Study on Effect of Foundation Soil on Mass Irregular Buildings Under Seismic Loads

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***Abstract*—All the commercial buildings and residential buildings are conceptualized as regular buildings while designing but in reality, no building is ideally regular. All the existing buildings have one or more types of irregularities. In this study, effect of foundation soil in the response of multistorey building with mass irregularity is considered by incorporating two types of soil under the raft foundation . Shear wave velocity of 150m/s and 600m/s are considered representing soft and dense soil. Transient analysis of three dimensional building frames resting on soil stratum is carried out with time history of acceleration of a ground motion using finite element software. The seismic response variation in these buildings for various mass ratios are evaluated and found significant increase in roof acceleration and base shear if mass irregularity is present at the bottom floors when the building rests on soft soil.**

Keywords – Mass irregularity, seismic analysis, soil-structure interaction

I. INTRODUCTION

In reality with the growing population and urbanization, complex building concept has become normal. In the conventional method of constructing a building, the structure is considered as a regular building, that is as a symmetric building without any irregularities in the horizontal or vertical direction. But all the existing buildings have some irregularities either in their vertical direction or in the horizontal direction. According to the IS 1893 code guidelines, the irregularities are mainly classified into two types: plan irregularity and vertical irregularity. Many studies reported the different behavior of structures with different types of irregularities. Das and Nau[5] studied various vertical irregularities on buildings from 5 to 20 storeys using time history analysis and equivalent lateral force method, wherein storey drifts at the combined irregularities exhibited an abrupt increase. Archana J Satheesh and Jayalekshmi B R [19] in their research work, the behavior of vertically irregular multistorey buildings of five, ten and fifteen storey under seismic loading and the variation in seismic behavior of the building structures due to stiffness irregularities along with both height and in-plan was evaluated and was concluded that the stiffness present at the base of a building is highly influential on the overall stability. Abdel et al.[1] in their work on the result of soil-structure interaction on tall buildings constructed on the mat foundation under the influence of seismic loading showed an increase in the buildings period of vibration if soil-structure interaction was considered and the total drift of the building increases with an increase in the soil flexibility. Tabatabaiefar and Massumi[14] in their research work examined the influence of soil-structure interaction on the seismic variation of reinforced concrete moment resisting building frames and concluded that the period of vibration was longer for structures modeled with soil.

In this study, the effect of one of the vertical irregularities namely mass irregularity is evaluated when it is located at different elevations of the building and also considering the effect of interaction among the structure and soil. Comparisons of base shear, interstorey drift, and roof acceleration are made considering two types of soil.

II. METHODOLOGY

A three-dimensional building frame with soil stratum was modeled using a finite element software ANSYS APDL. A five storey mass irregular building with a raft foundation resting on the soil was modeled with mass irregularity located on different floors. The seismic analysis was done using the El-Centro earthquake data.

A. *Mass irregularity*

IS 1893:2016 classifies the irregularities into two main types as horizontal irregularity and vertical irregularity.

Vertical irregularity is furthermore divided into five main types in which one of the irregularities is mass irregularity.

According to IS 1893:2016, a building is said to have mass irregularity when "the seismic weight of the floor considered is 150 percent more than the seismic weight of the floor below".

B. *Soil-Structure Interaction*

Soil-Structure Interaction (SSI) is a circumstance that occurs when the flexibility of the foundation soil affects the reaction of structures, as well as when the presence of structures affects the response of soils. In analytical and numerical models for dynamic analysis, SSI effects of the combined structure, foundation and soil stratum are usually ignored. SSI effects have been recognized as having a remarkable impact, particularly in circumstances where heavier constructions rest upon soft soil conditions.

There are two types of dynamic study of soil-structure interaction namely: The substructure approach and the direct approach.

The analysis of a structure is divided into several steps in Substructure approach. The soil-structure model has two parts, the structure part, and the soil part.

The soil and structure are modeled together in the Direct method. In this approach, both inertial interaction and kinematic interaction are considered. In the direct approach modeling in ANSYS, the boundaries at an appropriate distance from the foundation are defined so that we can consider for the dynamic absorption properties of soil beyond the boundaries. To avoid seismic waves reflecting into the model, the boundaries must absorb the wave energy. In this study direct approach is used for SSI analysis.

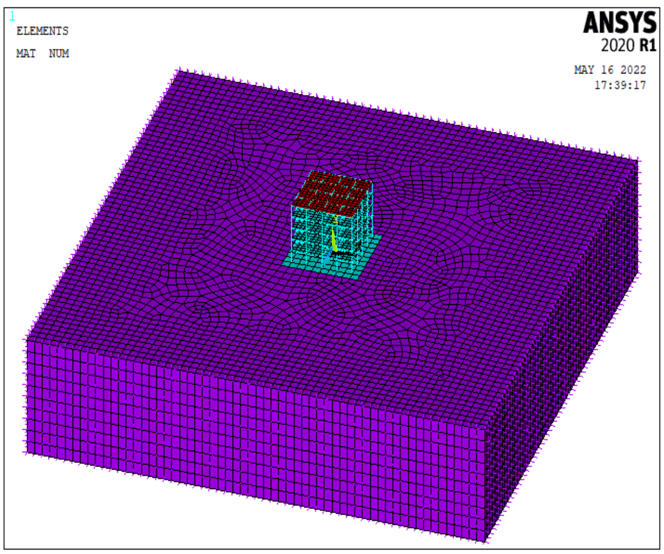

Fig 1. Direct approach modeling of soil-foundation-building system

C. Structural Idealisation

The building considered for the analysis was taken with different mass ratios distributed on different floors of the building. Mass Ratio is "the ratio of the seismic weight of the floor considered to the seismic weight of the floor below". [16] analyzed that the reason that every family member will be employed and busy, the health monitoring of elderly people and patients has become very crucial. In the proposed methodology caretakers can get the information of the temperature and the pulse rate of the people being monitored at home. User can also get the information about the air quality in the home so that the system will generate an alarm if any hazardous gas is detected..

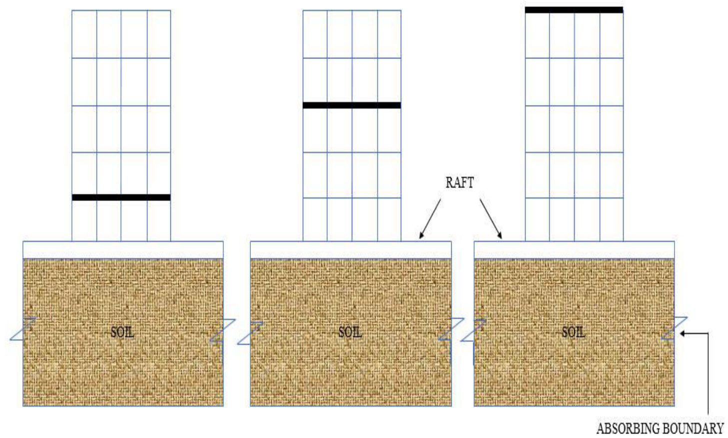

Fig 2. 5-storey building with mass irregularity at different storey height

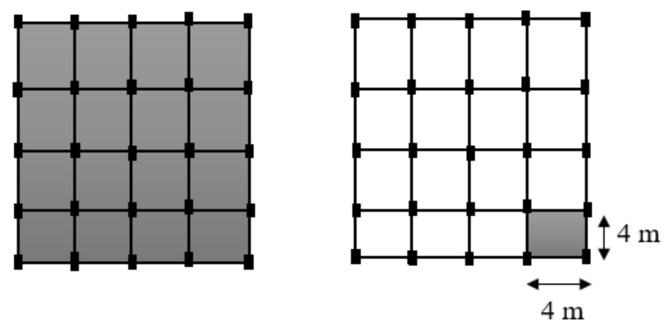

Fig 3. Plan of mass ratio distribution without and with eccentricity

The structural details of the building considered for the study are as per IS 456:2000 and IS 13920:2016 and are as follows

Number of storey - G+4

Plan dimension - 16m×16m

Height of the building - 15m

Height of each floor - 3m

Number of bay - 4

Bay width - 4m

Raft dimension – 20m×20m

Roof slab – 0.15m thick

Raft slab – 0.5m thick

Beam – 0.3m×0.4m

Column – 0.4m×0.4m

Steel – Fe415 Grade

Concrete – M25 Grade

Live load on the floor – $3kN/m^2$

Density – $2500kg/m^3$

Models considered for analysis are denoted as

M0B – mass irregularity without eccentricity when placed on the bottom floor (Fig 4)

M0M – mass irregularity without eccentricity when placed on the middle floor

M0T – mass irregularity without eccentricity when placed on the top floor

M1B – mass irregularity with eccentricity when placed on the bottom floor (Fig 5)

M1M – mass irregularity with eccentricity when placed on the middle floor

M1T – mass irregularity with eccentricity when placed on the top floor

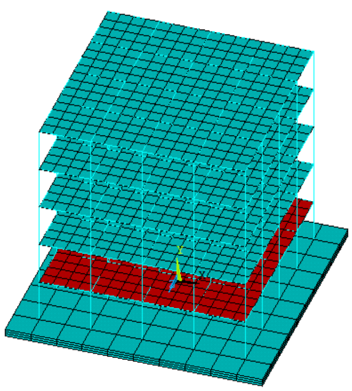

Fig 4. 5-storey building frame with M0B configuration

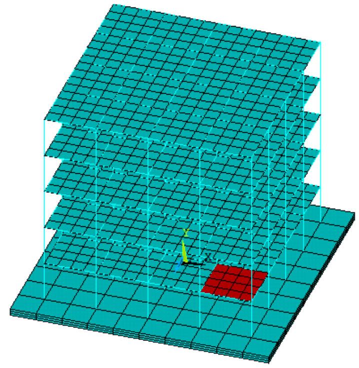

Fig 5. 5-storey building frame with M1B configuration

Soil idealization was done considering soil stratum of dimension 120m×120m and thickness 30m. The soil was modeled using the element type SOLID185 in ANSYS APDL with three degrees of freedom per node. Soft and dense soil is considered for the study according to FEMA 273 soil classification. The details are shown in Table 1.

Table 1. Soil Properties

Soil Type	Youngs modulus (E)(GPa)	Poissons Ratio (μ)	Shear wave velocity (V_s)(m/s)	Unit weight (ρ)(kN/m^3)
Dense Soil	1.872	0.3	600	20
Soft Soil	0.4374	0.4	150	16

D. Time history analysis

Earthquake is one of the most damaging natural hazards, and it strikes at any time. It creates varying degrees of shaking in various regions. It is critical to incorporate earthquake loads in the design of structures to reduce the danger of structural failure.

For the investigation of the response of building with varying mass distribution, seismic data in the form of earthquake records have been considered. The earthquake selected for investigation is the El-Centro earthquake of 1940, acceleration data of the same is scaled down to 0.3g and applied to the structure in the horizontal direction.

III. Results

The study analyses the seismic behavior of building models with two different mass ratios and various position of irregular mass distribution along the elevation of the structures. The effects of mass irregularities along with the height and within each floor of the building are examined for dynamic responses of 18 building frames and described in terms of interstorey drift, acceleration at roof level and base shear. The differences in irregular building responses to various types of foundation soil and mass ratios are estimated.

A. *Roof Acceleration*

The roof acceleration of the irregular building with the effect of soil when subjected to the ground acceleration of the El-Centro ground motion is taken and the obtained results are compared with the irregular buildings without considering the result of soil-structure interaction. Representative sketches of the time history of roof acceleration in M0T and M1T buildings are shown in fig 6 and fig 5.

In the five storey building considered, an increase of 152.74% and 155% was observed in the configuration M0B and M1B respectively when founded upon soft soil as compared to that of a fixed base. The difference between the roof acceleration is less in the case of the dense soil when compared with the fixed base condition.

In terms of mass ratios, when the mass ratio of 1.25 is located at the upper half of the structure there is an increase in roof acceleration of 4.08% in M0T and an increase of 6.617% in M1T building frame when compared with the mass ratio of 1.5.

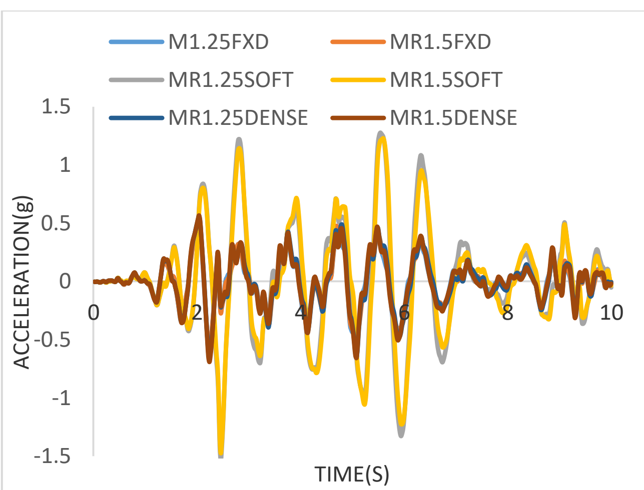

Fig 6. Roof acceleration of M0T building frame

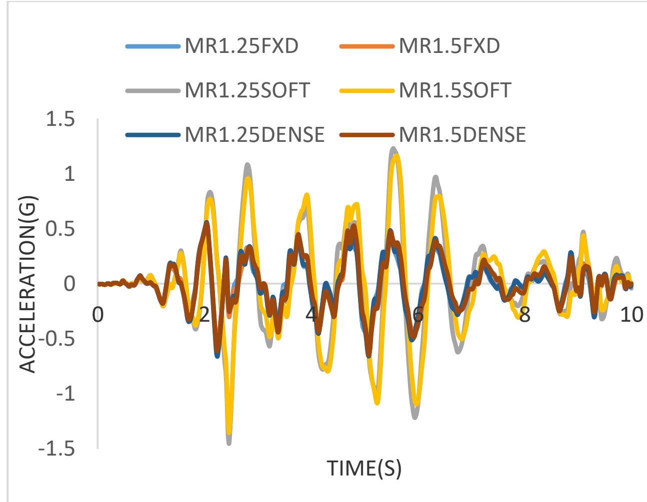

Fig 7. Roof acceleration of M1T building frame

B. *Interstorey drift*

Storey drift is the displacement of one floor of a building with respect to the floor below in lateral direction. Buildings exposed to El-Centro ground motion had their interstorey drift analyzed and the same is shown in figures 8, 9, and 10 for different mass ratios, soil, and position of mass irregularity for M0 building configuration. A similar variation in the graph was seen for the M1 building configuration.

[13] proposed a principle in which another NN yield input control law was created for an under incited quad rotor UAV which uses the regular limitations of the under incited framework to create virtual control contributions to ensure the UAV tracks a craved direction. Utilizing the versatile back venturing method, every one of the six DOF are effectively followed utilizing just four control inputs while within the sight of un demonstrated flow and limited unsettling influences..

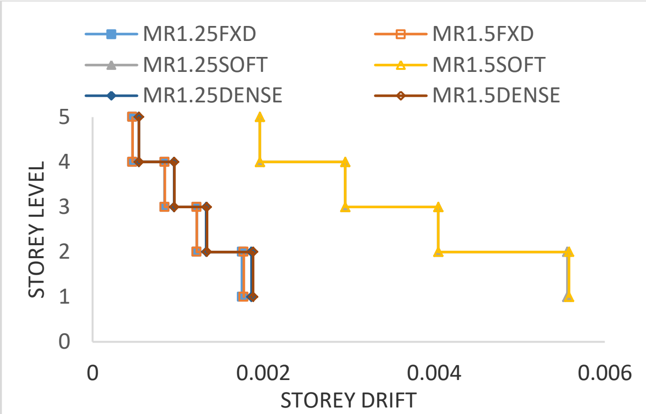

Fig 8. Interstorey drift of M0B building frame

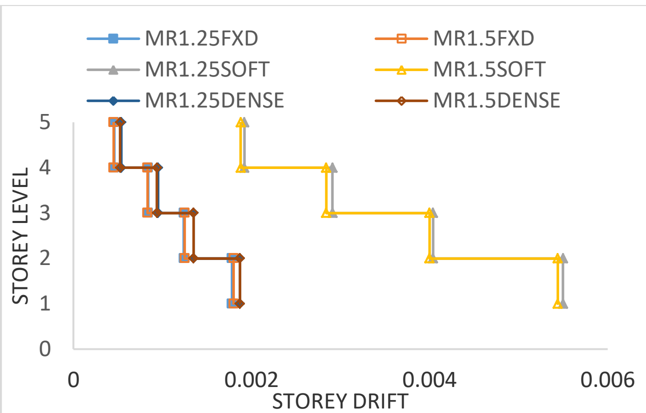

Fig 9. Interstorey drift of M0M building frame

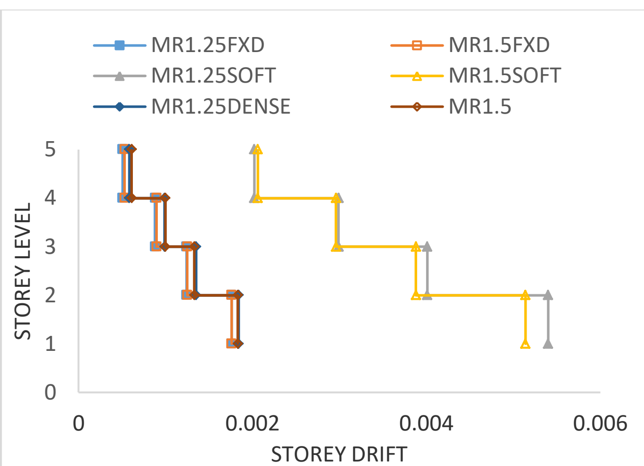

Fig 10. Interstorey drift of M0T building frame

C. *Base Shear*

The shear ratio describes the total shear force at the base of building as a factor of entire weight. The shear ratio of the buildings with mass irregularities along the elevation of the building, when the ground motion data of El-Centro earthquake is applied is shown in figures 11 and 12.

It is noticed from the results that the shear ratio increases with an increase in the flexibility of the soil as compared to the fixed base condition. A maximum increase of 186.88% and 165.89% were observed for M1B and M0B configurations respectively when situated on soft soil with respect to base fixed condition. The change or difference in the base shear in terms of shear ratio is less for dense soil conditions.

[9] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller..

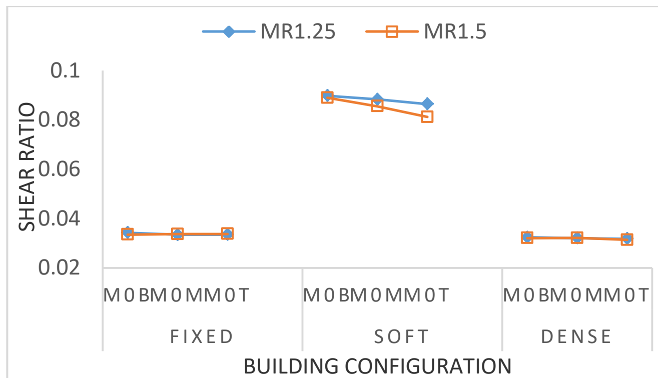

Fig 11. Shear ratio of M0 building configurations

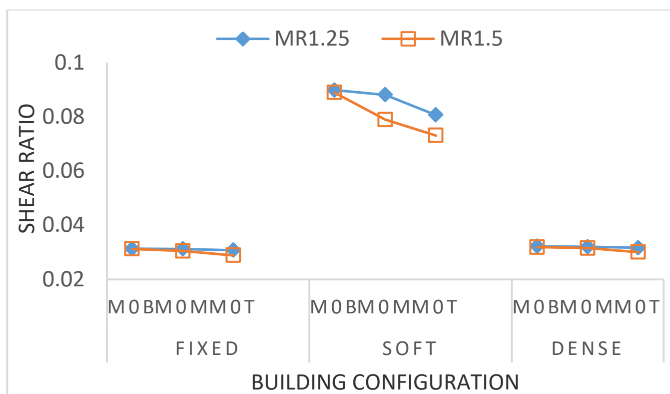

Fig 12. Shear ratio of M1building configurations

IV. CONCLUSION

- Maximum seismic base shear is observed for the building founded in soft soil conditions. An increase of 186% in the seismic shear ratio is noticed for building configuration M1B with soft soil conditions when compared with a conventional base which is assumed to be fixed.
- A maximum interstorey drift of 217% was observed in M0B building frame when placed in soft soil as compared with the base which is fixed.
- An increase of 155% in the roof acceleration was observed for soft soil conditions in M1B building frame.
- The mass ratio of 1.25 plays a significant role in increasing the interstorey drift when placed in the upper half of the five storey building.
- The shear ratio, interstorey drift, and roof acceleration increase with the increase in the flexibility of the soil.

From the above results, it is concluded that combined effect of interaction among soil, foundation and building should be considered when the building is constructed on soft soil.

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