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Effect of Soil Structure Interaction on High Rise Building using ETABS

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Abstract: **An asymmetrical R.C.Multi-storey building without infill walls (G+10) with plan irregularity, having four bays in x and y directions located in seismic zones II and III has been analysed with fixed base condition and flexible base condition. Flexible base is achieved by introducing the stiffness of the soil and further the foundation of the building is assumed to be resting on this soil, is called the Winkler's model approach to incorporate Soil-Structure Interaction to the building. Each individual footing has been designed, depending on the load transferred from column to the footing. Design of footing is carried out based on the IS: 456-2000 code. Using the designed isolated footing parameters, the values of spring stiffness under each column has been calculated using the empirical relationship given in NIST GCR 12-917-21 for assumed values of Modulus of Elasticity and Poisson's ratio of the soil. Equivalent static method is used in the analysis to take care of earthquake forces as per IS: 1893-2002. Results have been studied for fixed base and flexible base conditions for both the seismic zones. Conclusions are drawn from the graphs obtained from software tool, such as maximum storey displacement, maximum storey drift and overturning moments.**

Keywords: **R.C.Multi-storey building, Soil-Structure Interaction, Stiffness and Maximum storey displacement.**

I. INTRODUCTION

Most of the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces such as earthquake act on this system, neither the structure displacements nor the ground, displacements are independent of each other. 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. A seismic soil-structure interaction analysis evaluates the collective response of the structure, the foundation, and the geologic media underlying and surrounding the foundation, to a specified free-field ground motion. The term free-field refers to motions that are not affected by structural vibrations or the scattering of waves at, and around, the foundation. SSI effects are absent for the theoretical condition of a rigid foundation supported on rigid soil. Accordingly, SSI accounts for the difference between the actual response of the structure and the response of the theoretical, rigid base condition.In present work, an attempt is made to find the detrimental effect of inertial interaction and results are compared for both the fixity conditions, such as fixed base and flexible base. ETABS-2015 is used as an analysis software tool for computing soil structure interaction for high rise buildings subjected to gravity loads, wind forces and seismic forces. Building is modelled in the software with assumed material properties and structural details. The building is assumed to be situated in the seismic prone region, which lies on the seismic zones of II and III [15].

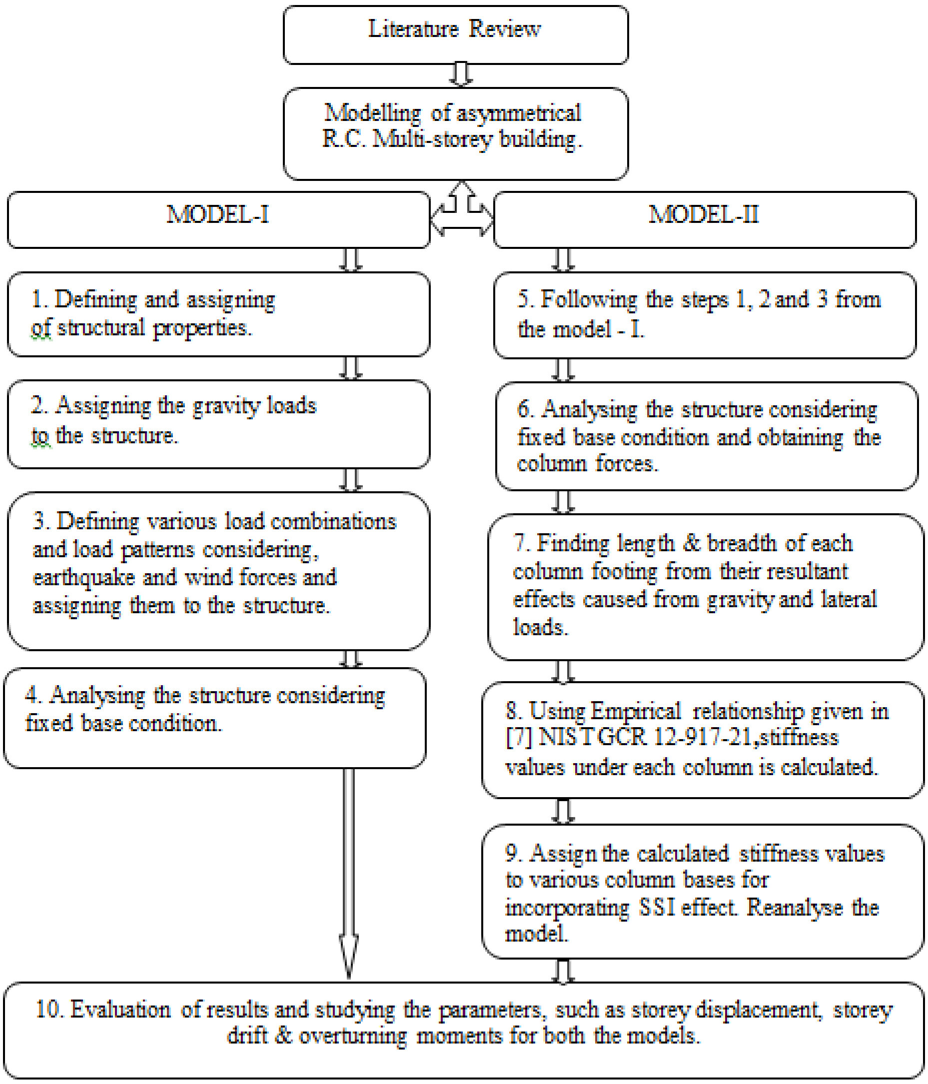
Many works have beencarried out to study the effect of SSI for multi-storey buildings situated under seismic prone regions. [1]Studied the influence of soil structure interaction and design of a 6-storey concrete frame building. Models are simulated under two different conditions: namely soil structure interaction and fixed base behaviour are considered. The influence of the soil structure in the dynamic behaviour of the structure is reflected in an increase in the vibration period as well as increase in the system damping in comparison with the fixed base model, which does not consider the supporting soil. And the author had proposed a design spectrum considering a critical damping of 13% consistent with the structural behaviour expected and according with the recommendation of the regulations has been proposed.[3]They had studied and suggested that the effect of soil-structure interaction is generally ignored in the design process of low-rise buildings resting on shallow foundations, though it has been shown that ignoring such effect may lead to unsafe seismic design. They had observed that the fundamental natural frequencies increase and base shear decrease with the increase of soil stiffness and this change is found more in soft soils.[4]The authors had studied that tall asymmetric buildings experience more risk during the earthquakes (Ming, 2010). This happens mainly due to attenuation of earthquake waves and local site response which get transferred to the structure and vice versa. This can be well explained by the dynamic soil structure interaction analysis. Authors have been concluded that for the given ground motion the displacement increases as from soil mass to superstructure in both X and Y direction, but this change is very minute for the vertical direction displacement.

A. Objectives:

The following are the objectives of the present work, they are

1) To study the effect of SSI on R.C.Multi-storey building for seismic zones II and III.
2) To compare the behaviour of R.C.Multi-storey building under fixed base condition and flexible base condition, the study investigates the parameters such as, maximum storey displacement, maximum storey drift and overturning moment.

II. METHODOLOGY



A. Building Configuration:

The following material properties and sectional properties are assumed to model the high rise building in the software.

- Grade of concrete: M30
- Characteristic yield strength of steel: Fe415
- Number of storey: G + 10
- Storey height : Ground floor: 4.2 m , Other floors: 3.2 m
- Size of column: (600×450)mm
- Size of beam: (500×300)mm
- Slab thickness: 175 mm
- Intensity of live load: 2 kN/m^2
- Intensity of floor finish: 0.75 kN/m^2

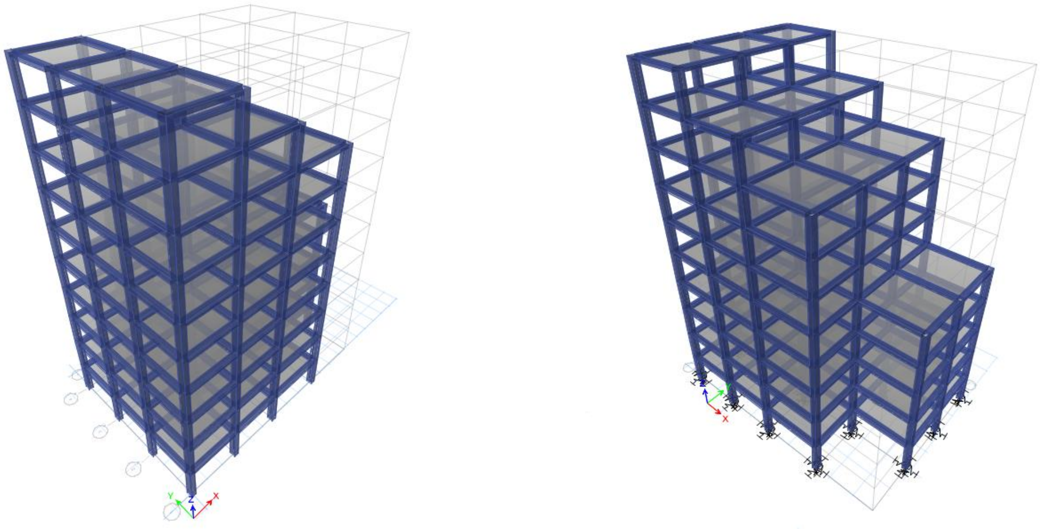


Fig 1: Three dimensional views of R.C.Multi-storey building with fixed base and flexible base

B. Load Combinations:

Indian code specifies [14], [15] the following load cases with partial safety factors under limit state design method. When a structural building is subjected to live load, wind load and seismic forces in addition to its self-weight, the load combinations are to be taken as follows,

- 1.5(DL+LL)
- 1.2(DL+LL+EL_x or WL_x)
- 1.2(DL+LL+EL_yor WL_y)
- 1.2(DL+LL-EL_xor WL_x)
- 1.2(DL+LL-EL_yor WL_y)
- 1.5(DL+EL_xor WL_x)
- 1.5(DL-EL_xor WL_x)
- 1.5(DL+EL_yor WL_y)
- 1.5(DL-EL_yor WL_y)
- 0.9DL+1.5EL_x

- 0.9DL-1.5EL$_x$
- 0.9DL+1.5EL$_y$
- 0.9DL-1.5EL$_y$

C. Equivalent Static Method of Analysis:

The equivalent static lateral force method is a simplified technique to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purposes. Earthquake motion causes vibration of the structure leading to inertia forces [9]. Thus a structure must be able to safely transmit the horizontal and vertical inertia of forces generated in the super structure through the foundation to the ground. For calculation of design horizontal seismic coefficient, the equations 1.1 and 1.2 are used.

$V_b = A_h \times W$ ...... (1.1)

Where,

$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)$ ...... (1.2)

W = Total weight of the building.

Zone factor (Z)[15]: 0.1

Importance factor (I)[15]: 1

Response reduction factor (R)[15]: 5

D. Spring Stiffness:

To calculate the spring stiffness, empirical equations given in table - I is used. The equations are mentioned in [7] NIST GCR 12-917-21, Soil Structure Interaction for Building Structures.

TABLE I: ELASTIC SOLUTIONS FOR STATIC STIFFNESS OF RIGID FOOTINGS AT THE GROUND SURFACE

Degree of freedom	**Stiffness of foundation soil**
Translation along x-axis	$K_x = \frac{GB}{2-V}\left[6.8\left(\frac{L}{B}\right)^{0.65} + 2.4\right]$
Translation along y-axis	$K_y = \frac{GB}{2-V}\left[6.8\left(\frac{L}{B}\right)^{0.65} + 0.8\left(\frac{L}{B}\right) + 1.6\right]$
Translation along z-axis	$K_z = \frac{GB}{1-V}\left[3.1\left(\frac{L}{B}\right)^{0.75} + 1.6\right]$
Rocking about x-axis	$K_{xx} = \frac{GB^3}{1-V}\left[3.2\left(\frac{L}{B}\right) + 0.8\right]$
Rocking about y-axis	$K_{yy} = \frac{GB^3}{1-V}\left[3.73\left(\frac{L}{B}\right)^{2.4} + 0.27\right]$
Torsion about z-axis	$K_{zz} = GB^3\left[4.25\left(\frac{L}{B}\right)^{2.45} + 4.06\right]$

From the Table-I,

L = Length of the footing.

B= Breadth of the footing.

G =Modulus of Rigidity.

v = μ = Poisson's ratio.

Modulus of elasticity, E = 80N/mm²

Poisson's ratio, μ = 0.3

In present work, the values of Modulus of elasticity (E) and Poisson's ratio (μ) of soil surrounding the footing are assumed suitably from [8]. Footing sizes are designed for each column axial load and they had checked for safety according to the IS code [11]. Using the 'E' and 'μ' values of assumed soil type, the stiffness values are calculated and they are assigned as flexible springs at all column bases replacing rigid base. With the designed values of length and breadth of footing, the spring stiffness is worked out. Nineteen individual springs are defined in the software and they are assigned to corresponding column base to achieve the flexible base. Table - II shows the values of spring constants based on their translations (K_x, K_y and K_z) to be expected in three direction and rotations (K_{xx}, K_{yy} and K_{zz}) in three directions.

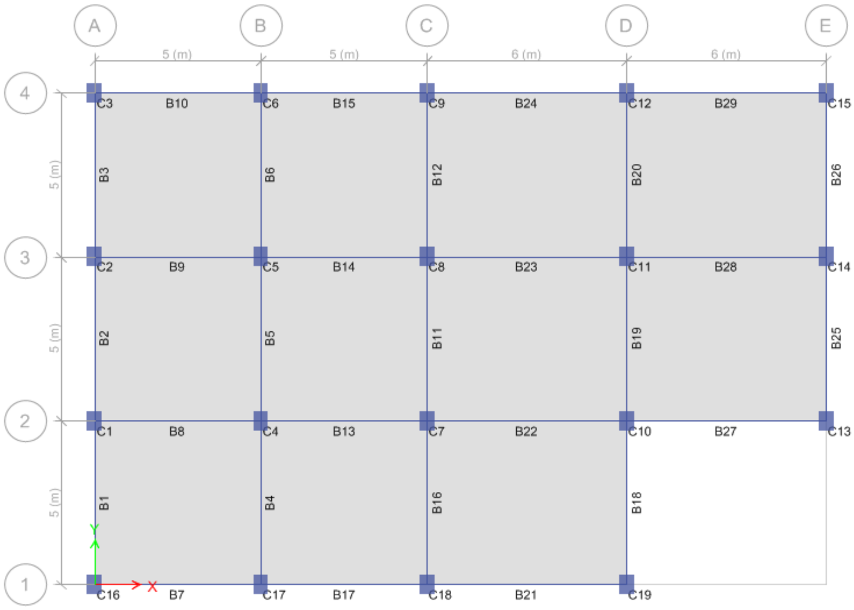


Fig 2: Numbering of the columns

TABLE II: SPRING STIFFNESS AT ALL COLUMN BASES

Column No.	P_u (kN)	L (mm)	B (mm)	K_x (10^3 N/mm)	K_y (10^3 N/mm)	K_z (10^3 N/mm)	K_{xx} (10^{11} N-mm/rad)	K_{yy} (10^{11} N-mm/rad)	K_{zz} (10^{11} N-mm/rad)
1	1269.260	2500	1900	181.03	185.37	225.85	1.88	2.84	3.27
2	2001.651	3100	2300	221.81	227.60	276.90	3.41	5.32	6.03
3	2001.48	3100	2300	221.81	227.60	276.90	3.41	5.32	6.03
4	1268.085	2500	1900	181.03	185.37	225.85	1.88	2.84	3.26
5	1965.014	3100	2300	221.81	227.60	276.90	3.42	5.32	6.03
6	3222.185	4000	3000	287.74	294.98	359.12	7.51	1.15	13.1
7	3222.170	4000	3000	287.74	294.98	359.12	7.51	1.15	13.1
8	1963.976	3100	2300	221.81	227.60	276.90	3.41	5.32	6.03
9	1927.827	3100	2300	221.81	227.60	276.90	3.41	5.32	6.03
10	3200.233	4000	3000	287.74	294.98	359.12	7.51	11.5	13.1
11	3198.468	4000	3000	287.74	294.98	359.12	7.51	11.5	13.1
12	1924.414	2800	2100	201.42	206.48	251.38	2.57	3.95	4.51
13	1633.267	2800	2100	201.42	206.48	251.38	2.57	3.95	4.51
14	2719.438	3600	2700	258.97	265.48	323.21	5.47	8.41	9.59
15	2332.597	3400	2500	242.19	248.70	302.43	4.42	6.98	7.86
16	1158.137	2400	1800	177.37	176.98	215.47	1.62	2.49	2.83
17	707.8027	1900	1400	135.48	139.10	169.17	7.75	1.22	1.38
18	1161.341	2400	1800	172.64	176.98	215.47	1.62	2.49	2.83
19	708.7931	1900	1400	135.48	139.10	169.17	7.75	1.22	1.38

III. RESULTS AND DISCUSSIONS

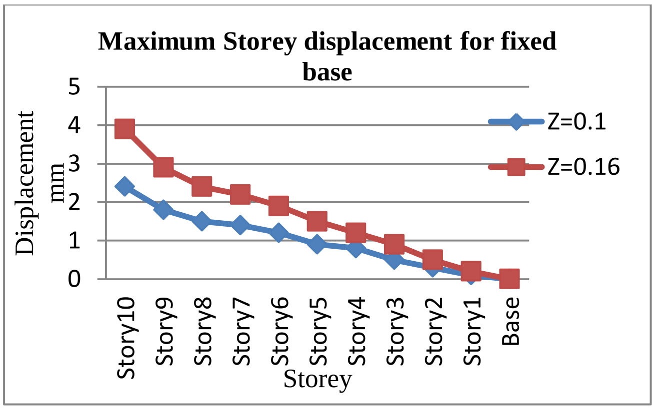
As per the results obtained from the software tool, the following numerical values have been drawn and they are compared. The table - III and table - IV gives the various parameters of the building with fixed base condition and flexible base condition over two seismic regions. The values are extracted across different storey level. Further they are represented in the form of graphs.

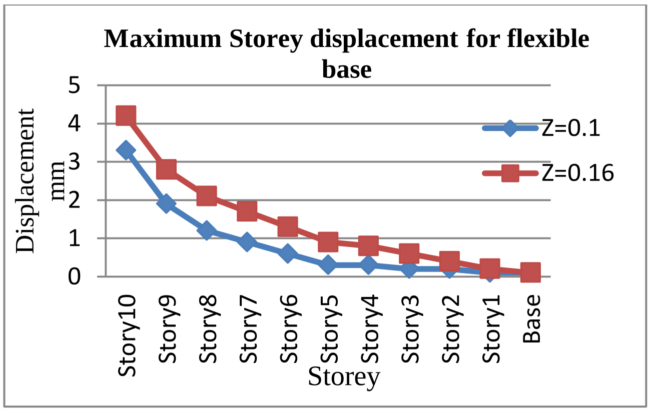
TABLE III: MAXIMUM STOREY DISPLACEMENT, MAXIMUM STOREY DRIFT AND OVERTURNING MOMENT VALUES OF A BUILDING WITH FIXED BASE CONDITION

Sl.No.	Storey	Max., Storey Displacement (mm)		Max., Storey Drift		Overturning Moments (kN-m)	
		Z = 0.1	Z = 0.16	Z = 0.1	Z = 0.16	Z = 0.1	Z = 0.16
1	Story10	2.4	3.9	0.000379	0.000379	6204.136	6204.136
2	Story9	1.8	2.9	0.000153	0.000153	23374.12	19999.12
3	Story8	1.5	2.4	0.000014	0.000014	50221.57	41446.57
4	Story7	1.4	2.2	0.000012	0.000012	78040.74	63865.74
5	Story6	1.2	1.9	0.000031	0.000031	105859.9	86284.9
6	Story5	0.9	1.5	0.000063	0.000063	141521.5	114746.5
7	Story4	0.8	1.2	0.000044	0.000044	178154.9	144179.9
8	Story3	0.5	0.9	0.000032	0.000032	214788.2	173613.2
9	Story2	0.3	0.5	0.000022	0.000022	251421.6	203046.6
10	Story1	0.1	0.2	0.000008	0.000008	288055	232480
11	Base	0	0	0	0	292913.5	237338.5

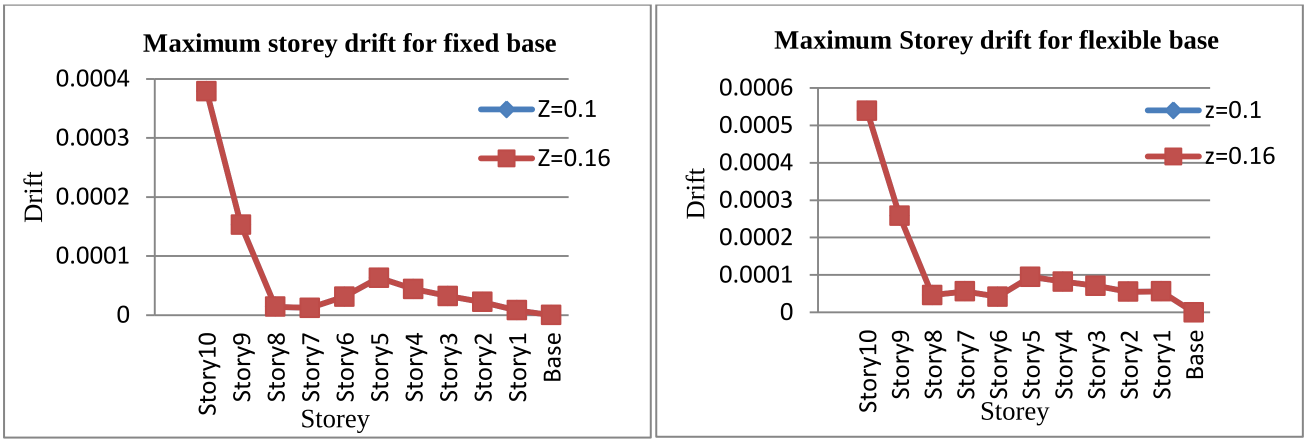
TABLE IV: MAXIMUM STOREY DISPLACEMENT, MAXIMUM STOREY DRIFT AND OVERTURNING MOMENT VALUES OF A BUILDING WITH FLEXIBLE BASE CONDITION

Sl.No.	Storey	Max., Storey Displacement (mm)		Max., Storey Drift		Overturning Moments (kN-m)	
		Z = 0.1	Z = 0.16	Z = 0.1	Z = 0.16	Z = 0.1	Z = 0.16
1	Story10	3.3	4.2	0.000539	0.000539	6204.136	6204.136
2	Story9	1.9	2.8	0.000258	0.000258	23374.12	23374.12
3	Story8	1.2	2.1	0.000046	0.000046	50221.57	50221.57
4	Story7	0.9	1.7	0.000056	0.000056	78040.74	78040.74
5	Story6	0.6	1.3	0.000042	0.000042	105859.9	105859.9
6	Story5	0.3	0.9	0.000095	0.000095	141521.5	141521.5
7	Story4	0.3	0.8	0.000082	0.000082	178154.9	178154.9
8	Story3	0.2	0.6	0.000071	0.000071	214788.2	214788.2
9	Story2	0.2	0.4	0.000055	0.000055	251421.6	251421.6
10	Story1	0.1	0.2	0.000056	0.000056	288055	288055
11	Base	0.1	0.1	0	0	292913.5	292913.5

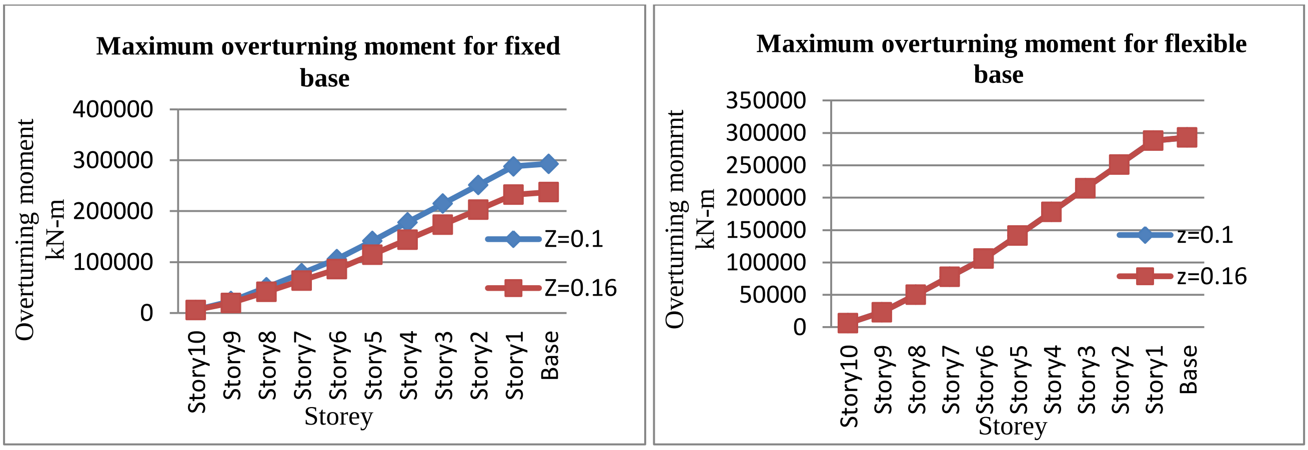




Graph 1.1: Maximum storey displacement for fixed and flexible base



Graph 1.2: Maximum storey drift for fixed and flexible base



Graph 1.3: Maximum overturning moment for fixed and flexible base

IV. CONCLUSION

1) The maximum storey displacement for fixed base at storey-10 works out to be 3.9 mm for z = 0.16 and 2.4 mm for z = 0.10. And for flexible base these values changes to 4.2 mm for z =0.16 and 3.2mm for z = 0.10 at the same storey level. There is an increase in the values of storey displacement when building with SSI effect is considered.

2) The maximum storey drift for fixed base is 0.000397 at 10th storey for both the seismic zones. And for flexible base 0.000539 at the same storey height, which is higher compared to fixed base.

3) The maximum overturning moments for fixed base condition at base level for z = 0.16 is 237338.51 kN-m and for z = 0.10 the value is 292913.51 kN-m. For flexible base, these values on z = 0.16 and 0.10 is 292913.518 kN-m. It may be also noted that the overturning moment is abundant at the base level of the building in comparison to the top storey.

4) From above three outcomes, it is possible to conclude that, the maximum storey displacement and maximum storey drift have significantly changed with higher values when SSI effect is considered.

5) There is no drastic change in the overturning moments with flexible base condition compared with fixed base condition.

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