of storeys. And medium rise buildings contain fifteen maximum numbers of storeys whereas high rise buildings contain more than 15 storeys.
- Spectrum compatible ground motion of Bhuj earthquake of January, 2001 with recommended 5% damping have been used in the analysis

For low rise building

- To have a more deep understanding of the problem, a simple three storey plane frame having various lateral fundamental periods has been analysed with variation of subgrade condition.
- The present investigation reveals that the SSI effect may enhance the seismic response of structures for low-rise buildings. The following observation may appear to be in accordance with the generalrecommendations given in the NHERP-97 code and the common beliefs regarding the influence of the same.
- In the small period range, ordinates of the response curve generally increases; while the same exhibits a decrease in the long period region and very little or no change in the medium period range.
- Depending upon the structural system characteristics and the ground motion under observation, SSI may increase, decrease, or have no natural period at flexible base condition and the same at fixed base condition as the independent variable.
- The above graphs clearly indicate that effect of SSI is pronounced with the decrease in stiffness of soil from hard to medium as the magnitude of base shear in X and Y direction for fixed base is minimum followed by the medium soil and is maximum for soft soil. This indicates that the effect of SSI is detrimental in our study.
- If we just take a glance on response spectrum graph of various soil condition we would see that the response generated due to time- history is minimum for hard soil and is maximum for soft soil. This corresponds to the graph of base shear which give similar results.

For high rise buildings

- A simple 25 and 31 storeys plane frame having various natural periods has been analysed with variation of subgrade condition.
- SSI for high rise is beneficial for soft soil followed by medium flexible soil. The response is more in case of hard soil showing that SSI is beneficial in high rise structure in soft soil which is just opposite to the result of low rise building.
- The above graphs clearly indicate that effect of SSI is pronounced with the increase in stiffness of soil from soft to medium as the magnitude of base shear in X and Y direction for fixed base is minimum followed by the medium soil and is maximum for hard soil. This indicates that the effect of SSI is beneficial in our study of high rise structures.
- If we just take a glance on response spectrum graph of various soil condition we would see that the response generated due to time- history is minimum for soft soil and is maximum for hard soil. This corresponds to the graph of base shear which give similar results.

Chapter 5: Discussion

For the analysis purpose we have considered three cases:

(1) Completely fixed-base-represents the structural flexibility.

(2) flexible-base – represents flexibility of the soil- structure system together; and

(3) Pseudo-flexible(medium fixity)base - represents flexibility rocking in the foundationand also in the structural system.

Pseudo-flexible (medium fixity) base and parameters related to it are new to research interest because they may be used in straight and unswerving approximations of flexible-base and its parameter. Based on the Bhuj earthquake input datawe have evaluated and recorded the types of motion that are important to evaluate completely fixed, completely flexible, and medium-flexible base vibration parameters of low rise and high rise structural system with the help of some parametric recognition methods.

The simulations and research work has brought the following conclusions:

1. The simulation and our study shows that the SSI effect can play a major role in enhancing the seismic base shear of low-rise building frames. However, the same response generally diminishes due to the effect of SSI for medium followed by the high rise buildings.
2. Enhancement in the base shear due to flexibility of supporting soil generally decreases with increasing hardness of soil and increasing number of stories.
3. It is also found out that introducing tie beam at plinth level lessens the increment in base shear due to SSI.
4. If the soil flexibility is taken under consideration in thestrength designing, then the incremented strength provided through the interaction effect in low rise systems may help to reduce the inelastic range demands of the interactive systems considerably.

Our complete study of SSI, recognisees the major parameters, which maycontrol the SSI effect on the variation in base shear of structural system.Such a thorough study also aidin identifying the category of worst influenced structural frames. The study can also help in formulating the improved guidelines for design purpose for short period structures/frames accounting for the effect of SSI.

6. Scope for the future work

1. Effect of SSI with varying the depth of foundation and soil of different stiffness.
2. SSI effect on high rise unsymmetrical buildings and low rise buildings.
3. Soil-pile interaction and superstructure on loose and liquefying sandy soil.
4. SSI on different shapes of foundation and different types of foundation.
5. Effect of montmorillonite in soil on SSI.

Annexure

For low rise buildings

For 3 storey buildings

For hard soil

TABLE 5: Base Reactions for hard soil								
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
COMB2	Combination	Max	25.852	26.019	5517.979	120.1616	118.8397	3.105E-13
COMB2	Combination	Min	-25.852	-26.019	-5517.979	-120.1616	-118.8397	-3.105E13

For medium soil

TABLE 6: Base Reactions for medium								
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
COMB2	Combination	Max	26.811	26.911	5517.979	127.2558	126.4948	8.938E-13
COMB2	Combination	Min	-26.811	-26.911	-5517.979	-127.2558	-126.4948	-8.938E13

For soft soil

TABLE 7: Base Reactions for soft soil								
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
COMB2	Combination	Max	27.04	27.007	5517.979	133.4913	131.4097	6.851E-13
COMB2	Combination	Min	-27.04	-27.007	-5517.979	-133.4913	-131.4097	-6.851E-13

For 5 storey building

For hard soil

TABLE 8: Base Reactions					
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**
Text	Text	Text	kN	kN	kN
COMB2	Combination	Max	47.497	47.473	33437.445
COMB2	Combination	Min	-47.497	-47.473	-33437.445

For medium soil

TABLE 9: Base Reactions					
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**
Text	Text	Text	kN	kN	kN
COMB2	Combination	Max	49.352	49.771	33437.445
COMB2	Combination	Min	-49.352	-49.771	-33437.445

For soft soil

TABLE 10: Base Reactions					
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**
Text	Text	Text	kN	kN	kN
COMB2	Combination	Max	51.261	51.475	33437.445
COMB2	Combination	Min	-51.261	-51.475	-33437.445

Annexure for high rise buildings

For 25 storey buildings

For hard soil

Table 11: Base reaction

OutputCase	CaseType	StepType	GlobalX	GlobalY	GlobalFZ	GlobalMX	GlobalY	GlobalMZ
Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
COMB1	Combination	Max	157.848	151.92	143602.593	7223.7398	7902.771	0.00009289
COMB1	Combination	Min	157.848	-151.92	-143602.593	-7223.7398	-7902.771	-0.00009289

For medium soil

TABLE 12: Base reaction

OutputCase	CaseType	StepType	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
COMB1	Combination	Max	156.027	151.362	143602.593	7383.568	7826.0805	0.0002315
COMB1	Combination	Min	-156.027	-151.362	-143602.593	-7383.568	-7826.0805	-0.0002315

For soft soil

TABLE 13: Base Reactions

OutputCase	CaseType	StepType	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
COMB1	Combination	Max	154.938	152.491	143602.593	7501.8288	7760.6915	0.0002337
COMB1	Combination	Min	-154.938	-152.491	-143602.593	-7501.8288	-7760.6915	-0.0002337

For 31 storey

For hard soil

TABLE 14: Base Reactions									
OutputCase	**CaseType**	**StepType**	**GlobalfX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	Text	kN	kN	kN	kN-m	kN-m	kN-m
COMB1	Combination	Max	215.284	225.861	197094.737	11352.4698	11397.0371	0.0004833
COMB1	Combination	Min(-)	215.284	225.861	197094.737	11352.4698	11397.0371	0.0004833

For medium soil

TABLE 15: Base Reactions								
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
COMB1	Combination	Max	214.451	224.759	197094.737	11248.6399	11246.8175	0.0006565
COMB1	Combination	Min(-)	214.451	224.759	197094.737	11248.6399	11246.8175	0.0006565

For soft soil

TABLE 16: Base Reactions								
OutputCase	**CaseType**	**StepType**	**GlobalFX**	**GlobalFY**	**GlobalFZ**	**GlobalMX**	**GlobalMY**	**GlobalMZ**
Text	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
COMB1	Combination	Max	213.101	223.181	197094.737	11197.7145	11103.31	0.00006629
COMB1	Combination	Min(-)	213.101	223.181	197094.737	11197.7145	11103.31	0.00006629

References

1. Roy R, Dutta SC. "Effect of soil –structure interaction on dynamic behavior of building frames on grid foundations." Structural Engineering Convention (SEC 2001) Proceedings, Roorkee, India 2001; 579-86.

2. Gregory L. Feneves, Stewart Jonathan. "Seismic soil-structure interaction in buildings." *J. Geotech. Engrg.*, ASCE, 1999.125:26-37

3. Dobry, R., Gazetas, G. (1986). ''Dynamic response of arbitrarily shaped foundations.'' *J. Geotech. Engrg.*, ASCE, 112(2), 109–135.

4. Duke, C. M., Leeds, D. J. (1962). ''Site characteristics of southern California strong motion earthquake stations.'' *Rep. No. 62-55*, Dept. of Engrg., Univ. of California, Los Angeles, Calif.

5. George Mylonakis ." Seismic soil-structure interaction: beneficial or detrimental?" Journal of Earthquake Engineering, Vol. 4, No. 3 (2000) 277–301

6. Boris Jeremic and Shashi Kannath. "Soil–Foundation–Structure Interaction Eff ects in Seismic Behavior of Bridges." 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 294

7. Stewart, J. P., Seed, R. B., and Fenves, G. L. (1999). ''Seismic soilstructure interaction in buildings. II: Empirical results.'' J. Geotech. Engrg., ASCE, 125(1), 38–48.

8. Dr. Valsson Varghese, YogeshRamakantBorkar. "Comperative Study of S.M.R.F. Building Over O.M.R.F. Building With Seismic And Wind Effect." International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, Jun 2013

9. Bhojegowda V T and K G Subramanya. "Soil Structure Interaction of Framed Structure Supported on Different Types of Foundation." International Research Journal of Engineering and Technology (IRJET), India 2005; 2395-0056.

10. Roy R, Dutta SC. Differential settlement among isolated footings of building frames: the problem, its estimation and possible measures. Int J ApplMechEng 2001;6(1):165–286.

11. Chandler AM, Correnza JC, Hutchinson GL. Seismic torsional provisions: influence on element energy dissipation. J StructEng, ASCE 1996;122(5):494–500.

12. Goel R, Chopra AK. Inelastic seismic response of one-storey, asymmetric plan systems: effect of stiffness and strength distribution. Earthquake EngStructDyn 1990;19(7):949–70.

13. Dobry R, Gazetas G, Stokoe II KH. namic response of arbitrarily shaped foundations: experimental verifications. J GeotechEng, ASCE 1986;112(2):136–54