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Effect of Soil Structure Interaction on the Storey Lateral Displacement of a Multi Storied Building

Surya Teja Ch[1], Sai Kiran T[2]

Post Graduate Student, Department of Civil Engineering, Andhra University, Visakhapatnam, India [1,2]

Abstract: Recent studies show that the effects of Soil Structure Interaction (SSI) may be detrimental to the seismic response of structure and neglecting SSI in analysis may lead to un-conservative design. Despite this, the conventional design procedure usually involves assumption of fixity at the base of foundation neglecting the flexibility of the foundation, the compressibility of the underneath soil and, consequently, the effect of foundation settlement. Hence the SSI analysis of a multi-storey building is the main focus of this work; the effects of SSI are analysed for the building considered by using springs to model the foundation. In the present work, the analysis of the building (G+9) with and without considering infill has been carried out by incorporating the effect of SSI by springs for three different types of soils such as silty sand, dense sand and dense gravel, and three different earthquake intensities according to IS 1893:2002 using ETABS. The stiffness of the springs are determined by the formulas given by Gazetas and Mylonkais. The storey lateral displacements are evaluated. From the study it has been observed that as the soil stiffness is increasing, the storey lateral displacements are decreasing. Silty sand having less stiffness has pronounced effect on the seismic response. Dense gravel having high stiffness has almost the same effect of fixed base model.

Keywords: Storey Lateral Displacement, Soil Structure Interaction, ETABS, Stiffness.

I. INTRODUCTION

The interaction among structures, their foundations and the soil medium below the foundations is called as Soil-structure interaction (SSI). Soil–structure interaction is an interdisciplinary field which lies at the intersection of soil and structural mechanics, soil and structural dynamics, earthquake engineering, material science, computational and numerical methods, and diverse other technical disciplines.The inclusion of the soil in the structural analysis provides results, stress and displacement values, which are closer to the actual behaviour of the structure than those provided by the analysis of a fixed-base structure.

The objective of this study is to consider the SSI effects in the building model. The main task is to incorporate the soil properties, particularly the soil stiffness and footing, into the structure model. Winkler based model is used for capturing the effect of SSI. The model is intended to be used for evaluating the Storey lateral displacement of building subjected to three earthquake intensities, located in three different type of soils.

II. LITERATURE REVIEW

Mahmoud Yahyai et al (2006) has dealt with therisk of uplift and other effects such as overturning and reduction of structure serviceability during earthquake in tall buildings having high ratio of height to width and located in geotechnically unsuitable places. The effect of Soil-Structure Interaction (SSI) on seismic behaviour of two adjacent 32 storey buildings such as time period, base shear and displacements has been evaluated and the interaction effects for variable distance between the two buildings considering three types of soil such as soft clay, sandy gravel and compacted sandy gravel by using ETABS and ANSYS for analysis. It has been concluded that the interaction effect increases the time period of both the buildings, base shear and lateral displacement.

George Gazetas (1990) had presented a complete set of algebraic formulas and dimensionless charts for readily computing the dynamic stiffnesses (K) and damping coefficients (C) of foundations harmonically oscillating on/in a homogeneous half-space. All possible modes of vibration, a realistic range of Poisson's ratios, and a practically sufficient range of oscillation frequencies had been considered. The foundations have a rigid basemat of any realistic solid geometric shape. He had explained using two numerical examples how to use the formulas and charts and elucidate the role of foundation shape for various modes of vibration.

III.METHODOLOGY

The Details of the building model (G + 9), with individual storey height of 3.2m is considered for the study. The total height of the building considered is 32m.

The Grade of Concrete and Steel used for analysis is M20 & Fe500 respectively. Masonry Infill is modelled using Clay burnt brick conforming to Class A, as confined unreinforced masonry with Density of 22 kN/m^3, Compressive Strength 5 MPa and Modulus of Elasticity 2750 MPa.

FEMA 365 recommends the equivalent diagonal strut method for considering unreinforced masonry infill in the analysis. The elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking is represented with an equivalent diagonal compression strut of width, a, given by Equation1. The equivalent strut shall have the same thickness and modulus of elasticity as the infill panel it represents.

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$$a = 0.175(\lambda_1 h_{col})^{-0.4}\ r_{inf} \quad \ldots\ldots\ldots (1)$$

$$\lambda_1 = \left[\frac{E_{me}\, t_{inf} \sin 2\theta}{4\, E_{fe}\, I_{col}\, h_{inf}}\right]^{1/4} \quad \ldots\ldots\ldots (2)$$

Where hcol = Column height between centerlines of beams; hinf = Height of infill panel; Efe = Expected modulus of elasticity of frame material; Eme = Expected modulus of elasticity of infill material; Icol = Moment of inertia of column; Linf = Length of infill panel; rinf = Diagonal length of infill panel; tinf = Thickness of infill panel and equivalent strut; θ= Angle whose tangent is the infill height-to length aspect ratio; λ_1= Coefficient used to determine equivalent width of infill strut.

Beam Sections of size B1: 300 x 450 mm, B2: 300 x 500 mm; Column Section of size C1: 300 x 600 mm along with 125mm thick Slab Section is used to model the structural elements.

The building is designed according to IS 456-2000. Loads are considered as per IS 875 (part 1, and part 2 for dead and live loads respectively) and the earthquake loads considered are as per IS 1893 (part 1): 2002. The loads due to Earthquake are determined by equivalent static method.

Isolated footings are designed based on the reactions of fixed model for service loads for the building considered for the analysis. The different types of footings considered are F1: 2.5 x 2.5 m, F2: 2.7 x 2.7 m, F3: 1.5 x 3.2 m, F4: 2.3 x 2.3 m, F5: 2.0 x 2.0 m shown in the Figure 2. To consider the effect of SSI on the response of the building the underneath soil is modelled by Winkler spring approach with equivalent static stiffness for three different types of soils having modulus of elasticity in the range from 13, 60 and 150 MPa for silty sand, dense sand and dense gravel. The properties of the soil considered are taken from "FOUNDATION ANALYSIS AND DESIGN by Joseph E. Bowles". The static stiffness of the springs are determined by using the Equations 3,4 and 5 are tabulated in the Table 1.

TABLE I: Static Stiffness of Footings

Soil Type	**Elasticity**	**Footing**	**k_x**	**k_y**	**k_z**
S-1 Silty Sand	13 MPa	F1	33088.2	33088.2	40535.7
		F2	35735.2	35735.2	43778.5
		F3	29291.5	31180.4	36626.7
		F4	30441.1	30441.1	37292.8
		F5	26470.5	26470.5	32428.5
S- 2 Den-se Sand	60 MPa	F1	152714.9	152714.9	187087.9
		F2	164932.1	164932.1	202055.0
		F3	135191.9	143909.9	169046.7
		F4	140497.7	140497.7	172120.9
		F5	122171.9	122172.0	149670.3
S-3 Den-se Gra-vel	150 MPa	F1	381787.3	381787.3	467719.8
		F2	412330.3	412330.3	505137.4
		F3	337979.9	359774.7	422616.8
		F4	351244.3	351244.3	430302.2
		F5	305429.9	305429.9	374175.8

Static Stiffness in vertical, horizontal and lateral direction is given by

$$K_z = \frac{2GL}{1-\vartheta}\,[0.73 + 1.54\,(\tfrac{B}{L})^{0.75}] \quad \ldots\ldots\ldots (3)$$

$$K_y = \frac{2GL}{2-\vartheta}\,[2 + 2.5\,(\tfrac{B}{L})^{0.85}] \quad \ldots\ldots\ldots (4)$$

$$K_x = K_y - \frac{0.2}{0.75-\vartheta}\,GL[1 - (\tfrac{B}{L})] \quad \ldots\ldots\ldots (5)$$

such that L≥ B and size of the foundation is 2L x 2B. Where G = $\frac{E}{2\,(1+\vartheta)}$ is Shear Modulus and $\vartheta$is poison's ratio of the soil.

IV. RESULTS AND DISCUSSIONS

The Building model (G +9) considered has been analysed using ETABS, incorporating foundation springs and infill walls as described above. The different models considered are represented by the following designation.MF:Model with fixed base; MS-1:Model with soil type S-1; MS-2:Model with soil type S-2; MS-3:Model with soil type S-3; MIF:Model with infill wall and fixed base; MIS-1:Model with infill wall and soil type S-1; MIS-2:Model with infill wall and soil type S-2; MIS-3:Model with infill wall and soil type S-3

The seismic response of the building is compared for different earthquake intensities and soil types. The results are presented separately for all the above models for three different earthquake intensities confining to the Zone – III, IV and V, according to IS 1893: 2002. The storey lateral displacements are evaluated.

A. Storey Lateral Displacements:

The storey displacement are investigated for the studied building of 10-storey using equivalent static earthquake load based on Indian Code provisions for seismic design. The storey displacement over the building height for different soil conditions ranging from silty sand, dense sand to dense gravel along with the response of the SSI model to that of fixed-base model are introduced in Figure 1 to Figure 6 and Table II to Table VII.

TABLE III: STOREY LATERAL DISPLACEMENTS FOR ZONE – III EARTHQUAKE

	Earthquake Loadings			
	Zone – III Displacements, mm			
Height,m	**MF**	**MS-1**	**MS-2**	**MS-3**
32.0	60.8	167.6	99.2	85.8
28.8	58.1	155.3	94.3	82.1
25.6	53.9	141.7	87.8	76.9
22.4	48.3	126.9	80.0	70.3
19.2	41.8	111.1	71.2	62.8
16.0	34.6	94.8	61.7	54.5
12.8	27.0	78.3	51.7	45.9
9.6	19.3	62.2	41.6	37.1
6.4	11.7	46.0	31.3	28.1
3.2	4.5	28.7	19.8	17.9
0.0	0.0	5.4	1.2	0.5

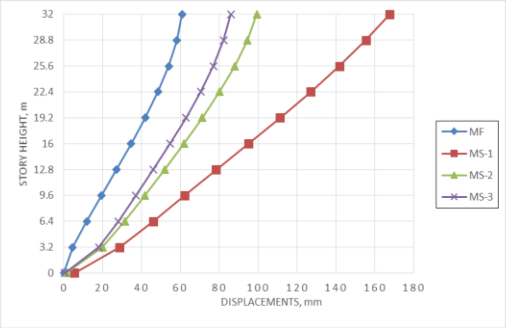

Fig. 1. Storey lateral displacements for zone – III earthquake

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TABLE IIIII: STOREY LATERAL DISPLACEMENTS FOR ZONE – IV EARTHQUAKE

	Earthquake Loadings			
	Zone – IV Displacements, mm			
Height,m	**MF**	**MS-1**	**MS-2**	**MS-3**
32.0	91.3	251.4	148.8	128.7
28.8	87.2	232.9	141.4	123.2
25.6	80.9	212.5	131.7	115.4
22.4	72.5	190.3	120.0	105.5
19.2	62.7	166.7	106.8	94.2
16.0	51.9	142.2	92.5	81.8
12.8	40.5	117.4	77.6	68.8
9.6	29.0	93.4	62.4	55.6
6.4	17.5	69.1	46.9	42.2
3.2	6.8	43.0	29.7	26.9
0.0	0.0	8.1	1.8	0.7

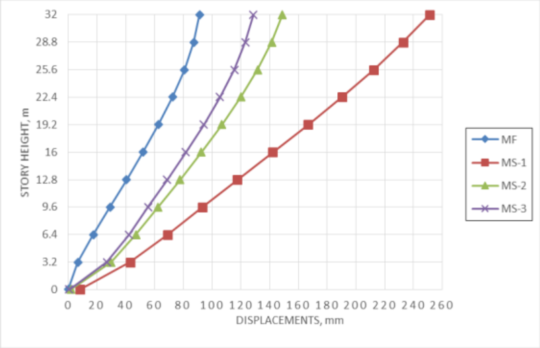

Fig. 2. Storey lateral displacements for zone – IV earthquake

TABLE IV: Storey Lateral Displacements For Zone – V Earthquake

	Earthquake Loadings			
	Zone – V Displacements, mm			
Height,m	**MF**	**MS-1**	**MS-2**	**MS-3**
32.0	60.8	167.6	99.2	85.8
28.8	58.1	155.3	94.3	82.1
25.6	53.9	141.7	87.8	76.9
22.4	48.3	126.9	80.0	70.3
19.2	41.8	111.1	71.2	62.8
16.0	34.6	94.8	61.7	54.5
12.8	27.0	78.3	51.7	45.9
9.6	19.3	62.2	41.6	37.1
6.4	11.7	46.0	31.3	28.1
3.2	4.5	28.7	19.8	17.9
0.0	0.0	5.4	1.2	0.5

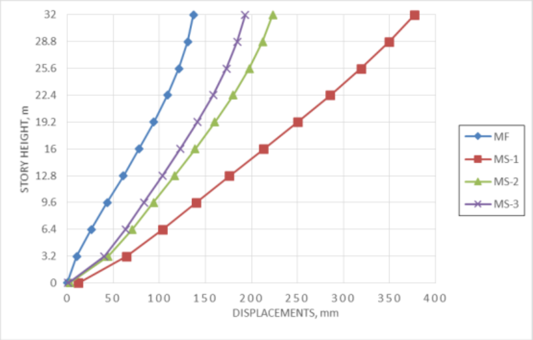

Fig. 3. Storey lateral displacements for zone – V earthquake

Figure 1 to Figure 3 show that the storey lateral displacements increases nonlinearly along the height of the building. The maximum displacement values in MF, MS-1, MS-2 and MS-3 are 60.8, 167.6, 99.2 and 85.8 mm for zone – III earthquake, 91.3, 251.4, 148.8, 128.7 mm for zone- IV earthquake and 136.9, 377, 223.2 and 193.1 mm for zone – V earthquake respectively.

Storey displacements for MS-1 are maximum compared to all other models. Storey displacements of MS-3 are nearer to that of MF model. As the soil stiffness decreases, the storey displacements are increasing. Storey displacement of MS-1 is 2.75 times the displacement of MF model for all the three earthquake zones. Storey displacement of MS-2 is 1.63 times the displacement of MF model for all the three earthquake zones. Storey displacement of MS-3 is 1.41 times the displacement of MF model for all the three earthquake zones.

TABLE V: Storey Lateral Displacements Considering Infill Wall For Zone – III Earthquake

	Earthquake Loadings			
	Zone – III Displacements, mm			
Height,m	**MIF**	**MIS-1**	**MIS-2**	**MIS-3**
32.0	14.6	40.6	23.7	18.1
28.8	13.9	37.5	22.5	17.2
25.6	12.8	34.2	20.9	16.1
22.4	11.5	30.6	19.0	14.7
19.2	9.9	26.8	16.9	13.1
16.0	8.2	22.8	14.6	11.4
12.8	6.4	18.8	12.3	9.6
9.6	4.6	14.8	9.8	7.7
6.4	2.8	10.9	7.4	5.8
3.2	1.1	6.8	4.7	3.7
0.0	0.0	1.3	0.3	0.1

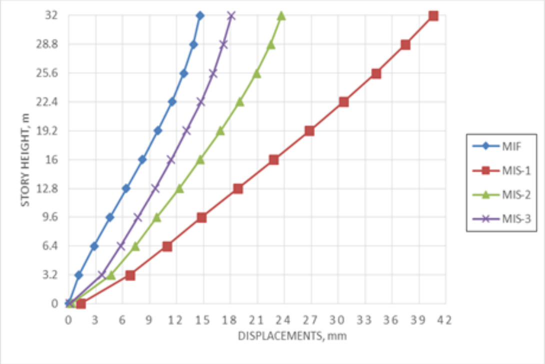

Fig. 4. Storey lateral displacements considering Infill wall for zone – III earthquake

TABLE VI: Storey Lateral Displacements Considering Infill Wall For Zone – IV Earthquake

	Earthquake Loadings			
	Zone – IV Displacements, mm			
Height,m	**MIF**	**MIS-1**	**MIS-2**	**MIS-3**
32.0	21.9	59.8	35.6	27.1
28.8	20.8	56.3	33.7	25.9
25.6	19.2	51.3	31.3	24.1
22.4	17.2	45.9	28.5	22.0
19.2	14.9	40.2	25.3	19.6
16.0	12.3	34.2	21.9	17.0
12.8	9.6	28.2	18.4	14.3
9.6	6.8	22.2	14.8	11.6
6.4	4.1	16.4	11.1	8.8
3.2	1.6	10.2	7.0	5.6
0.0	0.0	1.9	0.4	0.1

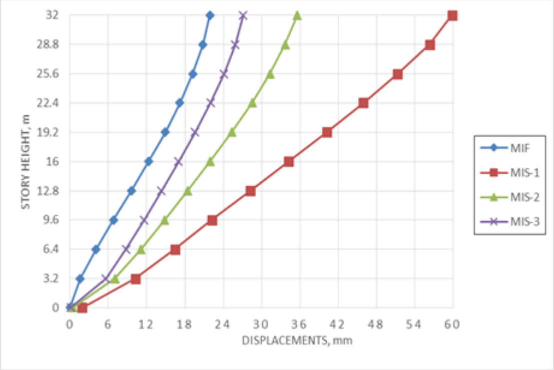

Fig. 5. Storey lateral displacements considering Infill wall for zone – IV earthquake

TABLE VII: Storey Lateral Displacements Considering Infill Wall For Zone – V Earthquake

	Earthquake Loadings			
	Zone – V Displacements, mm			
Height,m	**MIF**	**MIS-1**	**MIS-2**	**MIS-3**
32.0	32.8	91.3	53.4	40.7
28.8	31.2	84.5	50.6	38.8
25.6	28.8	77.0	47.0	36.2
22.4	25.8	68.8	42.8	33.1
19.2	22.3	60.3	38.0	29.5
16.0	18.4	51.4	32.9	25.6
12.8	14.4	42.3	27.6	21.5
9.6	10.3	33.3	22.2	17.3
6.4	6.2	24.6	16.7	13.2
3.2	2.4	15.3	10.5	8.4
0.0	0.0	2.9	0.6	0.2

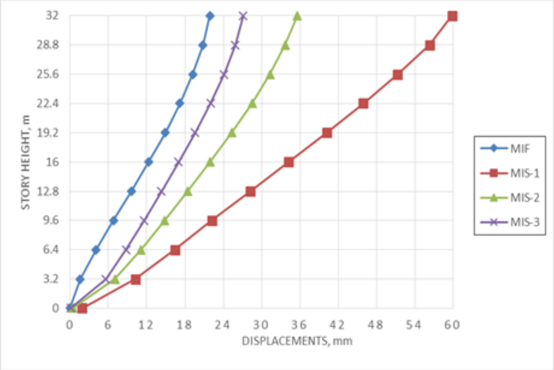

Fig. 6. Storey lateral displacements considering Infill wall for zone – V earthquake

Figure 4 to Figure 6 show that the storey lateral displacements increases nonlinearly along the height of the building. The maximum displacement values in MIF, MIS-1, MIS-2 and MIS-3 are 14.6, 40.6, 23.7 and 18.1 mm for zone – III earthquake, 21.9, 59.8, 35.6 and 27.1mm for zone- IV earthquake and 32.8, 91.3, 53.4 and 40.7 mm for zone – V earthquake respectively along Y-direction.

Storey displacements for MIS-1 are maximum compared to all other models. Storey displacements of MIS-3 are nearer to that of MIF model. As the soil stiffness decreases, the storey displacements are increasing. Storey displacement of MIS-1 is 2.78 times the displacement of MIF model for all the three earthquake zones. Storey displacement of MIS-2 is 1.63 times the displacement of MIF model for all the three earthquake zones. Storey displacement of MIS-3 is 1.24 times the displacement of MIF model for all the three earthquake zones.

V. CONCLUSION

From the above it can be concluded for the building considered that

- Storey lateral displacements for MS-1 and MIS-1 is maximum, i.e., silty sand having less stiffness has pronounced effect on the seismic response.
- Storey lateral displacements for MS-3 and MIS-3 are nearer to that of fixed base models, i.e., dense gravel having high stiffness has almost the same effect of fixed base model.
- As the soil stiffness is increasing, the storey lateral displacements are decreasing.
- Storey lateral displacements of MS-1 is 2.75 times the displacement of MF.
- Storey lateral displacements of MS-2 is1.63 times the displacement of MF.
- Storey lateral displacements of MS-3 is 1.41 times the displacement of MF.
- Storey lateral displacements of MIS-1 is2.78 times the displacement of MIF.
- Storey lateral displacements of MIS-2 is 1.63 times the displacement of MIF
- Storey lateral displacements of MIS-3 is 1.24 times the displacement of MIF

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