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# Soil Flexibility Effect on Dynamic Behaviour of Asymmetric 3d Building Frames with Strip Footing by Continuum Model

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*Abstract*—**In the present study Linear Dynamic Analysis is carried out using Response Spectrum Method for Seismic Zone-V (as per IS893-2002 Part-1 code of practice) on 3-D frames with strip footings incorporating soil flexibility. SAP2000*Ver14 FEM Structural analysis software package is used for the analysis. For the Interaction analysis space frame, foundation and soil are considered as parts of a single compatible unit and soil is idealized using the soil models for analysis**

**Influence of number of parameters such as number of storeys, soil types and height ratio for Seismic Zone-V is considered in present study. Building responses are considered for bare frame with and without accounting for soil flexibility. The Responses in terms of lateral natural period and seismic base shear and lateral displacement with and without soil flexibility is compared to evaluate the contribution of soil flexibility on building frames.**

***Keywords— Soil structure interaction*, *Continuum model, & Strip footing.***

## I. INTRODUCTION

Earthquakes are one of the most devastating natural hazards that cause great loss of life and livelihood. An earthquake is a spasm of ground shaking caused by a sudden release of energy in earth's lithosphere. This energy arises mainly from stresses built up during tectonic processes, which consists of interaction between the crust and the interior of the earth. Earth quake damage depends on many parameters including intensity, duration and frequency content of ground motion, geologic and soil condition quality of construction, etc.

Dynamic soil-structure interaction deals with the interaction of the foundation and the soil when subjected to dynamic loading. Dynamic loading refers to loads varying with time, e.g. earthquake, loads from rotating machinery etc. The interaction between a structure and its surrounding soil under dynamic loading has become an important issue due to the increasing design and construction of large and important structures.

Researches in the past few decades had elucidated that the soil-structure interaction has the following major effects: (1) reduction of the natural frequencies due to the soil flexibility; (2) partial dissipation of the vibrational energy of structure through wave radiation into the soil; and (3) modification of the actual foundation motion from the free field ground motion. Soil-structure interaction is an important issue, especially for stiff and massive structures constructed on the relative soft ground, which may alter the dynamic characteristics of the structural response significantly. Thus, the interaction effects should be accounted for in the dynamic analysis all soil-structure-system, particularly in severe soil conditions. Without considering the soil-structure interaction in analysis, the dynamic response of structure may be underestimated and consequently damage the structural safety. Such interaction may alter the dynamic characteristics of structures and consequently may be beneficial or detrimental to the performance of structures. Not taking into account these structural response amplifications may lead to an under-designed structure resulting in a premature collapse during an earthquake.

### *A. INFLUENCE OF SOIL STRUCTURE INTERACTION*

Soil-structure interaction is the phenomenon that involves the analysis of the relationship between the structure and the soil, and how it affects the motion that the structure experiences during an earthquake. As waves from an earthquake reach a structure, they produce motions in the structure; these motions depend on the structure's vibration characteristics and the building's structural layout. For the structure to react to the motion, it needs to overcome its own inertia, which results in an interaction between the structure and the soil.

#### *1. Soil- Structure – Interaction under Dynamic loading*

Structures are generally assumed to be fixed at their bases in the process of their analysis and design under dynamic loading. But the consideration of actual support flexibility reduces the overall stiffness of the structure and increases the period of the system. Soil medium imparts damping due to its inherent characteristics. The demolition of a part of a factory in 1970 earthquake at Gediz, Turkey; destruction of buildings at Carcas earthquake (1967) raised the importance of the issue. These show that the SSI should be accounted for the analysis of dynamic behaviour of structures, in practice. Hence SSI under dynamic loads is an important aspect to predict the structural response.

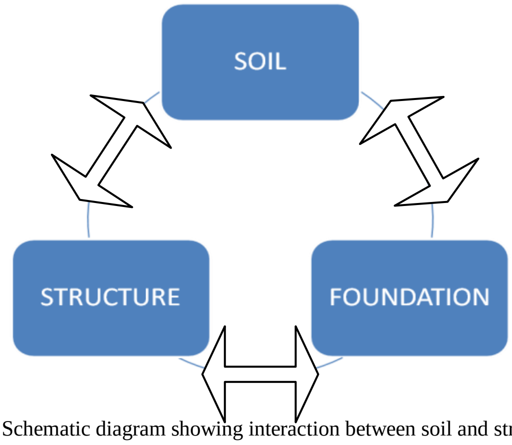



Fig.1. Schematic diagram showing interaction between soil and structure.

2. *Response Spectrum Method*

With the advent of personal computers and improved structural analysis techniques, the use of more precise methods increased. One of the most popular was response spectrum analysis. The method requires the determination of a response spectrum from measured seismic activity. Detailed information from the structural model was coupled with the corresponding spectral values for each specific mode of vibration. The independent results were then combined using an appropriate technique to determine the response of the overall structure. For the purpose of the seismic analysis the design spectrum given in IS: 1893 (Part1): 2002 is used. This spectrum is based on strong motion records of eight Indian earthquakes.

The response spectrum represents an envelope of upper bound responses based on several different ground motion records. For the purpose of the seismic analysis the design spectrum given in IS: 1893 (Part1): 2002 is used.

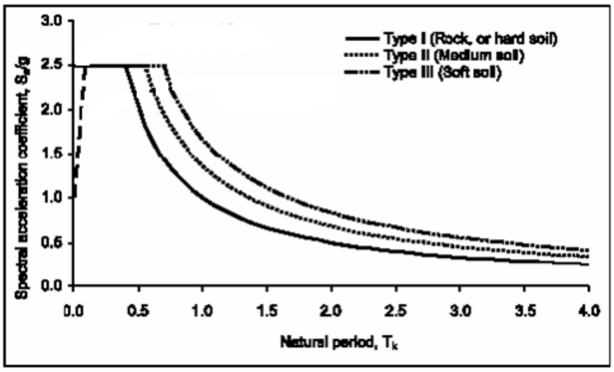



Fig.2. Design spectra as per IS1893:2002 (part-1) code of practice

Following procedure is generally used for the Response spectrum method of analysis:

i) Select the design spectrum.
ii) Determine the mode shapes and periods of vibration to be included in the analysis.
iii) Read the level of response from the spectrum for the period of each of the modes considered.
iv) Calculate participation of each mode corresponding to a single degree of freedom Response read from the curve.
v) Add the effect of modes to obtain combined maximum response.
vi) Convert the combined maximum response into shears and moments for use in design of the structure.
vii) Analyze the building for the resulting moments and shears in the same manner as the static loads.

3. *Continuum model approach*

It is a common experience that in the case of the soil media, surface deflections will occur not only immediately under the loaded region but also within certain limited zones outside the loaded region. It attempts to account for this continuous behavior, the soil media have often been idealized as three-dimensional continuous elastic solids or elastic continua.

Generally the distribution of the displacements and the stresses in such media remain continuous under the action of external force systems. The initial impetus for the continuum representation of the soil media stemmed from the work of Boussinesq's (1885), who analyzed the problem of a semi-infinite homogeneous isotropic linear elastic solid subjected to a concentrated force which acts normal to the plane boundary. The basic solution can then be used to obtain the response function for the three-dimensional elastic soil medium.

The use of continuum model has increased exponentially in the field of foundation engineering after the advent of fast computers and quick solution routines for numerical analysis. Further, development of different material models and constitutive relations over a long period has enhanced the use of continuum model particularly in the soil-structure interaction problems.

## B. *STRIP FOUNDATIONS*

In some cases it may be inconvenient to provide separate isolated footings for columns (or walls) on account of inadequate areas available in plan. This may occur when two or more columns (or walls) are located close to each other and/or they are relatively heavily loaded and/or rest on soil with low safe bearing capacity, resulting in an overlap of areas if isolated footings are attempted.

In such cases, it is advantageous to provide a single combined footing for the columns. Often, the term *'combined footing'* is used when two columns are supported by a common footing the term *'continuous strip footing'* is used if the columns (three or more in number) are aligned in one direction alone (Fig.1.8). The combining of footings contributes to improved integral behavior of the structure.

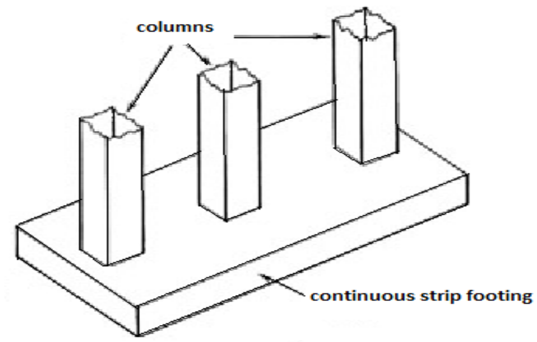



Fig.3. Strip footing

Figure 1.3 shows a three-column continuous strip footing, in case, the non-availability of space near the exterior column is circumvented by combining the footing with that of an interior column. The width of the footing is kept uniform.

## II. LITERATURE REVIEW

### A. Soil Structure Interaction Under Dynamic Loading

*Jenifer Priyanka, Anand, Justin (2012)* studied the effect of Soil-structure interaction on multi storeyed buildings. And also studied the response of buildings subjected to seismic forces with Rigid and Flexible foundations. Multi storeyed buildings with fixed and flexible support subjected to seismic forces were analyzed under different soil conditions like hard, medium and soft. The buildings were analyzed by Response spectrum method using software STAAD Pro. The response of building frames such as Lateral deflection, Storey drift, Base shear, Axial force and Column moment values were found to be lower for fixed base building when compared with flexible base building.

*Chinmayi and Jayalekshmi (2013)* studied SSI of a symmetric 16 storey RC frame shear wall building over raft foundation subjected to seismic loading. To examine thestructure-foundation- soil system, soil is treated as a homogenous, isotropic and elastic half space medium. The transient analysis of structure-soil-foundation system was carried out using LS-DYNA software. Earthquake motion corresponding to zone III of IS 1893:2002 design spectrum was used to excite the finite element model of soil-structure system. For integrating the SSI effect, four types of soils based on shear wave velocity were considered. Responses in terms of variation in natural period, base shear and deflection obtained from the analysis of the SSI model were compared with that obtained from conventional method assuming rigidity at the base of the structure. The results show that above said parameters have higher values for interaction analysis when compared to non- interaction analysis.

*Halkude S.A, Kalyanshetti M.G and Barelikar S.M (2014)* studied the effect of soil flexibility on the performance of building frames resting on raft foundation. This study focuses on SSI analysis of symmetrical space frame of 2 bay in both x and y direction for 2 storeys, 5 storeys and 8 storeys resting on raft foundation with fixed base and flexible base. Three types of soil i.e. Hard, Medium Hard and Soft Soil are used. Dynamic analysis was carried out using the Response Spectra of IS: 1893-2002. The soil modeling was done using Winkler approach (spring model) and elastic continuum approach (FEM model). SAP-2000 was used for developing these models. The effect of SSI on various structural parameters i.e. natural time period, base shear, roof displacement, beam moment and column moment are studied and discussed. The comparison was made between the approaches of SSI modeling i.e. Winkler approach and elastic continuum approach. This study reveals that the SSI significantly affects the response of the structure and Elastic continuum approach (FEM model) was proved to be the effective approach for consideration of elastic continuum beneath foundation.

### B. Interaction Analysis of Strip Foundation

*Spyrakos, Chaojin Xu (2003)* studied the seismic response of massive flexible strip-foundations embedded in layered soils. Emphasis was placed on the investigation of the system response with the aid of a boundary element–finite element formulation proper for the treatment of such soil–structure interaction problems. In the formulation, the boundary element method (BEM) was employed to overcome the difficulties that arise from modeling the infinite soil domain, and the finite element method (FEM) was applied to model the embedded massive flexible strip-foundation. The numerical solution for the soil-foundation system was obtained by coupling the FEM with the BEM through compatibility and equilibrium conditions at the soil–foundation and soil layer interfaces. It was observed that when the excitation frequency exceeds the fundamental frequency of the soil–foundation system, the response of soft foundations shows considerable difference from that of stiff foundations.

*Narayana G (2012)* studied the effect of dynamic soil structure interaction of single and two bay three dimensional building structures of 1, 2 and 4 storey with isolated, strip and raft foundations and soil medium represented by Winkler, Modified Winkler and Continuum soil models which were analyzed for different combinations of IS 1893 (Part-1)-2002 for all seismic zones and compared them with structures with conventional fixed base assumption. He found out that the effect of the interaction analysis considering different soil models was higher than that of structures with fixed base with respect to various parameters such as shear modulus of soil, base shear, lateral displacement, axial force and bending moment in the frame elements considered.

*Kraus & Džakić (2013)* studied three different approaches on numerical modelling of fixity of structures with the soil beneath: conventionally fixed structure, structure on Winkler springs and structure on half-space. Linear elastic analysis was carried out on three, seven and ten-story three-bay reinforced concrete frames using time history analysis. All of the structures were founded with strip footing on soft soil as defined according to Eurocodes. Ground motions used were selected from the European Strong-Motion Database. Analysis was carried out using SAP2000 software. It was observed that the building models with soil included, compared to conventional fixed base models had 70% higher fundamental periods. Also base shear and storey drift values were higher when soil structure interaction effects were considered.

## III. METHODOLOGY

### A. Method of Soil Structure Interaction Analysis

#### 1. Assumptions:

To analyze the building foundation-Soil system, the following assumptions are made:

a) The building with foundation is linearly elastic.
b) The building with foundation rests on the surface of an isotropic, homogeneous, linearly elastic soil medium the behavior of which can be idealized and represented using soil models.
c) There is no slippage between the base of the foundation and soil medium.
d) The soil properties do not change during the ground motion.
e) All the frame members are prismatic and all the joints act as rigid joints.
f) The vertical component of earthquake motion is ignored.

#### 2. General Method of Interaction Analysis

Response Spectrum Method is adopted for the Linear Dynamic Analysis using Finite Element method (FEM).

For the Interaction-Analysis, the super-structure, foundation under consideration and soil system are considered as parts of a single compatible unit. To obtain the Finite Element model of this interacting system, the super-structure and foundation are discretized and the soil medium is represented as idealized models. So obtained FE Model of the super structure-soil interactive unit is analyzed using Linear Dynamic analysis by Response Spectrum Method with SAP2000*Ver-14 Structural FEM Software Package applying different load combinations of seismic and gravity loads, for the type of soil and seismic zone under consideration.

The steps followed are as follows:

- Beams and columns of the superstructure (building frame under consideration) is idealized as three dimensional space frame with two noded line elements with each element having 6 degrees of freedom at each joint.
- The floor and roof slabs are modeled as thin shell using 4 noded plate element having 6 degrees of freedom at each node.
- Soil is idealized with the required soil model, Continuum Model. Soil has been modeled using eight node element (SOLID) having three degrees of freedom of translation each in the respective co-ordinate directions at each node.
- The masses of buildings and mass moments of inertia are lumped at floor levels at the corresponding degrees of freedom.
- Dynamic analysis (Response Spectrum Method) of the system is carried out as per IS 1893-2002 (part 1) applying appropriate boundary conditions.

### B. Finite Modeling of the Interactive Unit

#### 1. Modeling of Superstructure

The super structure as space frame consists of columns in each storey and beams and slabs at each floor level.

#### 2. Modeling of Beams and Columns

For any given layout of a super-structure, building can be best analyzed by a 3D space frame model Fig (4 & 5) consisting of assemblage of beams and column elements. Any torsion effects are automatically considered in the model. The ground motions can be applied in 1, 2 or 3 directions individually or simultaneously. In the present study earthquake load is applied individually along horizontal X and Y directions.

Super structure of the building frame as 3D space frame is modelled using SAP2000 V14 FEM structural analysis software package. Two noded line elements with six degrees of freedom at each node represent beams and columns in each storey as shown.

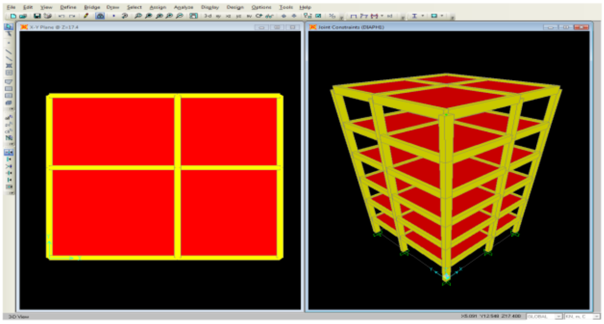


Fig.4. 3D Space frame with fixed base -2bay 2bay 6 Storey SR-1.25, HR-0.8

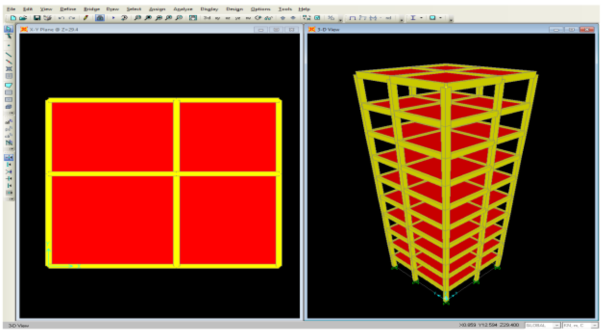


Fig.5. 3D Space frame with fixed base -2bay 2bay 10 Storey SR-1.25, HR-0.8

### 3. *Modeling of Floor Diaphragms*

Typically slabs are considered as rigid supports; these are analyzed and designed for gravity loads separately from the frame system. The floor slabs should be adequately represented in 3D model of the structure so that their dead loads and live loads are properly accounted for. Under seismic load, floor slabs play an important role of transmitting inertial loads to the frame and tying together element of the latter into a 3D entity. To perform these roles, slabs should be adequately connected with their supporting beams, walls and columns. The slabs are modeled in two ways either as rigid or flexible floor diaphragms. In present study, 3D space frame with flexible floor diaphragms for slab at each floor level is discretized and is modeled as thin shells with four noded plate elements having six degrees-of-freedom at each node (three translations and three rotations in their respective coordinate directions), for modeling in SAP2000 V14.

### 4. *Modeling of Foundations*

The dimensions of all strip footings considered are given in Table 3.3. The finite element idealization of strip foundation is carried out in the same way as that of the soil i.e. using eight noded SOLID elements for continuum model having three degrees of freedom of translation in the respective co-ordinate directions at each node.

### 5. *Modeling and Analysis of soil as Continuum model*

Soil is assumed to be an isotropic, homogeneous, linearly elastic soil medium, the behavior of which can be idealized and represented using soil models for which dynamic shear modulus and Poisson's ratio are the inputs. Soil is modeled using eight node element (SOLID) having three degrees of freedom of translation and rotation in the respective co ordinate directions at each node.

In order to fix the region of soil below and around the foundation which influence the soil behavior and necessary to be considered in the analysis, pressure isobars based on the Boussinesq equation (Bowles 1988) have been used. Based on this Continuum model for soil is represented by considering breadth equal to twice the width of the foundation along the plan dimension and thrice the width of foundation along the depth of foundation.

Trial analyses with few variations with respect to above considerations of size of the soil medium were carried out in order to fix the region of soil below and around the foundation which needs to be considered in the analysis to realistically represent continuum model, and it was found that for thickness of soil medium more than 2.5 times the least width of soil foundation, there was negligible influence on settlement and contact pressure below the footing. Figure 6 and 7 shows discretization of foundation-soil system in continuum model for strip footing.

Vertical translation is arrested at the bottom boundary while lateral translation has been arrested at vertical boundaries.

Another important effect to be considered in soil modeling is soil damping. Numerous studies on this aspect have been made by different investigators. However, critical damping of 5% is considered in each mode of vibration for all cases in the present study as suggested by IS 1893:2002 (Part 1).

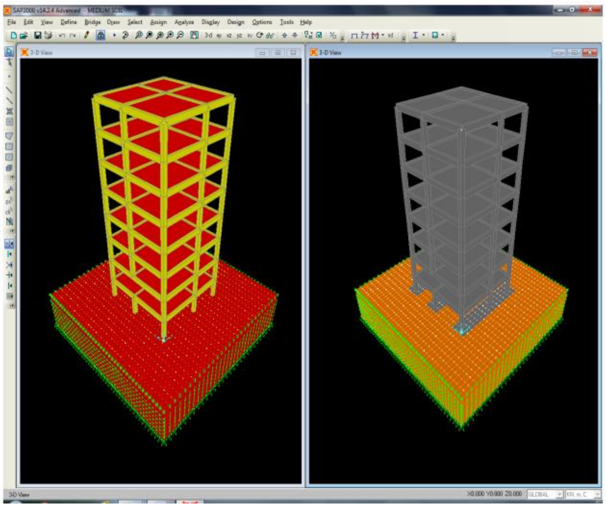


Fig.6. 2bay 2bay 8 storey SR-1.25 HR-0.8

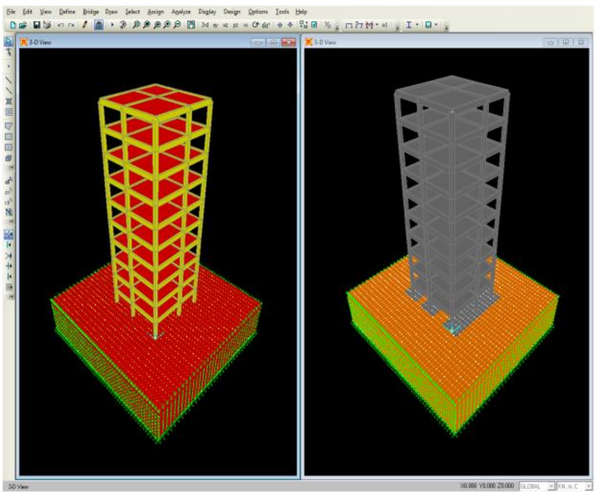


Fig.7. 2bay 2bay 10 storey SR-1.25 HR-0.8

### C. *Interaction Analysis (IA)*

3D frame-foundation-soil interaction units are discritized and modeled using SAP2000*Ver-14 Structural FEM Software package, soil being represented using Continuum model. Dynamic analysis (Response Spectrum Method) is carried out as per IS 1893-2002 (part 1). Such an analysis is termed as Interaction analysis.

### D. *Non-Interaction Analysis (NIA)*

The conventional analysis of the 3D frame is carried out by considering the column ends as fixed (without considering soil types) with all the structural input parameters being same as that of interaction analysis and is referred to as Non-Interaction analysis in the present study.

### E. *Soil Parameter and Building Design Input Data for the Present Study with Isolated Footing*

According to Bowles J E and Based on dynamic shear modulus soil is classified as hard, medium, soft, by using various parameters as shown below.

Table-1: Soil parameters

| Sl no | Type of soil | Shear modulus (G) KN/m$^2$ | Elastic modulus (E)KN/m$^2$ | Poisson's ratio (μ) |
|---|---|---|---|---|
| 1 | Hard(Type-1) | 30,000 | 72,000 | 0.2 |
| 2 | Medium(Type-2) | 20,000 | 50,000 | 0.25 |
| 3 | Soft(Type-3) | 10,000 | 26,000 | 0.3 |

The members properties are
Column size: 350mmX500mm
Beam size: 250mmX600mm,

Material properties are
Grade of concrete: M25
Young's modulus: 25X10$^6$ KN/m$^2$

Thickens of slab: 150mm, Density of concrete: 25 KN/m$^3$
Earthquake live load on slab, Density of brick masonry: 20 KN/m$^3$

Roof: 0.25X1.5=0.375 KN/m$^2$
Floor: 0.25X3.0=0.75 KN/m$^2$
Seismic data
Seismic Zone: V
Zone factor: 1
Response Reduction factor: 5

Load intensities are
Floor dead: 1.0 KN/m$^2$
Roof dead: 2.0 KN/m$^2$
Floor live: 3.0 KN/m$^2$
Roof live: 1.5 KN/m$^2$
Critical damping: 0.05

*F. Loads Applied*

For the Interaction analysis as well as Non Interaction analysis, the various load combinations considered as per IS1893 (part1) -2002 are

- 1.5(DL+IL)
- 1.2(DL+IL±EL$_x$)
- 1.2(DL+IL±EL$_y$)
- 1.5(DL±EL$_x$)
- 1.5(DL±EL$_y$)
- 0.9DL±1.5EL$_x$
- 0.9DL±1.5EL$_y$

*G. Results Obtained*

From the results of the IA and NIA the following 3 parameters of the 2bayx 2bay structures of 6, 8 and 10 storey are studied. The results of each parameter corresponding to the maximum values are presented in the tables for the following parameters namely.

i) Fundamental Natural Period
ii) Seismic Base Shear
iii) Maximum Lateral Displacement

The variations of the above parameters are studied as a function of the following variables namely,

- Soil type (Stiff, medium, Soft)
- Number of Storeys (6, 8 and 10)

## IV. RESULTS AND CONCLUSION

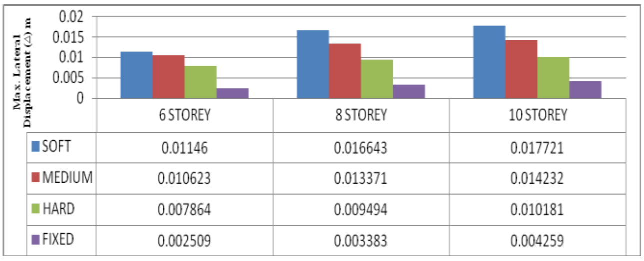



Fig.8. 2x2Bay 6, 8 & 10Storey HR-0.8 & SR-1.25 represents the variation of Lateral Displacement (Δ) m Vs Storey.

*A. Effect of Number of Storeys*

Lateral displacement between storey variation for different 3-D frame models. It is seen that with respect to increase in number of storey an increase in lateral displacement is observed.

*B. Effect of Soil Type*

The degree of reduction between different types of soil is not as much as that between interaction and non interaction analysis. Therefore, values of IA show higher value than that of NIA.

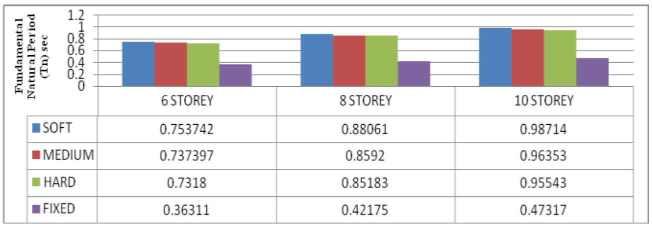


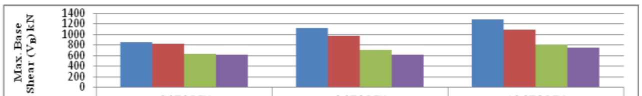

Fig.9. 2x2Bay 6, 8 & 10Storey HR-0.8 & SR-1.25 represents the variation of Natural Period (Tn) Vs Storey.

*C. Effect of Number of Storeys*

Fundamental Natural period between storey variation for different 3-D frame models. For any frame considered, **Tn** increases substantially with number of storey in case of both Interaction Analysis (IA) and Non Interaction Analysis (NIA)

*D. Effect of Soil Type*

The degree of reduction between different types of soil is not as much as that between interaction and non interaction analysis. Therefore, values of IA show higher value than that of NIA.




| | 6 STOREY | 8 STOREY | 10 STOREY |
|---|---|---|---|
| SOFT | 845.77 | 1112.022 | 1277.1 |
| MEDIUM | 824.243 | 962.513 | 1091.738 |
| HARD | 622.17 | 697.369 | 804.051 |
| FIXED | 605.332 | 615.962 | 737.601 |

Fig.10. 2x2Bay 6, 8 & 10Storey HR- 0.8, & SR-1.25 represents the variation of Base Shear (VB) VS Storey.

### *E. Effect of Number of Storeys*

Base shear between storey variations for different 3-D frame models. It is observed that number of storey plays an important role related to base shear, i.e the base shear increases with increase in number of storey for both IA and NIA.

### *F. Effect of Soil Type*

The degree of reduction between different types of soil is not as much as that between interaction and non interaction analysis. Therefore, values of IA show higher value than that of NIA.

## *G.* CONCLUSION

In present the effect of soil flexibility on dynamic behavior of asymmetric building frame resting on strip footing, such as fundamental natural period, base shear and maximum lateral displacement. Number of stories increases by increasing the fundamental natural period and the non-interaction analysis values are slightly lesser then its interaction analysis values. Number of stories increases by increasing the base shear values and the non-interaction analysis values less as compared to interaction analysis values. Number of stories increases by increasing the displacement values and the maximum lateral displacement is obtained in non-interaction analysis.

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