

Figure 3b: Elevation (Brick Infill Frame)

3.2 Structural Modeling and Analysis Method

In the present analysis, the beams and columns are modeled as frame element and slab are modeled as rigid diaphragms. The slab is assigned membrane type behavior to provide in plane stiffness. All the masses of the floor are lumped at centre of rigidity, the beam column joints are assumed to be rigid. And all the models are analyzed and designed for Gravity load case i.e. 1.5(DL+LL). This behavior of soil has been simulated by modeling the same with a set of linear elastic springs. Below the centre of gravity of the foundation, three translational springs along mutually perpendicular global axes together with two rotational springs about these mutually perpendicular global axes are assigned to simulate the effect of soil-flexibility. ATC-40 has prescribed the procedure for modeling and calculating the stiffness of equivalent soil springs along the various degrees of freedom. The surface stiffness factors are multiplied with stiffness of embedment factors to consider the effects of the depth of bearing and then the individual distributed stiffness intensities are calculated by dividing the uncoupled total embedded stiffness by the corresponding area of contact for translational stiffness parameters and by moment of inertia for rotational stiffness parameters. To obtain the final stiffness with appropriate units (kN/m for translational and kN/radian for rotational), individual distributed stiffness intensity parameters obtained above are multiplied with the corresponding areas. Soil parameters used to calculate these equivalent springs are tabulated in table 1.

Table 1: Soil parameter considered^[4]

Type of Clay	S.B.C of soil kN/m ²	Young's Modulus kN/m ²	Poisson ratio	Shear Modulus kN/m ²
Soft	120	15000	0.45	5172.41
Medium	160	50000	0.45	17241.37
Stiff	250	200000	0.45	68965.51

4. Results and Discussions

The results in terms of fundamental natural period, lateral displacements, storey drift and base shear for building models are presented and compared for different analysis. An effort is made to investigate the effect of soil structure interaction and nonlinear behavior of the building in the seismic analysis. Further, the building models with bare and brick infill frame models are evaluated using nonlinear static pushover analysis, in which the performance of the building models for the design earthquake are presented.

4.1 Fundamental Natural Period

The fundamental natural periods of bare frame and brick infill building models supported on different soil types for gravity design and seismic design are plotted in Fig 4a & Fig 4b. As in seismic design combination given in IS 1893 (Part 1): 2002, the sections of structural members are obviously larger as compared to those of gravity design combination. Hence, the stiffness of the building designed for seismic loads is much more which results in decrease in natural period. The stiffness of the gravity designed building is increased by retrofitting the corner walls at the ground storey hence there is decrease in natural period, compared with that of gravity designed.

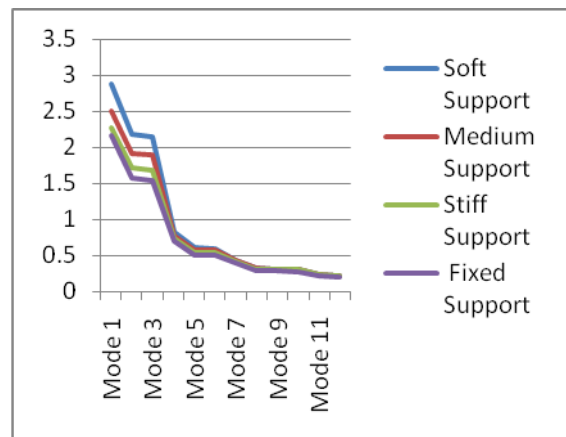


Figure 4a: Fundamental Natural Period on Bare Frame

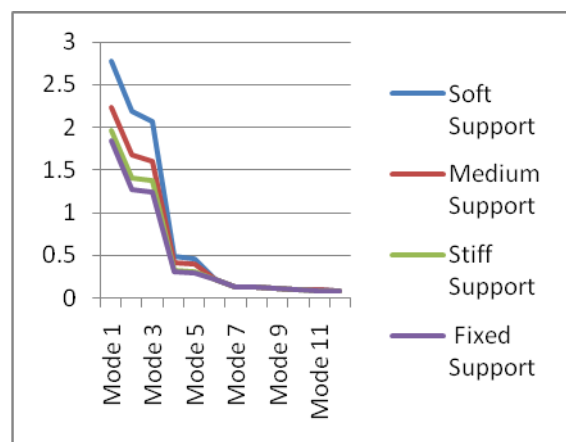


Figure 4b: Fundamental Natural Period on Brick infill Frame

4.2 Base Shear

The base shear is a function of mass, stiffness, height, and the natural period of the building structure. In the equivalent static method design horizontal acceleration value obtained by natural period given in code is adopted, and the basic assumption in the equivalent static method is that only first mode of vibration of building governs the dynamics and the effect of higher modes are not significant therefore, higher modes are not considered in this method. The base shear of bare frame and brick infill building models supported on different soil types for gravity design and seismic design are plotted in Fig 4c & Fig 4d.

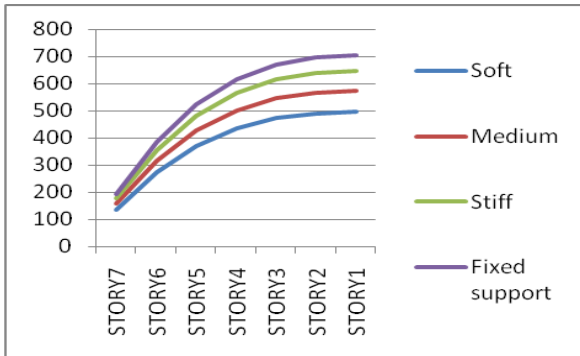


Figure 4c: Base shear for Bare Frame

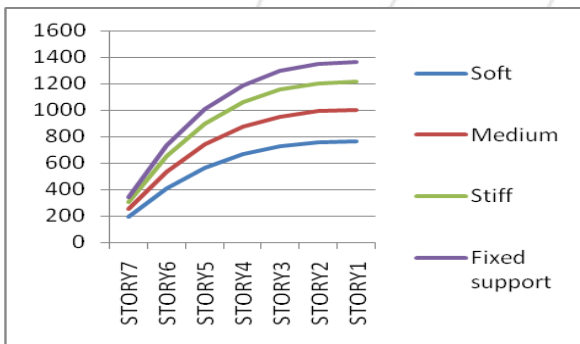


Figure 4d: Base shear for Brick infill Frame

4.3 Change in lateral displacements

Lateral displacements for different soil type are tabulated in figures 4e and 4f along longitudinal direction. From the figures it is observed that the displacement values are increasing as the soil type changes from rigid to soft.

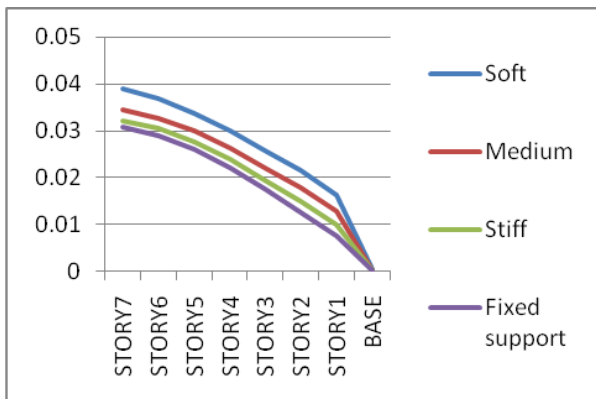


Figure 4e: Lateral displacement for Bare Frame

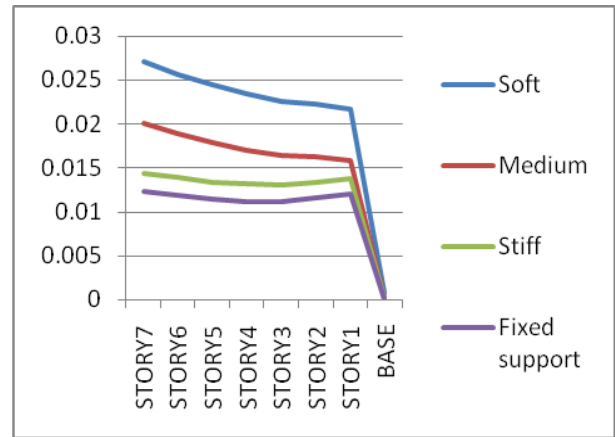


Figure 4f: Lateral displacement for Brick infill Frame

4.4 Inter Storey Drift

The variation of the inter storey drift for the building models along the longitudinal direction are shown in the Figs. 4g and 4h. Due to the open ground story of model 2 the inter storey drift was found to be more in the first storey along longitudinal direction. As per IS 1893 (Part 1): 2002, clause 7.11.1. The storey drift should not exceed 0.004 times the storey height. For the upper storeyes of model 2, the storey drifts are within limit but for the first storey it is exceeding the permissible limits because it possess stiffness irregularity due to the open ground storey

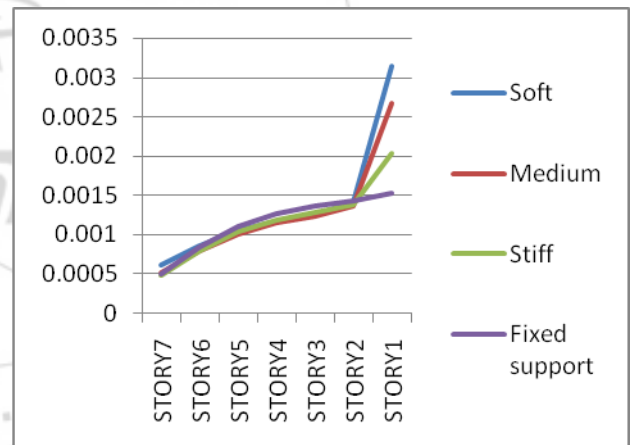


Figure 4g: Storey drift for Bare frame

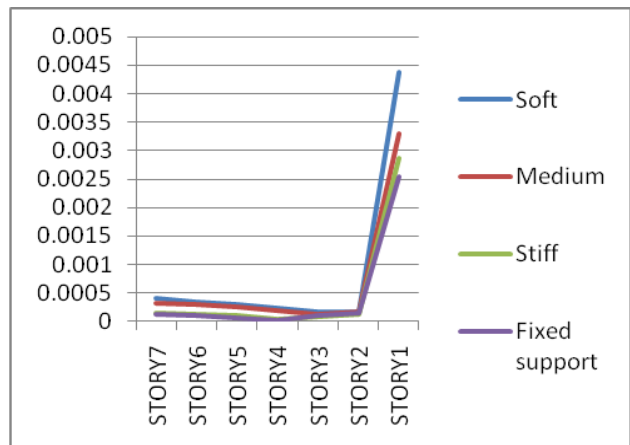


Figure 4h: Storey drifts for Brick Infill frame

4.5 Performance Evaluation of Building Models

Performance based seismic evaluation of all the models is carried out by nonlinear static pushover analysis. Default hinges are assigned for the most severe designed load combination for building models. The pushover analysis was including ten steps. It has been observed that, on subsequent push to building, hinges started forming in beams first. Initially hinges were in B-IO stage and subsequently proceeding to IO-LS and LS-CP stage. The performance points for building models are tabulated in table 2. Where V and D are the base shear and displacement respectively.

Table 2. Performance Point (V, D)

Soil Type	Bare Frame		Brick Infill Frame	
	V	D	V	D
Fixed base	1244.28	0.249	1634.40	0.076
Stiff soil	1241.29	0.255	1628.78	0.079
Medium Soil	1234.70	0.270	1603.69	0.090
Soft Soil	1178.11	0.290	1348.29	0.112

In most of the buildings, all the plastic hinges are formed in the first storey because of open ground storey. The plastic hinges are formed both in the beams and columns. Performance of the buildings lies in the collapse prevention range for bare frame and brick infill frame supported on all the types of soil. As the building is supported on soft soil, most of the plastic hinges are formed in the columns and beams of the first story and it is observed that plastic hinges are not at all formed in upper storeyes. Considering at the performance point, the plastic hinges are formed along both the longitudinal and transverse directions; the performance is found to be within the range of life safety and collapse prevention where the major structural components may get damaged but does not get collapsed and there is no threat to life safety either within or outside the building. While injuries during the earthquake may occur, the risk of life threatening from the structural damage is very low. However these buildings can be retrofitted and the performance of the building can be increased to life safety range.

At performance point, where the capacity and demand meets, out of 560 assigned hinges in bare frame on soft soil 412 were in A-B stage, 60, 24, 48, 0, 1 and 15 hinges are in B-IO, IO-LS, LS-CP CP-C, C-D and D-E stages respectively. As at performance point, hinges were in LS-CP range. Overall performance of bare frame buildings is said to be life safety to collapse prevention stage. Also out of 848 assigned hinges in brick infill frame on soft soil 823 were in A-B stage, 5, 4, 14, 0, 0 and 2 hinges are in B-IO, IO-LS, LS-CP CP-C, C-D and D-E stages respectively. As at performance point, hinges were in LS-CP range. Overall performance of brick infill frame buildings is said to be life safety to collapse prevention stage.

5. Conclusions

From the results discussed with respect to the building models considered leads to the following conclusions:

1. It is observed that the fundamental natural frequencies increase and base shears decrease with the increase of soil stiffness and this change is found more in soft soils.

2. The seismic response of the building frames such as Lateral deflection, Storey drift, and Base shear values were compared for both type of building frames. Lateral deflection, Storey drift, and Base shear values increases when the type of soil changes from hard to medium and medium to soft for fixed and flexible base buildings.
3. Lateral deflection, Storey drift, and Base shear values of fixed base building was found to be lower as compared to flexible base building. Hence suitable foundation system considering the effect of Soil stiffness has to be adopted while designing building frames for seismic forces.
4. Performance points of all building models were observed before the collapse prevention of the building and it is concluded that the injuries during the earthquake may occur, the risk of life threatening from the structural damage is very low. However these buildings can be retrofitted and the performance of the building can be increased to life safety range.
5. Soil-structure interaction cannot be ignored while designing important structures like buildings, bridges, nuclear power plants, liquid storage structures, dams etc., against expected earthquake forces.
6. Software used for nonlinear static analysis ETABS 9.7 having features of performing performance based analysis by going through some simple steps.

References

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