SEISMIC PERFORMANCE OF BUILDING FRAMES OF VARIOUS PLAN GEOMETRY WITH DIFFERENT INCIDENT ANGLE OF EARTHQUAKE FORCES CONSIDERING SOIL STRUCTURE INTERACTION

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Abstract: In recent decades, Soil Structure Interaction (SSI) has been given much attention in both research and practice. The two reasons are its important effect on the response of buildings in earthquakes and second its complexity. The need of seismic analysis is to determine the behavior of structure during earthquake. Earthquake forces can act in any direction on the structure and also seismic performance depends on plan geometry of structure. Thus there is a need of identifying the incident angle and the shape of the structure which produces worst effect. In the present study G+15 building of different plan geometry 'L' shape, 'Plus' shape, 'T' shape and 'Square' shape are considered for the analysis. The incident angles (IA) considered are '0^{0}', '30^{0}', '45^{0}' and '60^{0}'. The study is aimed to evaluate the SSI effect. Therefore the actual field conditions are considered which consists structure and a supporting soil media. The analysis is carried out considering structure resting on a soil mass consisting two layers. This SSI model is developed using ETABS application software. The seismic analysis is carried out using equivalent static method in accordance with IS 1893:2002. The parameters considered for the analysis is Beam Bending Moment, Roof Displacement and Storey Drift. Based on the result obtained most effective shape of the building and the worst incident angle are identified.

***IndexTerms* - Soil Structure Interaction, Seismic Response, Equivalent Static Force Method, Incident Angle, Seismic Zone.**

I.INTRODUCTION

All over the world, there is much need of construction of high-rise buildings due to increase in population and urbanization. These multi-storey structures are unsafe when they are subjected to the earthquakes. Earthquake forces are unpredictable and last only for the small duration but cause severe damage to the structures and harm lives of people. Yearly near 1.5 crore people lose their lives due to the earthquake. The weakness of structures is due to the presence of irregularities in stiffness, strength and mass. Excess mass leads in reduction of ductility of vertical load resisting elements and increase inertia forces and thus increase the tendency towards collapse. Thus, there is the necessity of analysing these structures for earthquake loading so that they sustain moderate to strong earthquake forces.

It is observed that symmetry of the building both in elevation and plan plays important role in the seismic performance. In the event of real earthquake the forces hit the structure in various directions and depending upon the stiffness of the structure in that direction the behavior depends. However the realistic simulation of earthquake is complex. Therefore there is a scope to study unsymmetrical structures subjected to earthquake forces of different incident angles. To evaluate their performances in view of overall stability.

II.OBJECTIVE

The objective of the present study is to investigate the Seismic Performance of various unsymmetrical building frames using Equivalent Static Force Method. The results are obtained by analytical study using structural analysis software ETABS. Following are the objectives of proposed study.

1) To study the effectiveness of building frames with various plan geometry.
2) To study the performance of building for different incident angle of earthquake forces.
3) To study the performance of building considering soil structure interaction effect.

III.PROTOTYPE BUILDING FRAME CONSIDERED FOR THE ANALYSIS

In the present work, four building frames are considered which are analyzed and designed as per codal provision. The plan geometry of structures considered are 'L' shape, 'Plus' shape, 'T' Shape and 'Square' shape. Dimensional characteristics are illustrated in Table 1.

Table 1 Geometric and Material Properties of Building Frames

Sr. No.	Detail	Description
1	Structure	OMRF
2	No. of stories	G+15
3	Storey Height	3 m

4	Grade of Concrete	M 20
5	Grade of Steel	Fe500
6	Bay width	3 m.
7	Size of Column	0.75m x 0.75m (Upto 5storey)
		0.65m x 0.65m (From6-10storey)
		0.50m x 0.50m (From 11-15storey)
8	Size of Beam	0.4m x 0.3m
9	Live load	3kN/m^2
10	Importance Factor(I)	1
11	Response Reduction Factor	5

IV. TYPICAL DETAIL OF G+15 BUILDING

The various plan geometry considered are shown in Fig no.1 to Fig no.4.

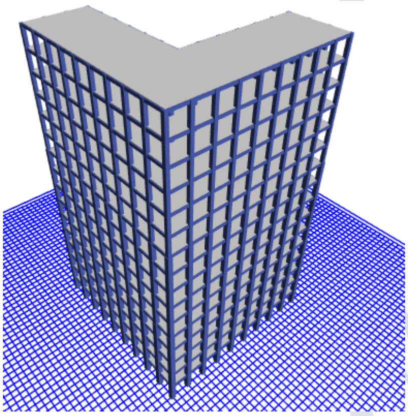

Fig 1(a). 3-D View

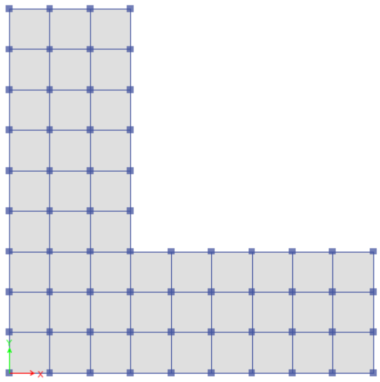

Fig 1(b). Plan View (IA-0^0)

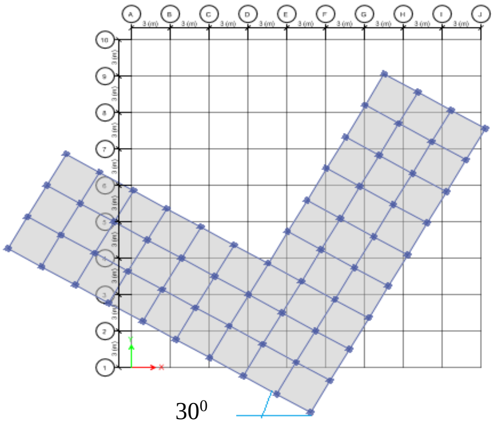

Fig 1(c). Plan View (IA-30°)

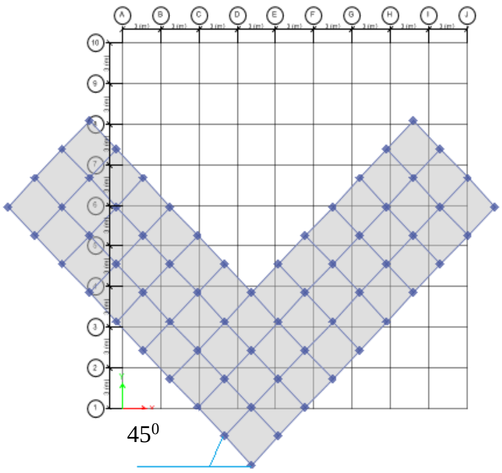

Fig 1(d). Plan view (IA-45^0)

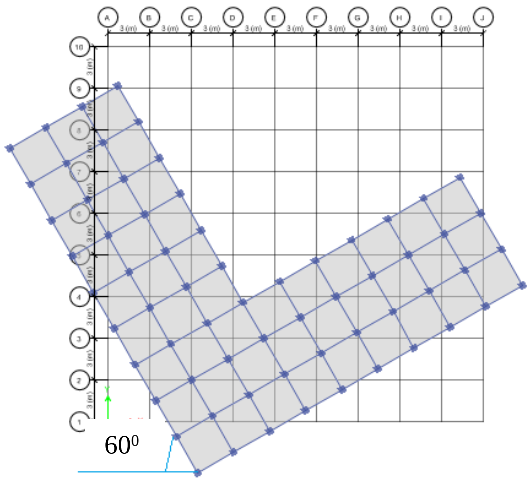

Fig.1(e). Plan view (IA-60^0)

Fig 1. 'L' Shape Building

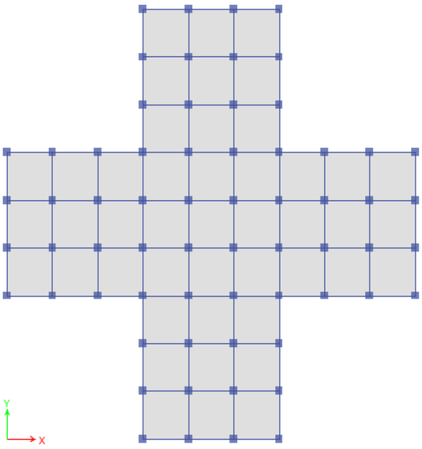

Fig 2(a). Plan View

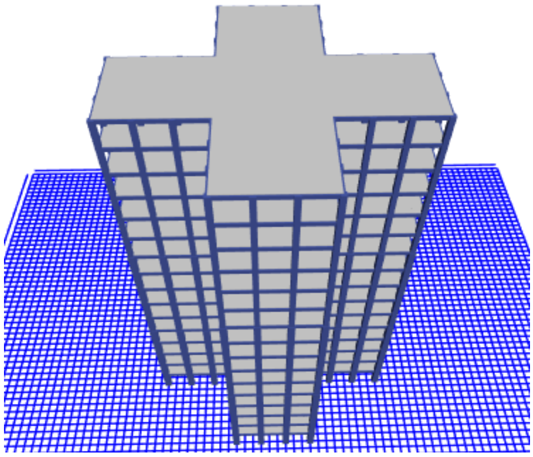

Fig 2(b). 3-D View

Fig 2. 'Plus' Shape Building

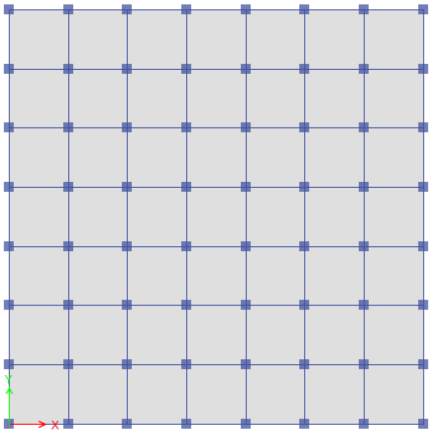

Fig 3(a). Plan View

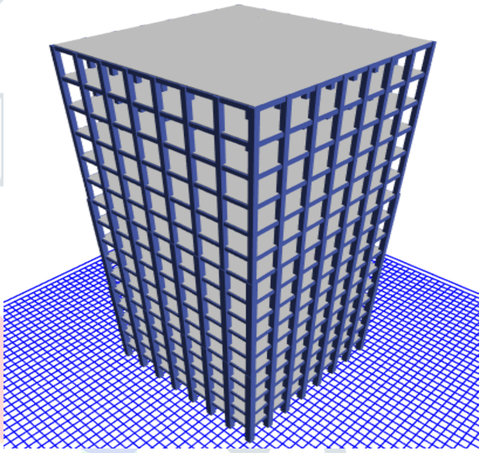

Fig 3(b). 3-D View

Fig 3. 'Square' Shape Building

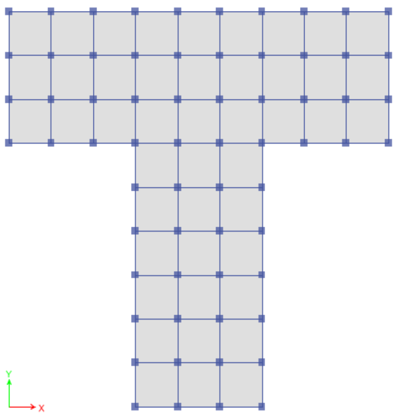

Fig 4(a). Plan View

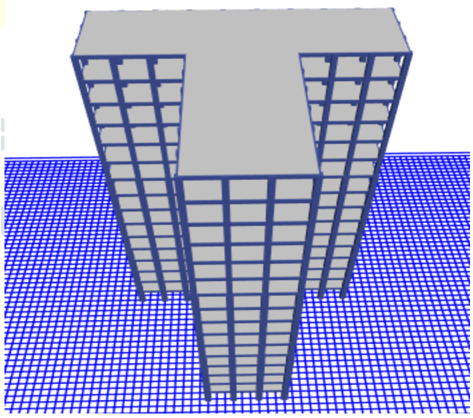

Fig 4(b). 3-D View

Fig 4. 'T' Shape Building

V. SOIL USED FOR STUDY

The study is also aimed to evaluate the SSI effect. Therefore the actual field conditions are considered which consists structure and a supporting soil media. In the present study, the soil layers are used as shown in Fig.5. In 1st layer of (5m) thickness, medium soil is considered and the 2nd layer (Infinite) hard soil is considered. The dimensions of footing considered for analysis is 1500x1500 mm and the thickness is 750mm. The shear wave velocity and shear modulus of the soil for various layers is considered as per Borcherdt 1994.Various index properties of soil considered for analysis is given in the Table 2.

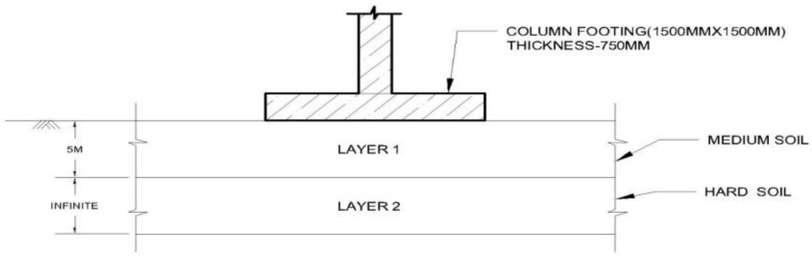

Fig 5. Soil Layers

Table 2 Properties of Soil in different layers

Soil Layer Name	Unit Weight (kN/m^3)	Modulus of Elasticity (N/mm^2)	Shear Modulus (kN/m^2)	Poisson's Ratio	Cohesion (kN/m^2)	Friction Angle (degree)	Shear Wave Velocity (mm/sec)
Layer 1	16	60	19250	0.3	10	28	250000
Layer 2	18	140	23000	0.3	15	30	300000

VI. METHOD OF ANALYSIS:-EQUIVALENT STATIC METHOD

The method of finding design lateral forces is also known as static method or the equivalent static method or the seismic coefficient method. Mass in a building is subjected to an equivalent lateral force. Earthquake (Dynamic) force are idealised as equivalent static force. Design base shear is determined by following expression:

$$V_b = Ah*W$$

where, V_b= Total design lateral force at the base of a structure,
W= Seismic weight of a building
Ah= Design horizontal seismic coefficient for a structure

$$Ah = \frac{(ZISa)}{(2Rg)}$$

where, Z= Zone factor given in table 2,

Table 3 : Seismic Zone Factor

Seismic Zone	II	III	IV	V
SeismicIntensity (Z)	Low 0.10	Moderate 0.16	Severe 0.24	Very Severe 0.36

I= Importance factor (In accordance with IS 1893)
R= Response reduction factor (In accordance with IS 1893)
Sa/g= Average Response Acceleration Coefficient (In accordance with IS 1893)

VII.RESULTS

The analysis of all building frames with various plan configuration is carried out using equivalent static method in accordance with IS 1893. The results are also obtained for various incident angles i.e. 0^0, 30^0, 45^0, and 60^0.The responses studied are Beam Bending Moment, Roof Displacement and Storey Drift.

VII. I RESPONSE OF G+15 BUILDING FRAME

The variation of Beam Bending Moment, Roof Displacement and Storey Drift for various shape building for various incident angles is presented in fig no.6 to fig no.8.

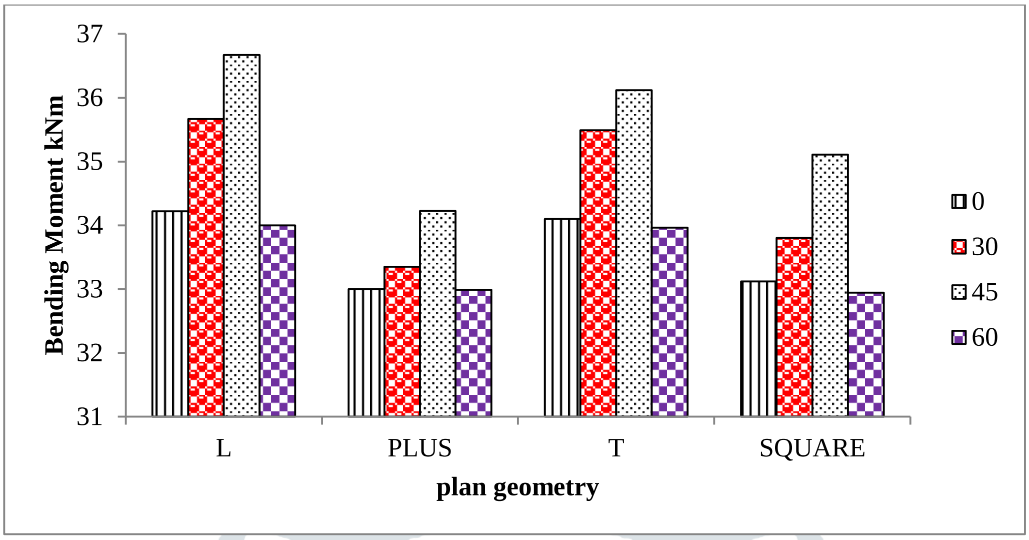

Fig. 6 Variation of Beam Bending Moment

- The Bending Moment is observed to be higher in case of unsymmetrical building frame i.e. ‘L’ shape and ‘T’ shape. Whereas in case of ‘Plus’ shape and ‘Square’ shape it is observed to be lesser.
- With increase in the incident angle from 0^0 to 30^0, the Bending Moment increase by 30to 35% and from 30^0 to 45^0, it increases by 20 to 23%. Further increase in the incident angle from 45^0 to 60^0 decreases the Bending Moment by 40 to 43%. Same trend is observed for ‘T’ shape.
- Variation in the incident angle is observed to be ineffective in case of symmetric building frames such as ‘Plus’ shape and ‘Square’ shape.

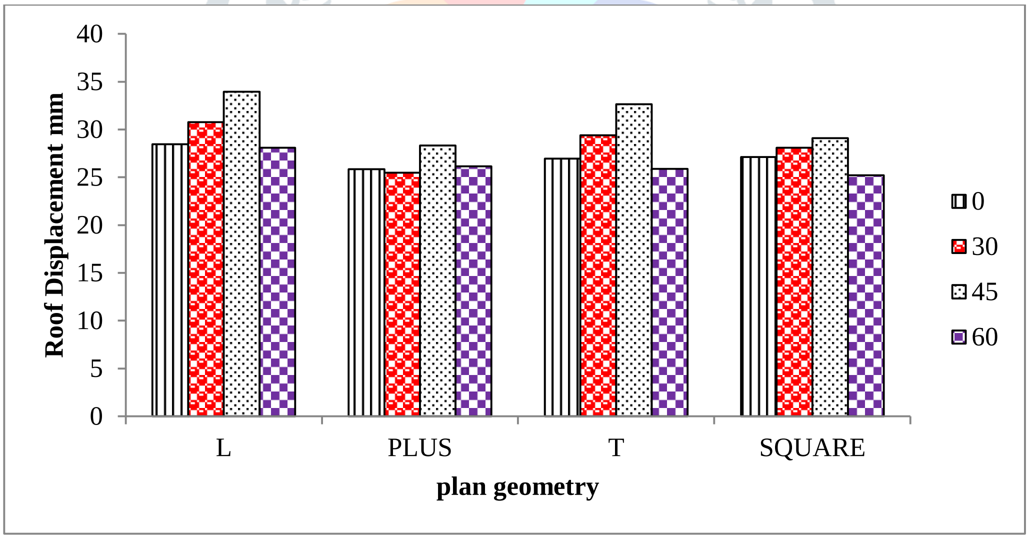

Fig. 7 Variation of Roof Displacement

- The Roof Displacement is observed to be higher in case of unsymmetrical building frame i.e. ‘L’ shape and ‘T’ shape. Whereas in case of ‘Plus’ shape and ‘Square’ shape it is observed to be lesser.
- With increase in the incident angle from 0^0 to 30^0, the Roof Displacement increase by, 12to 15% and from 30^0 to 45^0, it increases by 25 to 30%. Further increase in the incident angle from 45^0 to 60^0 decreases the Roof Displacement by 25 to 30%. Same trend is observed for ‘T’ shape.
- Variation in the incident angle is observed to be ineffective in case of symmetric building frames such as ‘Plus’ shape and ‘Square’ shape.

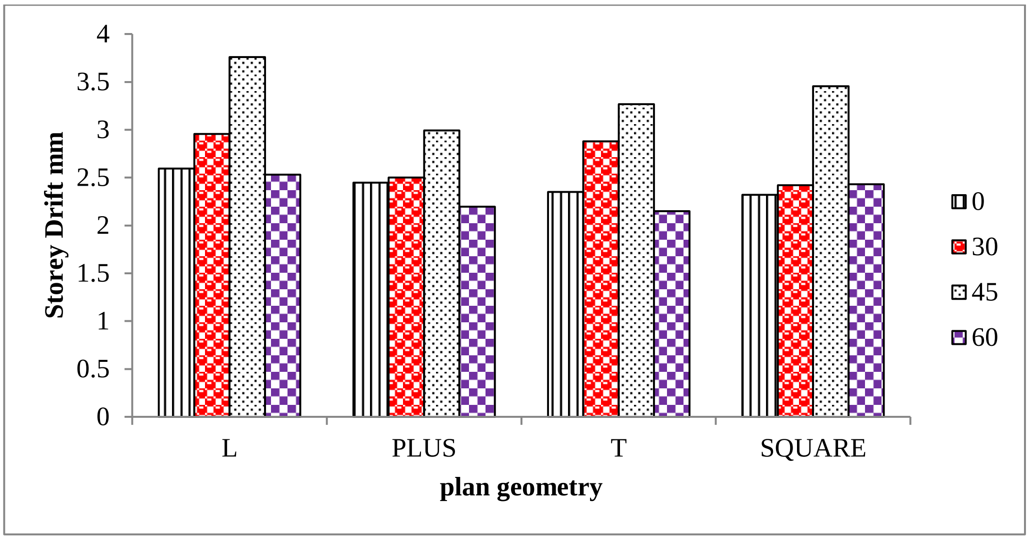

Fig. 8 Variation of Storey Drift

- The Storey Drift is observed to be higher in case of unsymmetrical building frame i.e. 'L' shape and 'T' shape. Whereas in case of 'Plus' shape and 'Square' shape it is observed to be lesser.
- With increase in the incident angle from 0^0 to 30^0, the Storey Drift increase by, 13 to 17% and from 30^0 to 45^0, it increases by almost 19 to 23%. Further increase in the incident angle from 45^0 to 60^0 decreases the Storey Drift by 25 to 30%. Same trend is observed for 'T' shape.
- Variation in the incident angle is observed to be ineffective in case of symmetric building frames such as 'Plus' shape and 'Square' shape.

VIII. EFFECT OF SOIL STRUCTURE INTERACTION

The prime objective is to investigate the effect of plan geometry of building and incident angle of earthquake forces the building is considered to be situated in zone III. The consolidated graphs for various shape of building and incident angle is presented below.

VIII.I Variation of Bending Moment for all shape with various incident angle

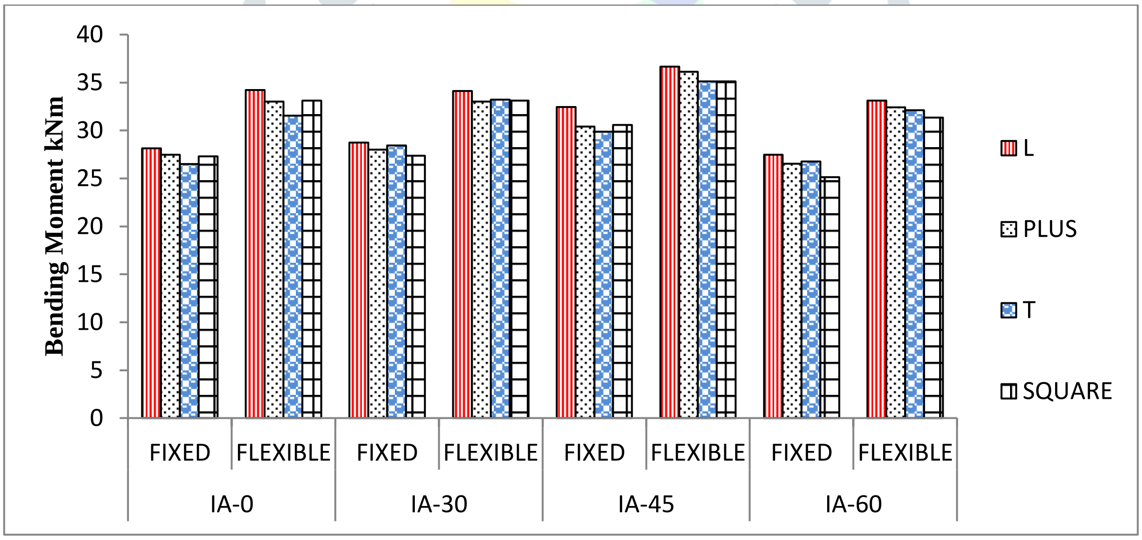

Fig. 9 Variation of Bending Moment for all shape with various incident angle

- From Fig. 9 it is observed that Bending Moment in flexible base condition is observed to be higher than fixed base condition. Same pattern is observed for all shape of building with various incident angles.
- Fig. 9 shows that Bending Moment of 'L' shape building increases by 10 to 12% than 'Plus', 'T', and 'Square' shape.
- From Fig. 9 it is observed that with increase in the incident angle, the Bending Moment goes on increasing from 0^0 to 30^0 by 25 to 27% and from 30^0 to 45^0, it increases by 34 to 37%. Further increase in the incident angle from 45^0 to 60^0 decreases the Bending Moment by 40 to 45%. Same pattern is observed for all shape of building.
- The study reveals that the bending moment in the building is observed to be higher for 45^0 incident angle i.e. diagonal direction. Therefore there is a need to analyse the building for 45^0incident angle instead of 0^0 incident angle which is the conventional practice.

VIII.II Variation of Roof Displacement for all shape with various incident angle

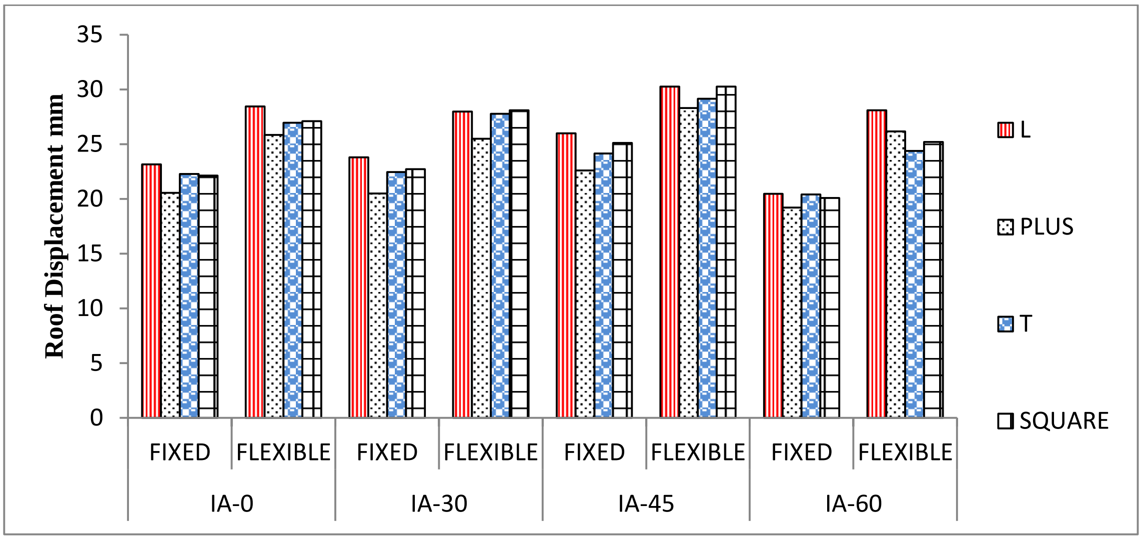

Fig. 10 Variation of Roof Displacement for all shape with various incident angle

- From Fig. 10 it is observed that Roof Displacement in flexible base condition is observed to be higher than fixed base condition. Same pattern is observed for all shape of building with various incident angles.
- Fig.10 it is observed that Roof Displacement of 'L' shape building increases by 13-15% than 'Plus', 'T', and 'Square' shape.
- Fig. 10 it is observed that with increase in the incident angle, the Roof Displacement goes on increasing from 0^0 to 30^0 by 11 to 15% and from 30^0 to 45^0, it increases by almost 25 to 30%. Further increase in the incident angle from 45^0 to 60^0 decreases the Roof Displacement by 35 to 40%. Same pattern is observed for all the shape of building.
- The study reveals that the roof displacement in the building is observed to be higher for 45^0 incident angle i.e. diagonal direction. Therefore there is a need to analyse the building for 45^0incident angle instead of 0^0 incident angle which is the conventional practice.

VIII.III Variation of Storey Drift for all shape with various incident angle

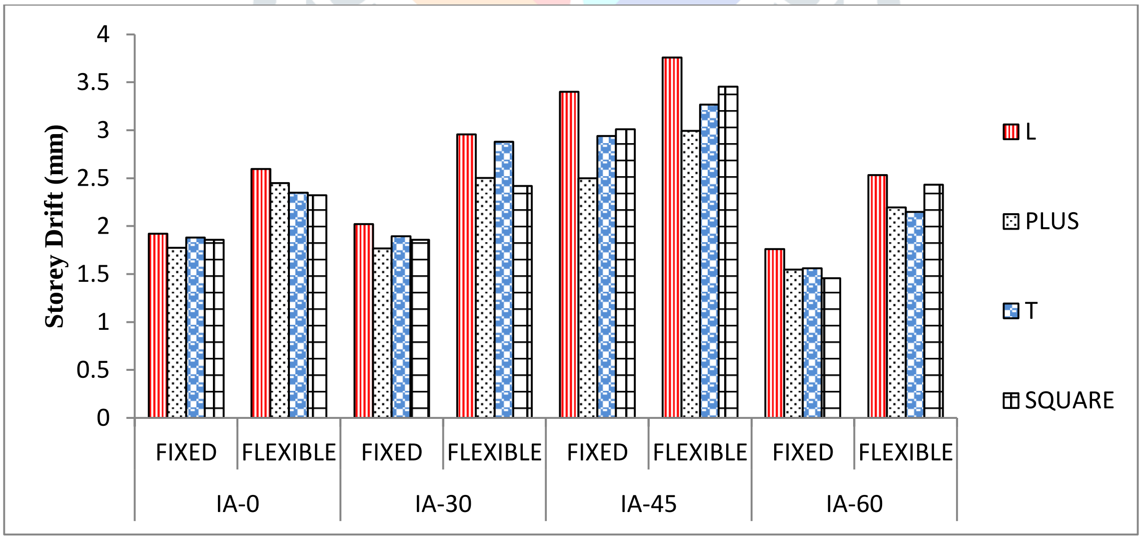

Fig. 11 Variation of Storey Drift for all shape with various incident angle

- From Fig. 11 it is observed that Storey Drift in flexible base condition is observed to be higher than fixed base condition. Same pattern is observed for all shape of building with various incident angles.
- Fig.11 it is observed that Storey Drift of 'L' shape building increases 11-13% than 'PLUS', 'T', and 'SQUARE' shape.
- Fig. 11 it is observed that with increase in the incident angle, the Storey Drift goes on increasing from 0^0 to 30^0 by11 to 15% and from 30^0 to 45^0, it increases by almost 33 to 38%. Further increase in the incident angle from 45^0 to 60^0 decreases the Storey Drift by 35 to 40%. Same pattern is observed for all the shape of building.
- The study reveals that the storey drift in the building is observed to be higher for 45^0 incident angle i.e. diagonal direction. Therefore there is a need to analyse the building for 45^0 incident angle instead of 0^0 incident angle which is the conventional practice.

IX.CONCLUSION

The study is carried out on four building frames having "L" Shape, "Plus" Shape, "T" Shape and "Square" Shape with different plan geometry cosidering soil structure interaction effect.The parameters considered for the analysis is Beam Bending Moment, Roof Displacement and Storey Drift. Based on the result obtained most effective shape of the building and Beam Bending

Moment, Roof Displacement and Storey Drift on different models are determined by using Equivalent Static Method considering soil structure interaction effect. Following are the conclusion:-

1. Conventionally analysis of building frame is carried out considering fixed base condition which is not realistic condition. Therefore, Soil Structure Interaction study needs to be carried out to understand the realistic behavior.
2. The study reveals that the structure behaves differently for different plan geometry and for different incident angle of earthquake forces.
3. The Beam Bending Moment, Roof Displacement and Storey Drift are observed to be higher in case of 'L' shape building frame indicating that unsymmetrical structure are less effective in resisting the earthquake forces. Also it is observed that symmetric building (Plus shape, Square shape) derives better resistance to earthquake forces. Hence symmetric structures are recommended which derives more strength and stability.
4. In the present study beam bending moment, roof displacement, storey drift increases by almost 25 to 30% due to soil structure interaction effect. This variation is likely to change for different soil condition below the footing. Therefore, it is recommended to carry out soil structure interaction study considering the prevailing ground condition to estimate different structural parameters more realistically.

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