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Effects of Soil Structure Interaction on Behaviour of Structural Frames

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Abstract- ***The present paper examines the effect of soil-structure interaction on a single bay, two-bay with symmetry and asymmetry multistory frames. The finite element analysis was carried out independently for the frame on the premise of fixed column bases in which members of the superstructure are discretized using the 2-node uniaxial beam elements. The model was analyzed separately for the soil base and foundation, by using the beam elements and plane elements to model the soil and foundation respectively. The foundation was used in the interaction analysis of the frame to quantify the effect of soil-structure interaction on the response of the superstructure. The response of superstructure was measured by the displacement at top of the frame and moments in the columns-beam joints. The effect of soil-structure interaction was found to be significant for two bay asymmetric structures. In this paper, the effect of interaction on the predicted settlements, forces and moments of two dimensional multi-bay frame structure was investigated. Interaction between soil and structure had been found to significantly affect the estimated structural forces and footing loads of different types frame structures.***

Keyword: FEM, framed structure, soil structure interaction

1. Introduction

Most of the civil engineering structures involve some type of structural element with direct contact with ground. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil. In most of the Civil Engineering analysis, structure is assumed to be fixed at the base. Thus, the flexibility of foundation and the compressibility of the supporting soil medium are neglected. Consequently, the effect of uneven foundation settlements on redistribution of forces and moments in the superstructure is also neglected [1, 2].

Behavior of Soil Media

Dutta and Roy [1] express that the mechanical behavior of soil media is so complex that a mathematical simulation of the same is always a mammoth task to the engineers. Soil is basically composed of particulate materials. The behaviour of soil, mainly the stressïstrainïtime property, influences the soilïstructure interaction phenomenon. Physically, when a load is applied on the soil mass (not completely saturated), the soil particles tend to attain such a structural configuration that their potential energy will be a minimum and hence stability is achieved. Up to a certain stress level, strain imparted to the soil mass in this process is elastic and then it may enter the plastic range depending on the magnitude of the applied load. This deformation is followed by a mostly viscoplastic deformation (dominant for fine grained soil) due to viscous intergranular behavior that implies strain with passage of time[2]. This deformation occurs by the expulsion of the pore fluid and simultaneous transfer of excess pore pressure to the solid soil grains. Hence, the rate of such strain approaches a small value after a long time.

The strain caused by the expulsion of water from the soil mass is identically equal to the strain of the soil skeleton. This is because soil skeleton is an aggregate of mineral particles, which together with bound water constitutes the soil mass. However, after primary consolidation of the soil structure, continues to adjust to the load for some additional time and secondary compression occurs approximately following a logarithmic function of time. But for such a fully saturated soil sample, strain will always be the function of time, since the external load will first be shared by the pore fluid under such condition and then viscoelastic settlement will occur. It has been observed that the hardening of soil due to consolidation and the thixotropic processes must be taken into analysis as it causes manifold increase in the cohesion and angle of internal friction of soil. Thus well-selected rheological models in conjunction with the model to represent the phenomenomenologacal behaviour may offer some useful means to study the interactive system [3, 4].

2. Methodology

The structural designers usually obtain the foundation loads from structure analysis without making allowance for soil settlements, and the foundation settlements are estimated assuming a perfectly flexible structure. However, the stiffness of the structure can restrain the displacements of the foundations, and even tiny differential settlements of foundations will also alter forces of the structural members. Interaction between soil and structure affect the estimated settlements, forces and moments of different types of loading condition [5, 6].

The present work is aim to understand the influence of soil structure interaction of symmetrical and unsymmetrical structures. The building framed structures were analyzed using ANSYS. The structures considered for the analysis were symmetrical and unsymmetrical multi bay multi storey frames with different loading conditions.

3. Problem statement

The study was focused on symmetrical and unsymmetrical frames subjected to uniformly distributed, lateral and eccentric loading. These frames were single bay and multibay as well single and multistory. All these different frames are as shown in Fig. 1. The frames size and material

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properties used were given in Table 1. The frames used on different cases and modeled on ANSYS 11 were as shown in Fig.2.

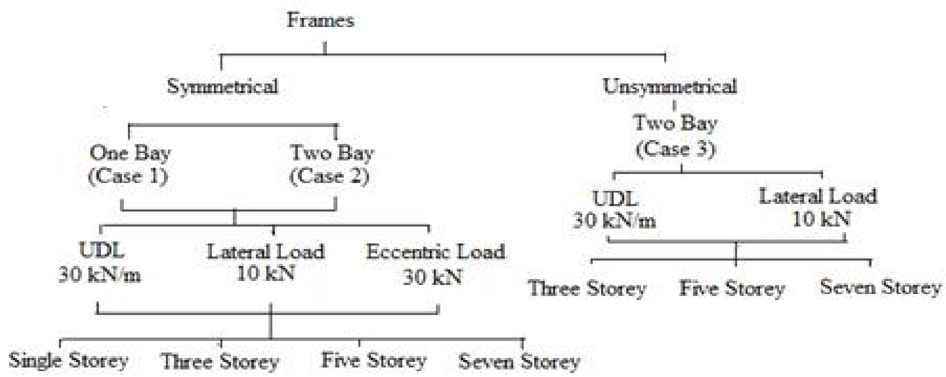
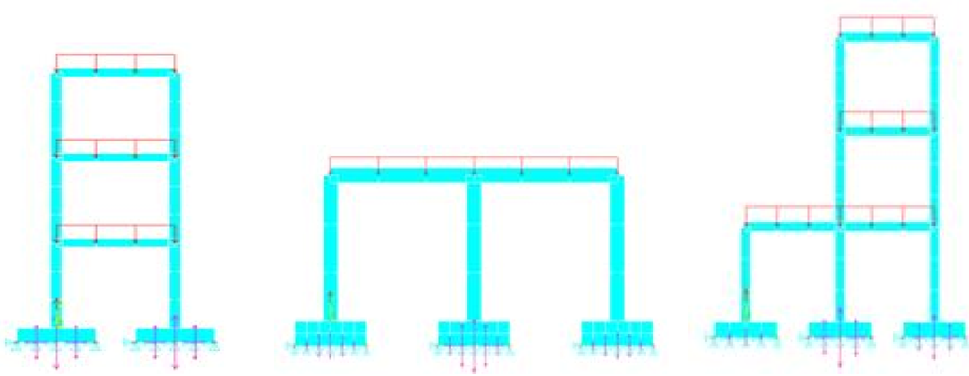


Figure 1: Different Frames for Analysis

Table 1: Properties of Parameters for Analysis of 2-D Frames

S. No	Structure	Component	Details
1	Frame	Storey height	3m
		Bay width	3m
		Beam size	0.23 m × 0.3 m
		Column size	0.23 m × 0.3 m
		Concrete Grade	M 20
2	Single storey	Footing	1.5m ×1.5m
3	Three storey		2m × 2m
4	Five storey		2.5m × 2.5m
5	Seven storey		
6	Elastic modulus of soil		2×10^{7} N/m^2
7	Poissonǿs ratio of soil		0.3
8	Elastic modulus of concrete		2.4×10^{10} N/m^2
9	Poissonǿs ratio of concrete		1.5



(a) Single Bay Frame (b) Two Bay Symmetrical Frame (c) Unsymmetrical Frame
Figure 2: ANSYS Model of Framed Structures

4. Results and Discussions

Soil structure interaction (SSI) is a collection of phenomena in the response of structure caused by the flexibility of the foundation soils, as well as the response of soils caused by the presence of structures. In this work the analysis of different types of models were carried out by using ANSYS. The result of analysis and influence of soil structure interaction of different frames and loads was discussed with reference to different parameters. The results of different single bay symmetrical frames, two bay symmetrical and unsymmetrical frames were discussed.

Uniformly distributed load

Single bay structure with different stories was subjected to uniformly distributed load in the form of live load and dead load. The frames considered for the analysis are single, three, five and seven storey frames. The influence of soil structure interaction on these frames has been studied with reference to moment, X and Y displacement and X and Y forces. Fig. 3 shows the comparison of moment produce in one bay five storey frame considering with and & without SSI (WSSI). Node 1 to 26 and 47 to 59 shows nodes on the frame and other nodes are belongs to footing. The moments in the frame is rare as seen in Fig. 3. Results for the remaining cases considering with and without SSI are also in the same pattern. So, the variation of these parameters had been compared to maximum value occurred in WSSI with value from SSI analysis at same nodes. The results of various cases were compared and discussed.

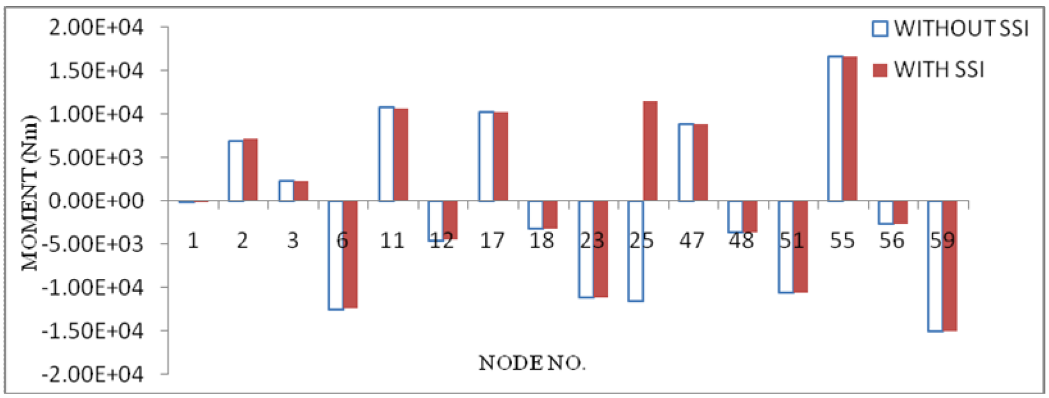


Figure 3: Comparative Moment Considering with & without SSI for Five Storeys

Fig. 4 shows that for single storey one bay frame subjected to UDL, the effect of SSI is negligible. For single and three storey symmetrical two bay frames subjected to UDL, the moment due to SSI is less than the WSSI while for five storey and seven storey frames with and without symmetry; SSI shows higher value of moments change than WSSI.

Fig. 5 shows that one bay frames subjected to UDL, SSI shows less value for X-displacement change than WSSI. For two bay frames subjected to UDL with and without symmetry, SSI shows higher value of X-displacement change than WSSI.

Fig. 6 indicate that one bay, two bay frames subjected to UDL with and without symmetry, SSI shows higher value for Y-displacement change than WSSI.

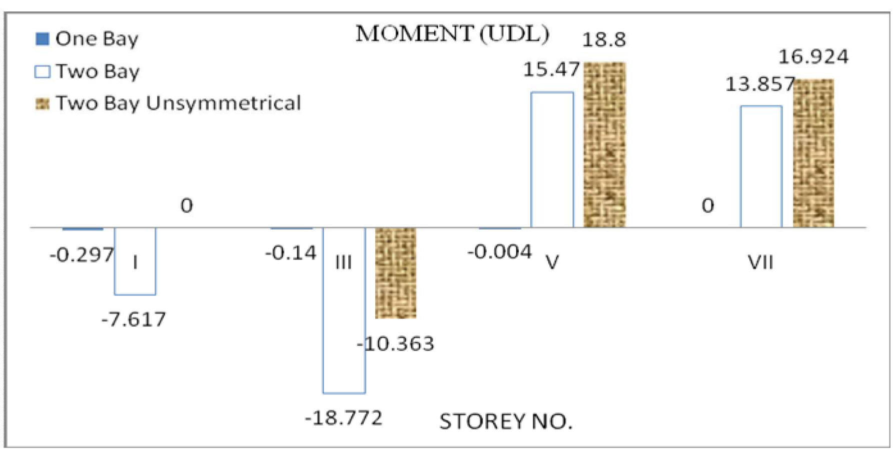


Figure 4: % Change of Maximum Moment for Various Cases Considering UDL

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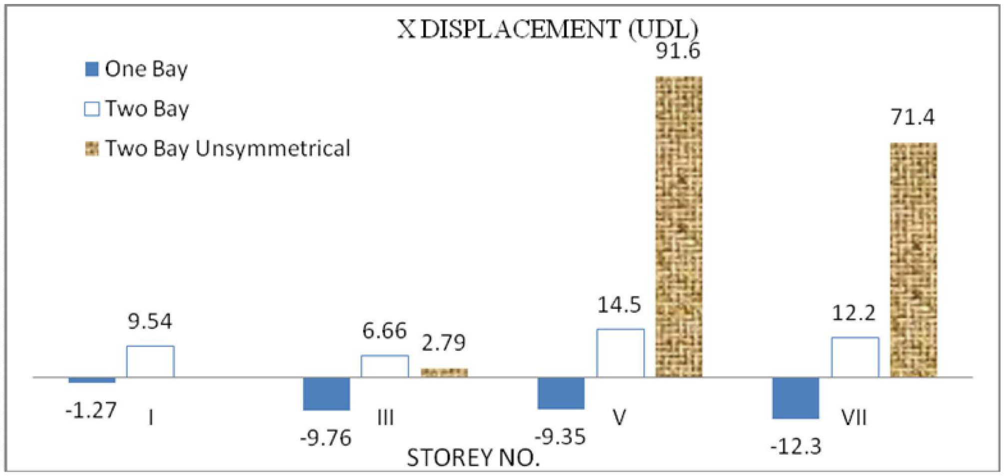

Figure 5: % Change of Maximum X-Displacement for Various Cases Considering UDL

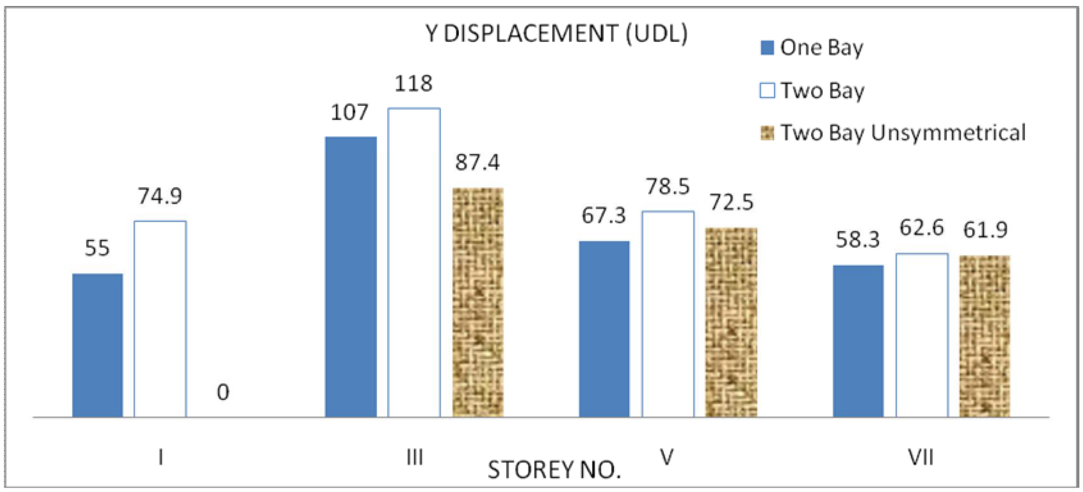

Figure 6: % Change of Maximum Y-Displacement for Various Cases Considering UDL

Lateral load

For one bay, two bay frames with and without symmetry subjected to lateral load, WSSI has higher value of moments than the SSI. In one bay for single storey and in two bay with and without symmetry foe three storey, % change in moment is critical as seen in Fig. 7.

For one bay, two bay frames subjected to lateral load with and without symmetry, SSI shows higher value for X-displacement change than WSSI as shown in Fig.8.

For one bay single storey frame subjected to lateral load, value of Y-displacement is higher due to WSSI than SSI while in three, five and seven storey frames SSI value is higher than that of WSSI. For two bay single, five and seven storey symmetrical frame, SSI shows higher value than that of WSSI while in three storey, WSSI has higher value of Y-displacement than SSI. For two bay three storey unsymmetrical frame, SSI has less value than that of WSSI while in five and seven storey, SSI has higher value of Y-displacement than that of WSSI as shown in Fig. 9.

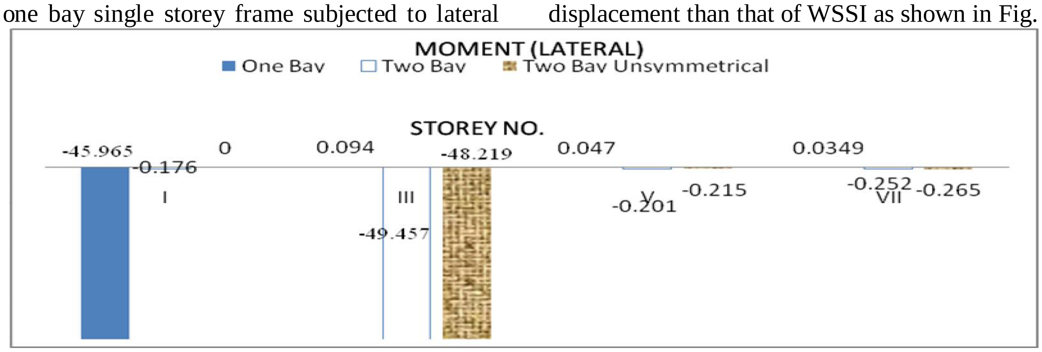

Figure 7: % Change of maximum Moment for Various Cases Considering Lateral Loading

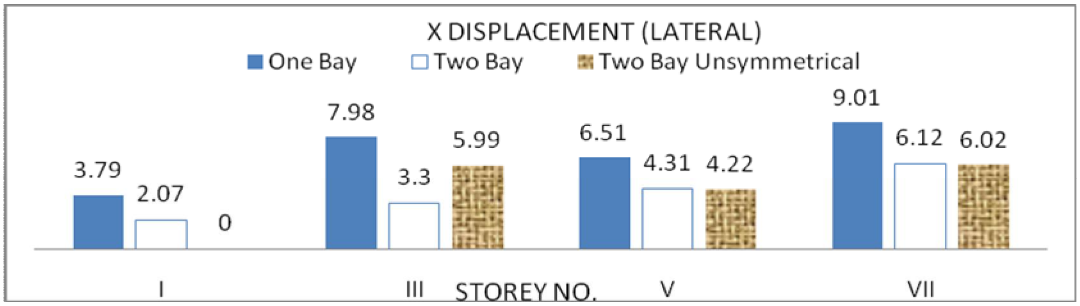

Figure 8: % Change of maximum X-Displacement for Various Cases Considering Lateral Loading

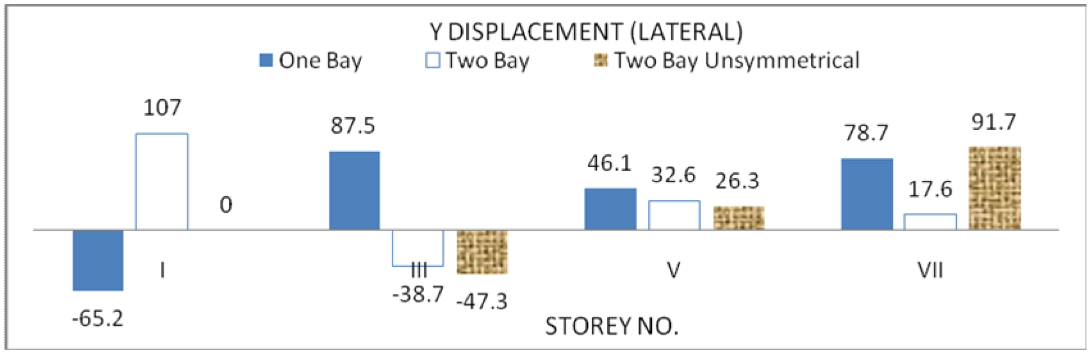

Figure 9: % Change of maximum Y-Displacement for Various Cases Considering Lateral Loading

Eccentric loading

For one bay single, three and five storey frames subjected to eccentric loading, value of moment due to WSSI is higher than that of SSI with critical variation at single storey frame while in seven storey frame the value of moment is higher due to SSI than WSSI with critical variation as shown in Fig.10.

For one bay frames subjected to eccentric load, the value of X-displacement is higher for WSSI than that of SSI. For two bay single storey symmetrical frame subjected to eccentric load, SSI has less value of X-displacement than WSSI while in case of three, five and seven storey frames SSI show higher value than that of WSSI as shown in Fig. 11.

For one bay single storey frame subjected to eccentric load, the value of Y-displacement is less due to SSI than that of WSSI while SSI shows higher value for three, five and seven storey frames. For two bay symmetrical frame subjected to eccentric load, SSI gives higher value of Y-displacement than that of WSSI as shown in Fig. 12.

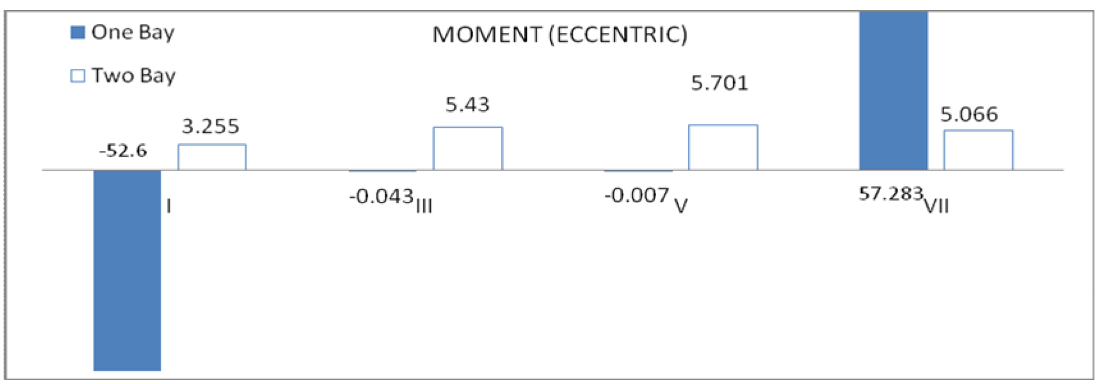

Figure 11: % Change of maximum Moment for Various Cases Considering Eccentric Loading

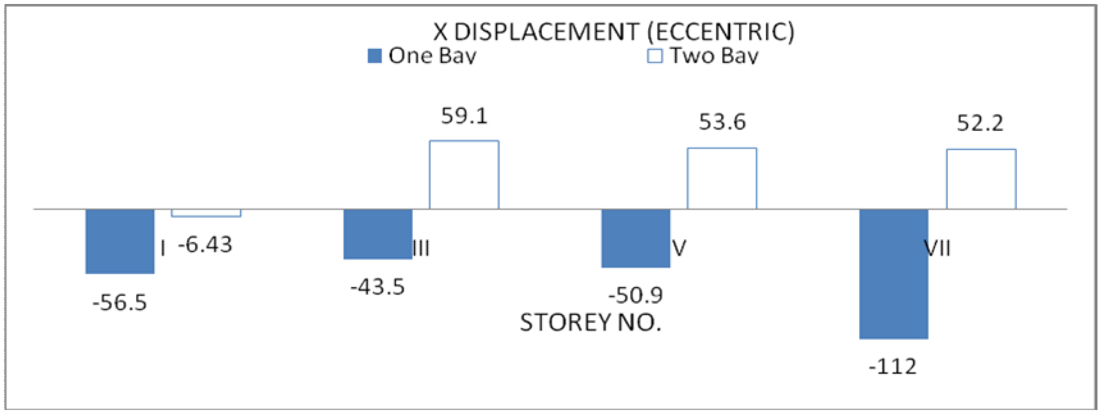

Figure 12: % Change of maximum X-Displacement for Various Cases Considering Eccentric Loading

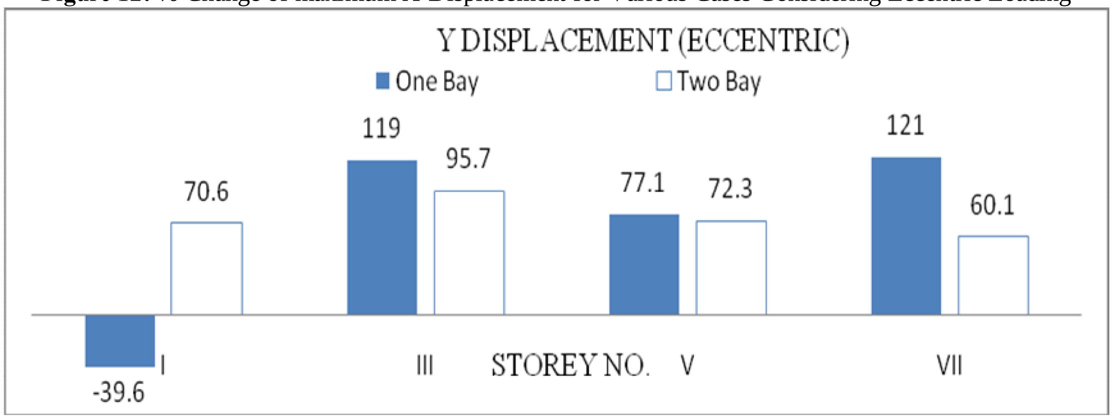

Figure 13: % Change of maximum Y-Displacement for Various Cases Considering Eccentric Loading

5. Conclusions

The interaction of frame with soil had been studied for different frames and various loads. The frame include single to seven storey frames and loads are UDL, lateral load and eccentric load. The analysis had been carried out using ANSYS 11. The conclusions drawn from the analysis with SSI indicates that:

i. Maximum value of moment was observed at joints in case of lateral and eccentric loading.

ii. The X-displacement observed maximum at nodes of column for eccentric load in one bay single storey frame and two bay unsymmetrical frames.

iii. In two bay single storey frames, maximum displacement in X-direction was observed at column nodes for frame subjected to UDL while at beam nodes for frame subjected to lateral and eccentric loading.

iv. The Y-displacement was observed more with SSI than WSSI for all cases studied.

v. In one bay frame X-force was observed maximum in nodes of beam and variation also found in footing nodes considering different types of loading pattern.

vi. For all two bay frames subjected to UDL, maximum value of X-force is observed in column nodes and its variation at nodes of footing.

vii. For all two bay frames subjected to lateral and eccentric loading, maximum X-force observed at nodes of beam and the variation is found at nodes of footing.

viii. Maximum value of Y-force is observed in column nodes and more variation was observed in footing nodes for all cases.

ix. In two bay unsymmetrical frames subjected to UDL, maximum value of moment was observed at joint nodes and it varies at bottom storey.

x. The X and Y displacement variation was more at the footing nodes with SSI effect. This leads to redistribution of structural forces and moments due to SSI analysis.

xi. X and Y forces also varies when analyze with SSI compared with WSS

xii.

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