Effect on Seis-mic Response of Building with Underground Storey Considering Soil Structure Interaction

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***Abstract*-Researches in past indicates that response of soil under seismic forces influences the seismic response of the building. Soil structure interaction (SSI) has a significant impact on dynamic response of structure, which may lead to unexpected seismic response or failure of structure. Due to the urbanization multi-storey building with underground storey for parking space and storage are very common in practice. Failures of these types of buildings during earthquake show the significance of soil structure interaction effect on underground storey buildings. Aim of this paper is to study and understand the effect of underground storey on structure considering soil structure interaction during earthquake. In this study seismic response of G+9 fix base and underground storey buildings are compared. Response Spectrum method of dynamic analysis has been used to analyze the building for seismic zone V according to IS 1893:2002 in FEM software CSI SAP2000, Version14. Elastic continuum approach is use to idealize the soil. Two different types of soils SW and ML categorised under hard, low stiff respectively in IS 1893(Part I):2002 are used in this research. Design forces in terms of storey shear is calculated for underground storey building and results are compared with the conventional fix base building. The study reveals that on considering SSI, there is an increase in lateral time period of the building and re-distribution of storey shear forces in flexible base model as compared to fixed base model.**

Keywords— Soil-structure Interaction (SSI), Structural response, Storey shear, Time period, Inter storey drift

I. INTRODUCTION

After 1964 Nigatta (M 7.5) and Alaska (M 8.6) earthquake, it was observed that behaviour of the soil beneath the super structure effects the response of building during earthquake. Since, then researchers studied the behaviour of soil under dynamic loading. From there investigation, they concluded that under dynamic loading response of soil influences the seismic response of structure. In present scenario vertical growth of buildings in urban parts of India is very common to provide shelter and workspace for the peoples. Now a day’s underground stories and basements are important segments. Also due to rapid urbanization and dearth of land, hard strata is not available for the foundation of building which force designer to design and construct building over weaker strata. Analysis of the building over hard strata is done by assuming base of building as fixed base but for weaker strata response of soil influences the analysis of building. Seismic analysis and design of multi-storey building with underground storey considering soil structure interaction (SSI) is a topic of discussion among the structural engineers from past few years. In current state of practice, most building codes treat such type of underground storey buildings with the same recommendations adopted to design conventional fixed base building. Researches in past found that seismic response of these type of underground storey buildings is a complicated phenomenon. G.Saad, F. Saddik and S. Najjar [2012] analyzed twenty storey building with underground stories, they observed that for low rise building storey shear and storey moment increased for low stiff soil. Hamid Reza Tabatabaiefar and Fatahi Behzad [2013] studied the structural response of 10 storey concrete building under three different soil conditions .According to them on decreasing the dynamic properties of soil lateral deflections and inter-storey drift increases. In some other researches Heshma EI Ganainy, M Hesahm and EI Naggar [2009], concluded that deformations and storey moment in steel building with underground stories increases on considering SSI. In this study, an attempt is made to study the seismic response of multi-storey building with multiple underground stories considering soil structure interaction under different soil conditions.

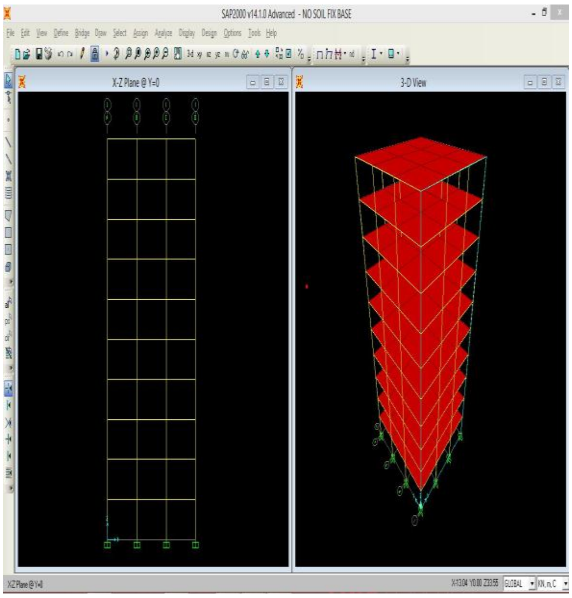
II. MODELLING

A. Building modelling

A G+9 storey R.C.C building was modelled in SAP2000 V14 with two different base conditions i.e. conventional fixed base model and flexible base model considering SSI. Fixed based building is cropped at ground level while flexible base building contains multiple underground stories. Building was assumed to be situated in Zone V as per IS 1893(Part I):2002. Total height of the building is 35 m with floor to floor distance of 3.5m each .Building was supposed to be resting on raft foundation of 1.2 m depth and a plan area of 15 X 15 m. Specification of the structural components modelled are tabulated in table 1. In SAP2000, dead load is calculated accordingly to the dimension and density of material used in modelling. Brick masonry load of 15.4 kN/m and 7.7 kN/m have been taken on external and internal beams respectively. M25 grade of concrete is used RCC members. Different load combinations of dead load, live load and seismic load have been considered as per codal provision.

TABLE I. GEOMETRIC PROPERTIES OF BUILDING FRAME AND FOUNDATION

Component	Element	Dimension
Beam	Frame	0.6 X 0.3 m
Column	Frame	0.6 X 0.3 m
Slab	Shell	15 X 15 m , 0.150 m (thickness)
Raft Foundation	Thick Plate	15 X 15 m, 1.2m (depth)
Retaining Wall	Shell	0.400 m



B. Soil modelling

Soil has been modelled using finite element method i.e. elastic continuum model. In elastic continuum model soil is model using solid element with certain sizes and meshes. Indrajit Chowdhary and shambhu P. Dasgupta [2009],suggests some relations to calculate the mesh size of soil. Well graded sandy soil (SW) and clayey fine sand (ML) are taken for this experiment which is considered as hard and low stiff soil in IS 1893(Part I):2002. Engineering properties of soils are given in table 2.Shear wave velocity of well grade sand and clayey fine sand are calculated by the relation given by Ottho & Gotto [1978].Depth of soil is considered as 50 m which is more than 2.5 times of width of foundation . Fixed condition is assumed at the bottom of soil base.

TABLE II. SOIL PROPERTIES

Parameters	SW(Hard)	ML(Soft)
Unit Weight γ	20.5 kN/m^3	16 kN/m^3
Modulus of Elasticity E_c	160 kN/m^2	8 kN/m^2
Soil Friction Angle ϕ	45^0	30^0
Interface Friction Angle δ	22^0	22^0
Shear Modulus G	61538.46 kN/m^2	3076.92 kN/m^2
Bulk Modulus K	133333 kN/m^2	6666 kN/m^2

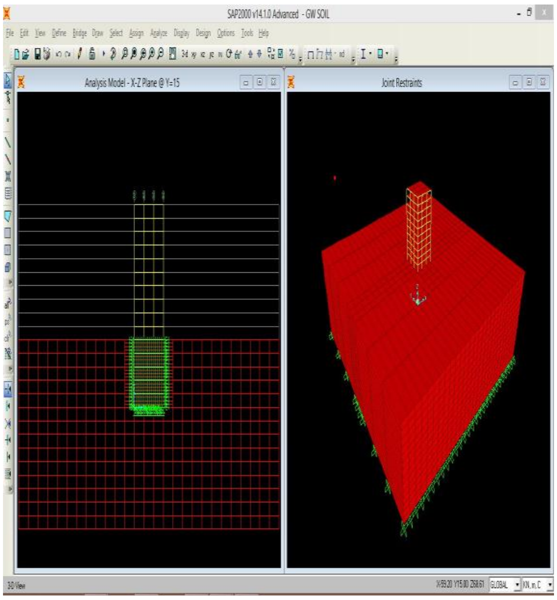


Fig.2. SSI building

C. Vertical Interface Element

Interface element is modelled between soil and structure so that no tensile forces are transmitted between the structure and the soil and the behaviour of the element is linear elastic under compressive forces. For modelling of vertical interface element spring is taken and the stiffness is calculated so that the compressive forces are transmitted with negligible displacement between the foundation and soil. For calculation of stiffness of M.H Rayhani, M.H Naggar [2008] gives an empirical formula,

$$K_n = K_s = 10 \times \max \frac{K+\frac{4}{3}G}{(\Delta z)} \qquad (1)$$

Where, *K* and *G*=bulk and shear modules,

Δz is smallest dimension of continuum zone adjacent to the interface in normal direction.

For well graded sandy soil (SW) and clayey fine sand, values of spring stiffness is calculated as 437067 and 21534 kN/m respectively.

D. Horizontal Interface element

G. Saad, F. Saddik and S. Najjar, [2012], suggestsed modelling of side soil with the help of P-y curve. Earth pressures at a given depth are given by:

Active Pressure, $P_a = K_a.\gamma.Z.\cos\delta$ (2)

Passive Pressure, $P_p = K_p.\gamma.Z.\cos\delta$ (3)

$$K_a = \frac{\cos^2\emptyset}{\cos\delta\left[1+\left(\frac{\sqrt{\sin(\delta+\emptyset)\sin\emptyset}}{\cos\delta}\right)\right]^2} \qquad (4)$$

$$K_p = \frac{\cos^2\emptyset}{\cos\delta\left[1-\left(\frac{\sqrt{\sin(\delta+\emptyset)\sin\emptyset}}{\cos\delta}\right)\right]^2} \qquad (5)$$

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Where, γ is the unit weight of soil, *Z* is the embedment depth at which the soil pressure is calculated, δ is the wall-soil friction angle, and ϕ is the angle of friction of the soil.

As suggested by Briaud and Kim (1998), displacement caused by the active earth pressure Pa and the passive earth pressure Pp could be 1.3 mm away from the retained soil and 13 mm in to soil respectively to model P-y curve.

III. RESULTS AND DISCUSSIONS

Static and response spectrum analysis of the models are performed using SAP2000 Version14. Effect of SSI on different parameters of seismic analysis i.e. natural time period, inter storey drift, roof displacement and storey shear are studied

A. Storey Shear

It is observed that on considering SSI effect with SW soil, storey shear increase at stories nearer to ground and decreases in upper stories. It is also noticeable that on increasing the underground stories of building in soil structure interaction storey shear increases at each level as compare to building without underground stories.

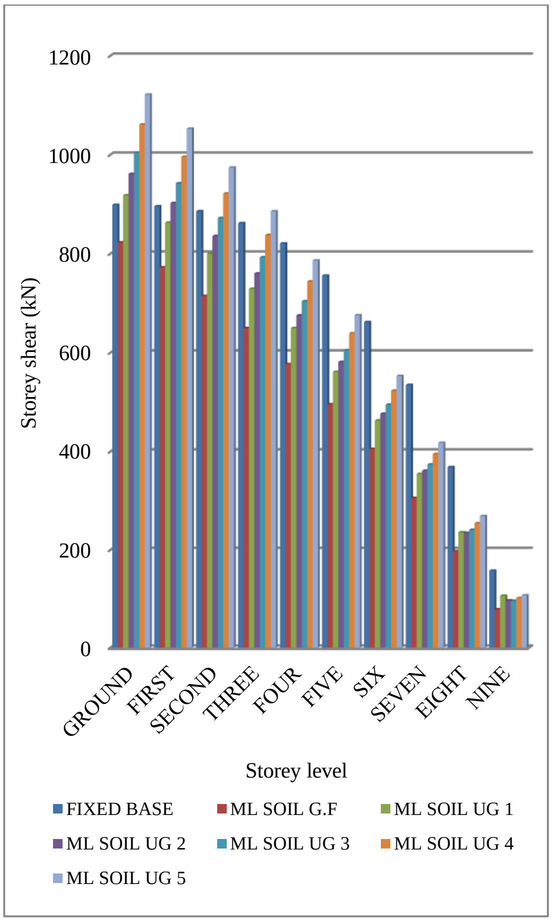

Fig.3. Storey shear comparison cropped building vs. SW soil (SSI effect)

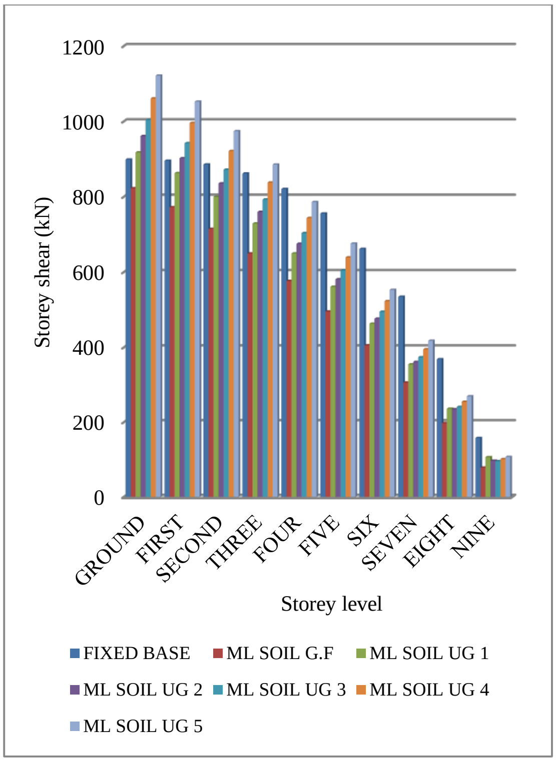

Fig.4. Storey shear comparison cropped building vs. ML soil (SSI effect)

On replacing the SW soil with ML, low stiff soil having dynamic properties less than SW, storey shear for building without underground storey decreases as compared to fixed base building but on considering underground stories in ML soil, storey shear increase in bottom stories while decreases in upper stories which indicated for SSI effect re distributed the design forces in building with underground storey.

B. Inter storey drift

Inter-storey drift is the difference between the roof and floor displacement of any given storey as the building sways during the earthquake, normalized by the storey height .The greater the drift, the greater the likelihood of damage. As per IS 1893(Part I):2002, maximum allowable storey drift is 0.004 times the storey height. Comparison of inter-storey drift for SW and ML with fixed base building is shown in fig.5 and fig. 6. From the study it is found that on increasing the underground stories inter-storey drift increases. Effect is more noticeable at bottom stories, as for low stiff soil (ML) percentage increase is about 126% as compared to fixed base building.

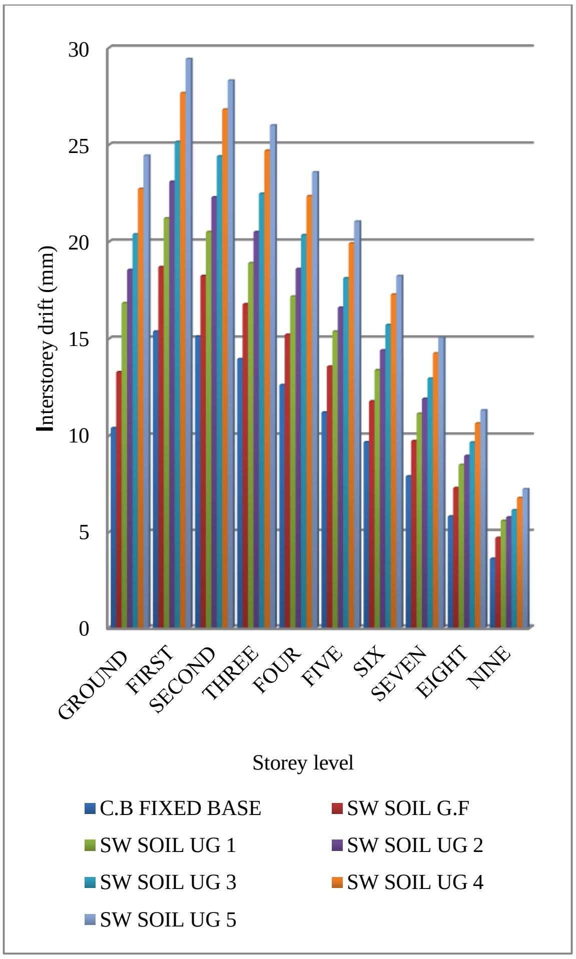

Fig.5. Inter-storey drift comparison fixed base v/s SSI effect (SW soil)

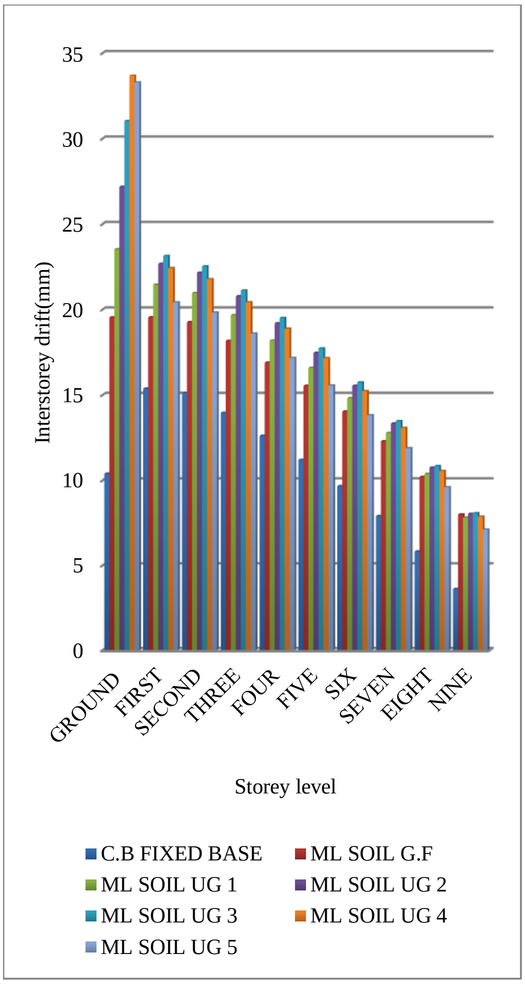

Fig.6. Inter-storey drift comparison fixed base v/s SSI effect (ML soil)

C. Time period

Time period comparison for conventional fixed base building and building with SSI effect is tabulated and shown in fig.7. It is found that time period increases for the building with SSI effect due to the flexibility of soil. Maximum time period is observed for low stiff (ML) soil which is about 10% more than fixed base building. As discussed earlier due to the SSI effect time period of flexibility of the building increases with increase in time period which results into larger relative displacements. Results show that effect of soil structure interaction is more significant for low stiff soils.

D. Roof Displacement

Roof displacement results are shown in fig.8, in which it is observed that on considering SSI effect roof displacement of the building increases with a maximum change in roof displacement of 95%.From the graph it is clear that on increasing the underground stories of the building roof

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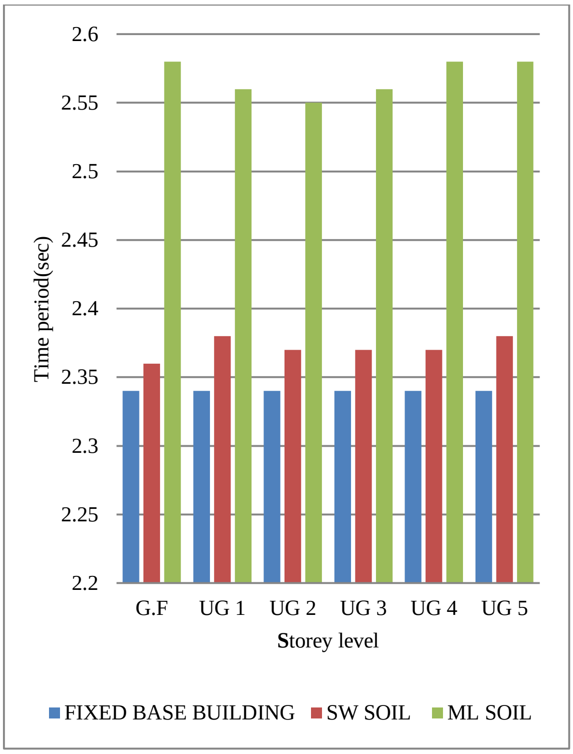

Fig.7. Time period comparison fixed base v/s SSI effect

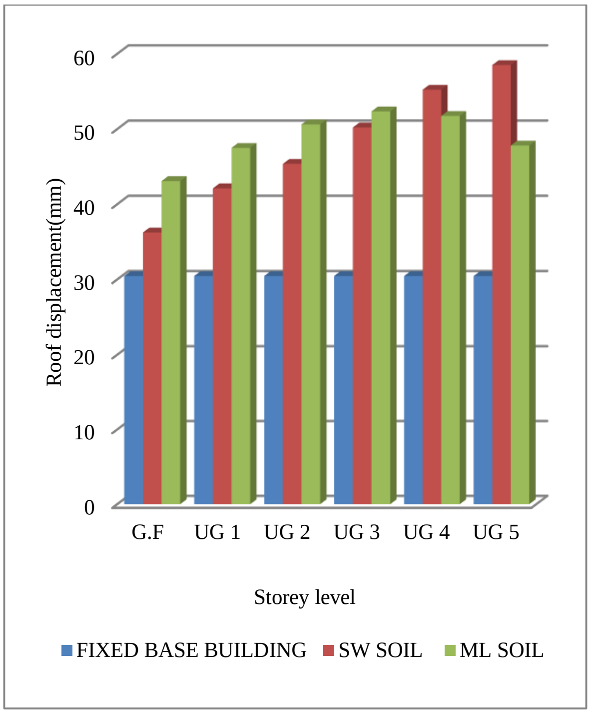

Fig.8.Roof displacement comparison fixed base v/s SSI effect

IV. CONCLUSIONS

Following conclusions can be drawn from the response spectrum analysis of different types of multi-storey underground storey building with SSI effect and conventional fixed base building.

a) For both SW and ML soil, Storey shear decreases at upper and middle floor and increases in bottom stories which emphasize the structural designer to design ground floor columns for higher values of shear as compare to fixed base building.
b) With increase in underground stories, storey shear increases at each level as compare to building without underground stories.
c) Natural time period of building increase on considering the flexibility of soil which results increase in flexibility of building.
d) Inter storey drift increases in flexible base building at each floor as compare to fixed base building.
e) Roof displacements also increases on considering soil structure interaction which sometimes causes adverse effect over the structure in terms of large displacement of top stories which causes discomfort for occupants.
f) From the study it is concluded that SSI effect is more significant for underground storey building when it is constructed on low stiff soil.

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