Case Study on a Structural Building Subjected to Earthquake Forces Considering Soil Structure Interaction

Nawaraj Kapil[1], Karthik N.M[2], Dr. Rajendra .S[3], Likhitha.R[4]
[1]P.G Student, Department of Civil Engineering, N.C.E.T, Visvesvaraya Technological University, Bangalore, India
[2]Assistant Professor, Department of Civil Engineering, C.M.R.I.T, Visvesvaraya Technological University, Bangalore, India
[3] Professor and Head (P.G) Student, Department of Civil Engineering, N.C.E.T, Visvesvaraya Technological University, Bangalore, India
[4]Assistant Professor, Department of Civil Engineering, N.C.E.T, Visvesvaraya Technological University, Bangalore, India
strtenggnavraj@gmail.com, nm.karthik0@gmail.com, rajendra_nulenur@rediffmail.com, Likhithakr@gmail.com

***Abstract*—** In recent years India has been considered as one of the disaster prone countries in the world. Studies are carried out to study the seismic behavior of the structure when hit by an Earthquake. The course of tremor depends upon the type of soil and varying topographical region which are classified under various seismic zones i.e. II, III, IV, V. Past researchers revealed that the vertically irregular structures are mostly prone to Earthquake damages. In this paper, attempt has been made to study the effects of vertical irregularities on a structural building and seismic behavior of the structural building during an earthquake. The structural model considered has been already constructed in Earthquake prone area: - Sikkim, India, which falls under seismic zone [IV]. The structure was modeled and analyzed by Response Spectrum analysis considering soil structure interaction using E-tabs software.

***Keywords*-** *Response Spectrum Analysis, Soil Structure Interaction,Storey Displacement, Storey Shear, Base Shear, E-tabs.*

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I. INTRODUCTION

Swift release of stress in the form of waves during the deformation and brittle rupture of rocks due to the gigantic tectonic plates is known as an Earthquake. These seismic waves travel in all directions through the earth layer with large strain energy, reflecting and refracting at each interfaces. The severity of the ground shaking at a given location during an earthquake can be minor, moderate and strong. When seismic wave hits the structure, one or more foremost peaks of magnitude of motion are noticed which signify the impinging of ground shaking. But, the impact of the seismic waves depends upon the distance of the building commencing from the epicenter.

In 2011, an earthquake of magnitude 6.9 with depth of 19.7 Km hit the North-East Himalayan state of India-Sikkim. This earthquake was also known as the 2011 Himalayan earthquake. 18th September, 2011 was the “Black Day” for the people of Sikkim and the neighboring countries like Nepal, Bhutan and Tibet. More than 112 people were killed in the earthquake while most of the deaths occurred in Sikkim. After a month of research and study, experts came to conclusion that the collapse of structures were caused mainly due to the irregularities in the structural Building.

The main objective of this study is to analyze already constructed RC structure (vertically irregular) in order to know the seismic behavior of the structure when hit by an earthquake. The structure was modeled and analyzed by Response Spectrum analysis using E-tabs software. Parameters such as time period, displacement, base shear, stiffness were calculated and compared.

II. LITREATURE REVIEW

S. Monish, S.Karuna (2015); investigated on Effects of vertical Irregularities in RC Framed Buildings in Severe Seismic Zone. The result of analysis revealed that if number of stories are increased the lateral displacement increases in both method of analysis. Lateral displacement up to specific floors are similar, but varies on the above floors.

E.Pavan Kumar, A. Naresh, M. Nagajyoti, M. Rajasekhar (2014), investigated on Earthquake Analysis of Multi-storied Residential Buildings- a Case Study. The result of analysis revealed that the static analysis in OMRF & SMRF values is low when comparing to that of dynamic analysis in OMRF & SMRF values. The performance of dynamic analysis SMRF structure is quiet good in resisting the earthquake forces compared to that of the static analysis OMRF & SMRF.

J.H Cassis, E. Cornejo (2013), have investigated on Influence of Vertical Irregularities in the Response of Earthquake Resistance Structure. The result of analysis revealed that Buildings with soft storey, displacement capacity are less. When walls extended to first floor, it provides enough stiffness and strength to the weak and soft stories. The distribution of shear and overturning moment in the vertical substructure possess variations in the zone of irregularities.

Shreya Thusoo, Karan Modi, Rajesh Kumar, Hitesh Madahar (2015) have investigated on “Response of Buildings with Soil Structure Interaction with Varying Soil Types”. Their main objective was to determine or check for the extent of variations rooted to foundation stiffness. This paper concluded that deflection in hard or medium soil is less compared to soft soil, for moderate stiff soil, inflation in deflection takes place with increase on number of story’s, the spectral acceleration response pattern changes as stiffness of base soil increases and time period of all the response increases as stiffness of the soil increases from soft soil to hard soil.

III. VERTICAL IRREGULARITIES

Vertical irregularities are the irregularities which are caused due to the sudden change in mass, stiffness and geometry which leads to discontinuity in load transfer. Vertical

irregularities is one of the major reasons behind the irregularities and failure of the structure during Earthquake forces.
It is classified into various types, such as:

A. Vertical Irregularities in Load Path

One of the major causes of vertical irregularities is critical load path. The structure must possess continuous load path for the load transfer. If load transfer is asymmetrical the structure gets severely damaged and even collapse.

Earthquake forces which are produced from the structural element of the building are delivered to vertical members by the help of a diaphragm. The diaphragm is a structural element that transfer loads to columns or shear walls of the structure, so the diaphragm must be of adequate stiffness.

Irregular in load transfer leads to floating box type situation. Such cases, the columns do not get extended till the ground floor which leads to discontinuity in load transfer and structure may get severely damaged. The critical region for damage is the column and beam joints. Primary concern must be taken regarding discontinuity of columns and at the column beam joints.

B. Vertical Irregularities in Strength and Stiffness

Irregularities due to strength and stiffness are broadly classified into two types;

a. Weak storey.
b. Soft storey.

Weak storey is defined as one whose lateral strength of the store considered is less than 80% of the stories above it. Lateral loads are generally the strength of all the lateral load resisting elements sharing sheer force of the storey based on the direction considered.

Soft storey is defined as one whose lateral stiffness is less than 70% of the storey immediately above or less than 80% of the all above storey's. Extreme soft storey is one in which the lateral stiffness is less than 60 percentage of that in the storey above or less than 70 percentage of the average stiffness of the three storey's above.

C. Mass Irregularities

Mass irregularities in a structure exist when the effective mass of any storey is more than the 200% of the effective mass of adjacent storey. It can lead to increase in lateral inertial force, decrease in ductility of vertical members and collapse of the structure due to P-delta effect. Mass irregularities can lead to complex dynamics and irregular response of the structure. During earthquake the structure swings due to change in mass in upper and lower floors. Such case, the lateral load is shifted above the base which leads to large bending moment.

IV. Soil Structure Interaction

Soil Structure Interaction can be defined as the coupling of the structure and the soil during an Earthquake. It is one of the most flourishing areas of research for structural engineer. SSI is influenced by two types of loading .i.e. Dynamic loading and static loading. Basically, engineers neglect SSI while designing ordinary structure as they evaluate the structure under the assumption of fixed based dynamic response.

When the structure is hit by the seismic waves, these waves tend to generate vibrations or motion on the structure. In order to resist the motion, the structure needs to overcome its own inertia force which in result deals with SSI.
There are two types of primary issues of soil structure interaction:

- Inertial Interaction.
- Kinematic Interaction.

When soil undergoes deformation and stress, they induce base shear and moments in the vibrating structure. Such cases lead to dynamic response of the structure by creating dynamic interacting system between soil and the structure. This type of interaction is known as Inertial Interaction.

When seismic waves enter the soil, a discontinuity in medium of wave propagation is encountered at the interface of foundation and soil. This leads to reflection, scattering deflection, refraction of seismic waves at soil foundation interface along with change in nature of ground motion. Slippage occurs across the soil foundation interface which is affected by wave propagation in elastic medium. This phenomenon due to the wave propagation consideration is known as Kinematic Interaction.

V. Structural Detailing

The structural building considered has been already constructed in Sikkim, India. It is vertically irregular in nature and comprises of B-3 and G+4. The total area comprises of 18.01m x 16.92 m. The soil condition of the structure is dense gravel soil with soil bearing capacity of 180 kN/m^2. The grade of concrete used is M30 and grade of steel is Fe 500. The loads considered are: Dead load of 1 kN/m^2, Live Loads of 3 kN/m^2, 4 kN/m^2 and 5 kN/m^2 respectively. The frame Loads provided were of 11 kN/m as exterior wall load and 5.08 kN/m as partition wall load. The structure was modeled and response spectrum analysis was carried out using E-tabs software. The same structure was analyzed considering soil structure interaction for X and Y direction respectively. The material properties of a structure are shown in Table 1, frame properties of beam are shown in Table2, frame properties of slab are shown in Table 3 and frame properties of column are shown in Table 4. The frame loads are shown in Table 5 and the shell loads are shown in Table 6.

Table 1: Material properties of a structure considered.

SL.NO	MATERIAL PROPERTIES	VALUES	UNIT
1	Characteristic compressive strength of concrete	M 30	kN/m^2
2	Characteristic strength of reinforcement	Fe 500	kN/m^2

Table 2: Frame Properties of beam

SL. NO	PROPERTIES	DIMENSION	UNITS
1	Beam(B1)	500X400	mm
2	Beam(B2)	600x600	mm

Table 3: Frame Properties of slab

SL. NO	PROPERTIES	DIMENSION	UNITS
1	Slab(S1)	127	mm

Table 4: Frame Properties of column

SL. NO	PROPERTIES	DIMENSION	UNITS
1	Column (C1)	400X300	mm
2	Column (C2)	500X450	mm
3	Column (C3)	600X500	mm
4	Column (C4)	300X400	mm
5	Column (C5)	500X400`	mm

Table 5 : Frame loads

SL. NO	FRAME LOAD	VALUES	UNITS
1	Exterior wall load	11.65	kN/m
2	Partition wall load	5.08	kN/m

Table 6: Shell loads

SL. NO	SHELL LOAD	VALUES	UNITS
1	Dead Load	1	kN/m^2
2	Live load	3	kN/m^2
3	Live load	4	kN/m^2
4	Live load	5	kN/m^2
5	Floor Finish	1	kN/m^2

VI. RESULTS

After analysis of the structure, seismic weight was obtained and base shear was calculated. The base shear calculated manually was compared to that obtained from E-Tabs. The seismic weight and base shear of the structure are shown in Table 7 and Table 8 respectively. The parameters considered such as Displacement and Story Shear was calculated and compared considering with and without soil structure interaction for both X and Y direction respectively.

Table 7: Seismic Weight

SL. NO	Seismic weight	VALUES	UNITS
1	Dead Load	13834.1368	kN
2	Live Load	1506.8116	kN
3	Floor Load	1766.6434	kN
4	Wall Load	12797.0864	kN

Table 8: Base Shear

SL NO	BASE SHEAR	VALUES	UNITS
1	X direction(V_{BX})	945.94	kN
2	Y direction(V_{BY})	952.404	kN

The comparison of storey displacement and storey shear are done and the comparative result are shown in figure 1 to figure

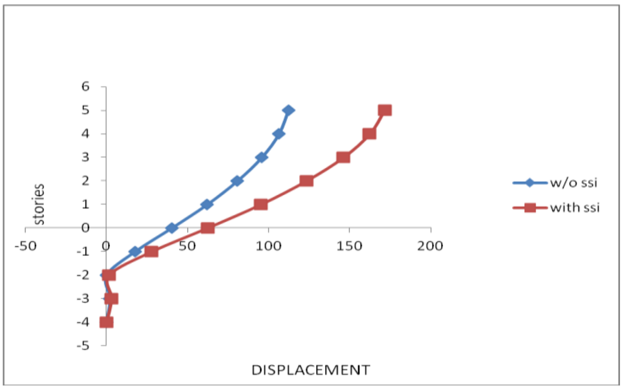

Fig. 1: Comparision of storey displacement of the strcture with and without soil structure interaction in X-direction

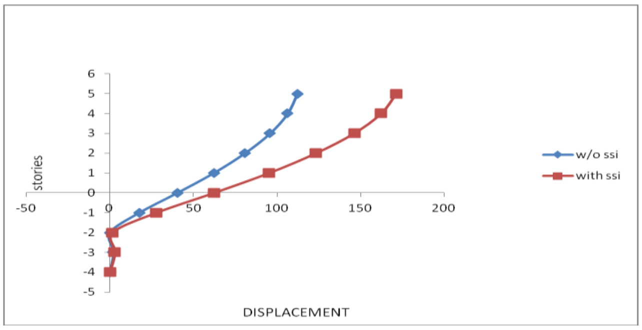

Fig. 2: Comparision of storey displacement of the strcture with and without soil structure interaction in Y-direction

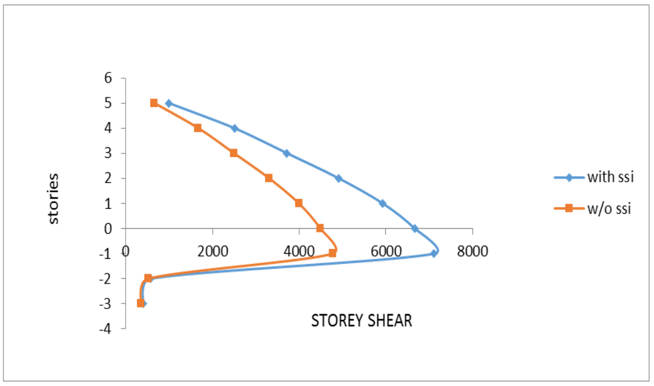

Fig. 3: Comparision of storey shear of the strcture with and without soil structure interaction in X-direction

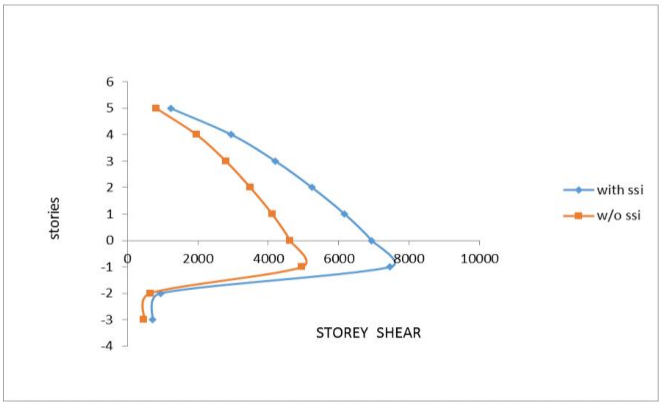

Fig. 4: Comparision of storey shear of the strcture with and without soil structure interaction in Y-direction

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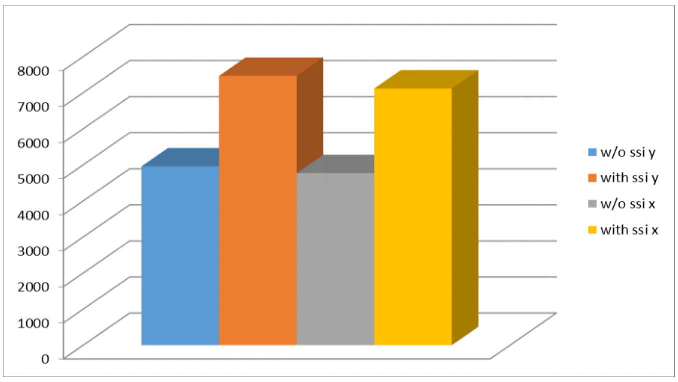

Fig. 5: Comparision of storey shear of the strcture with and without soil structure interaction for Basement-1 in X and Y direction

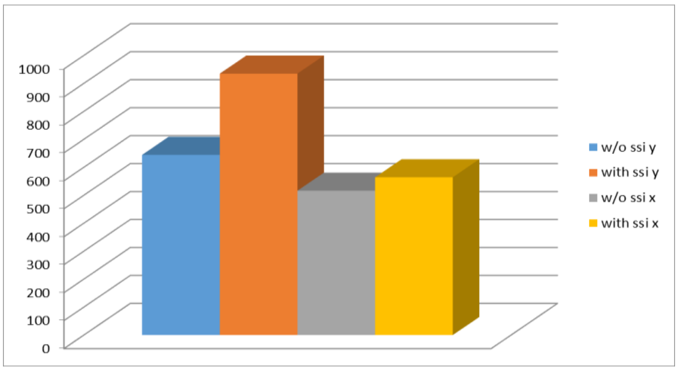

Fig. 6: Comparision of storey shear of the strcture with and without soil structure interaction for Basement-2 in X and Y Direction

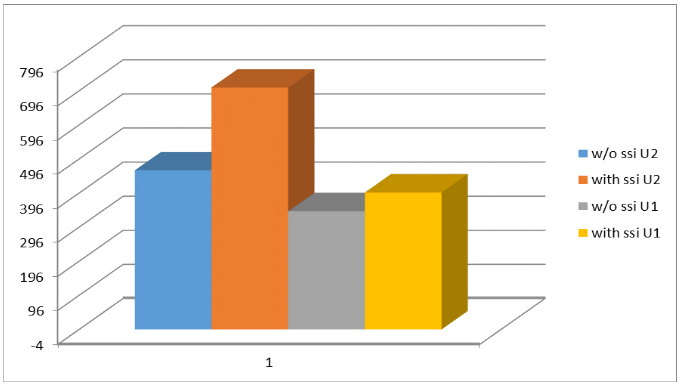

Fig. 7: Comparision of storey shear of the strcture with and without soil structure interaction for Basement-3 in X and Y Direction

VII. CONCLUSION

From the above study, the parameters considered were compared and the following conclusion were drawn:

1. From figure 1; the structure undergoes 53.52 % more displacement when soil structure interaction is taken into consideration comparative to without soil structure interaction in x direction.
2. From figure 2; the structure undergoes 52.95 % more displacement when soil structure interaction is taken into consideration comparative to without soil structure interaction in y direction.
3. From figure 3; 49.14 % more story shear was observed when soil structure interaction was taken into consideration comparative to without soil structure interaction in x direction.
4. From figure 4; 71.32 % more story shear was observed when soil structure interaction was taken into consideration comparative to without soil structure interaction in y direction.
5. From figure 5, 8.65 % more story shear was observed in x direction than in y direction for basement 1.
6. From figure 6, 21.6 % more story shear was observed in x direction than in y direction for basement 2.
7. From figure 7, 0.835 % more story shear was observed in x direction than in y direction for basement 3.
8. Displacement below ground level was negligible due to presence of foundation at each of these levels.
9. As per above conclusion it is advisable to check model with the SSI for max deflection and min base shear.

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