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DESIGN DEMAND OF RC BUILDING AS PER SOIL TYPE

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Abstract

The RC-framed building is one of the most common construction techniques for seismic-resistant structures due to its ductile nature. But the seismic performance of the RC structure is affected by various factors among which site soil condition is vital. The sub-soil condition affects the time period of the structure which eventually impacts the earthquake force in the structure, thus making variations in seismic loadings. Although several studies have been performed and design elastic spectra have been defined as per soil types in the design codes, there are no studies quantifying the effect of design demand in the buildings due to variation of soil type in the context of Nepal and NBC 105:2020. Therefore, this study aims to present the variation in design demand for moderately high-rise RC buildings in different soil types. A representative sample building has been taken and analyzed in the Finite Element platform SAP 2000. Numerical analysis is performed using linear static and response spectrum methods. Based on the study, variation in the base shear, story displacement, inter-story drift, and section size to meet the limit state of strength are compared for soil types A, B, C, and D.

Keywords: *Soil type, High rise structure, RC building, Base shear, Numerical modelling*

1. Introduction

Nepal lies in a seismically active region as it lies on the ridge between the Tibetan and the Indian tectonic plates[1][2]. This fact of seismic vulnerability makes it more important to conduct seismic analysis of the structure based on soil type for the safe, sound, and economic design of the buildings. The reinforced concrete structure has been developed as the most common construction material since the 19th century[3]. The RC-framed structure is a widely accepted form of seismic-resistant structure as it is economical, easily available, durable, easy to construct, and also very common in Nepal. RC (Reinforced Concrete) refers to the mix of concrete and rebar which works together to resist the load imposed on the structure. Rebar is ductile in nature which provides strength & flexibility to the structure enhancing its capacity of withstanding inelastic deformations[4].

Among various factors affecting the seismic design of the building, the site-soil condition is the prominent one[5]. The soil at the site needs to be considered for the seismic design of the structure as different soil type has different level of stiffness and shear strength[6]. The site soil condition affects the time period of the structure which eventually impacts the base shear of the structure leading to impact the seismic performance of the structure[7]. Soft soil is more vulnerable for the construction of structures as it is more vulnerable to differential settlement, high compressibility and poor shear strength which increases the seismic hazard[8]. Linear and nonlinear, static and dynamic methods of structure analysis like equivalent static method, modal response spectrum method, time history analysis are applied to address the effect of soil type on seismic performance of the structure[9][10][11].

According to Nepal Building Code NBC105:2020 the soil is classified as soil type A, B, C, and D on the basis of shear strength and SPT value for which elastic response spectra has been defined. From the elastic spectrum for each soil type, it is evident that the spectral acceleration is constant for a certain time period [12]. The softer the base soil, the more will be the amplification of the earthquake shock waves[13]. As the seismic wave passes through the soft soil, its magnitude amplifies which increases the extent of damage to the structure. This phenomenon of magnitude amplification is called site amplification[14].According to the composition and mechanical properties, soil type exhibits different seismic response characteristics. For instance, soft soil like clay and silt have lower shear strength and high compressibility which leads to the amplification of ground motions due to earthquakes. On the other hand, stiff soil like sand and gravel has high shear strength and low compressibility, which reduces the seismic amplification and helps in dissipating the seismic energy[15].Even for the isolated building, spectral acceleration and spectral displacement are maximum in soft soil i.e., soil type -D[16].

Many researchers have investigated the effect of soil type on the seismic design of structures such as buildings, bridges, dams, and retaining walls. Soil liquefaction is a major concern in earthquake engineering since it can lead to significant damage to structures. Soil liquefaction occurs when the strength and stiffness of soil are lost after being subjected to cyclic loading caused by an earthquake and it is more common in loose, saturated soils, such as sandy and silty soils. Studies have revealed that the dynamic stiffness, damping ratio and shear modulus of the soil is strongly influenced by the amplitude and frequency of applied stress[17]. Soil amplification is occurred when the soil properties affect the intensity and duration of the seismic waves as they reach the ground surface. According to Kuo et al., [18] the building experience varying level of seismic movement depending upon their location on site, soil structure and their height.

Although numerous studies have been carried out regarding the effect of soil type on seismic performance of the structure, it was found that Modal Response Spectrum Method (MRSM) with reference to NBC105:2020 has not been applied yet. Findings obtained with respect to the use of national building code can be applicable practically. Therefore, this study aims to quantify the variations occurring in seismic design of the structural components (beam, column and slab) due to the changes in site soil type for a particular building type. A moderately high-rise building with a higher fundamental time period is considered in this study for the analysis as the effect is visible in high rise building and negligible in low rise building.

2. Methodology

A representative twelve storey office building is taken into account for seismic analysis. Numerical modelling of the building is done for four different soil types namely soil type-A, soil type-B, soil type-C and soil type -D as per NBC 105:2020 in finite element software SAP 2000. The seismic load is calculated with reference to NBC 105:2020 and the building is analyzed by linear static and response spectrum method. The building was first analyzed without changing the size of structural components to observe the effect of soil type only on base shear of the building and then it was analyzed with variation in size of structural components as per the safety requirement in different soil types. The building in soil type A is considered as the base building and the variation was observed in soil type B, C and D with respect to A. Horizontal earthquake loading in X & Y direction are taken into consideration for design. The reinforcement percentage is confined to less than 1% in beams and in the range of 0.8% to 3% in columns. Structural elements are designed following the requirements of IS 456:2000 and NBC105:2000. The building details used for the study is summarized in Table 1.

a) Location	Kathmandu
b) Type of the building	Office Building
c) Structural System	Moment resisting framed system
d) Seismic Zoning Factor	0.35
e) No. of storey	Double basement+(G+11) storey+ stair cover
f) Dimension of the building	Maximum length=25.2 m Maximum breadth=33.65 m
g) Type of staircase	Open well
h) Floor height	Lower Basement=3.4m Upper Basement = 2.85m Typical =3.75 m
i) Floor area	Lower basement= 847.35 m^2 Upper basement= 847.50 m^2 Ground floor to 1st floor = 773.45m^2 2nd floor = 759.43 m^2 3rd to 11th floor = 795.25 m^2 Top floor = 795.25 m^2
j) Wall	Brick masonry wall

Table 1 -Building Details

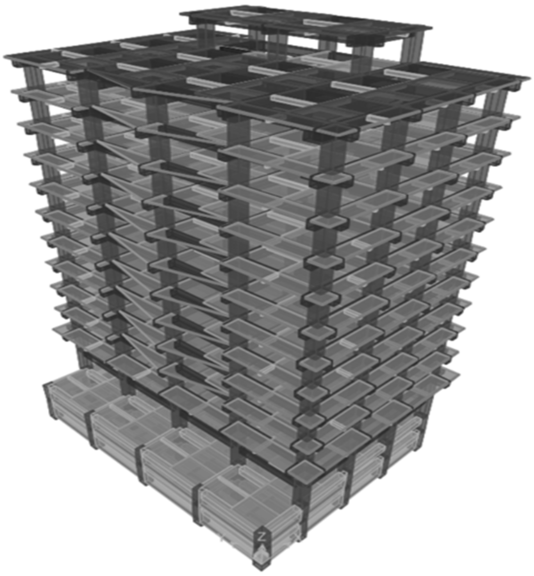

Figure 1- 3D model of the Building

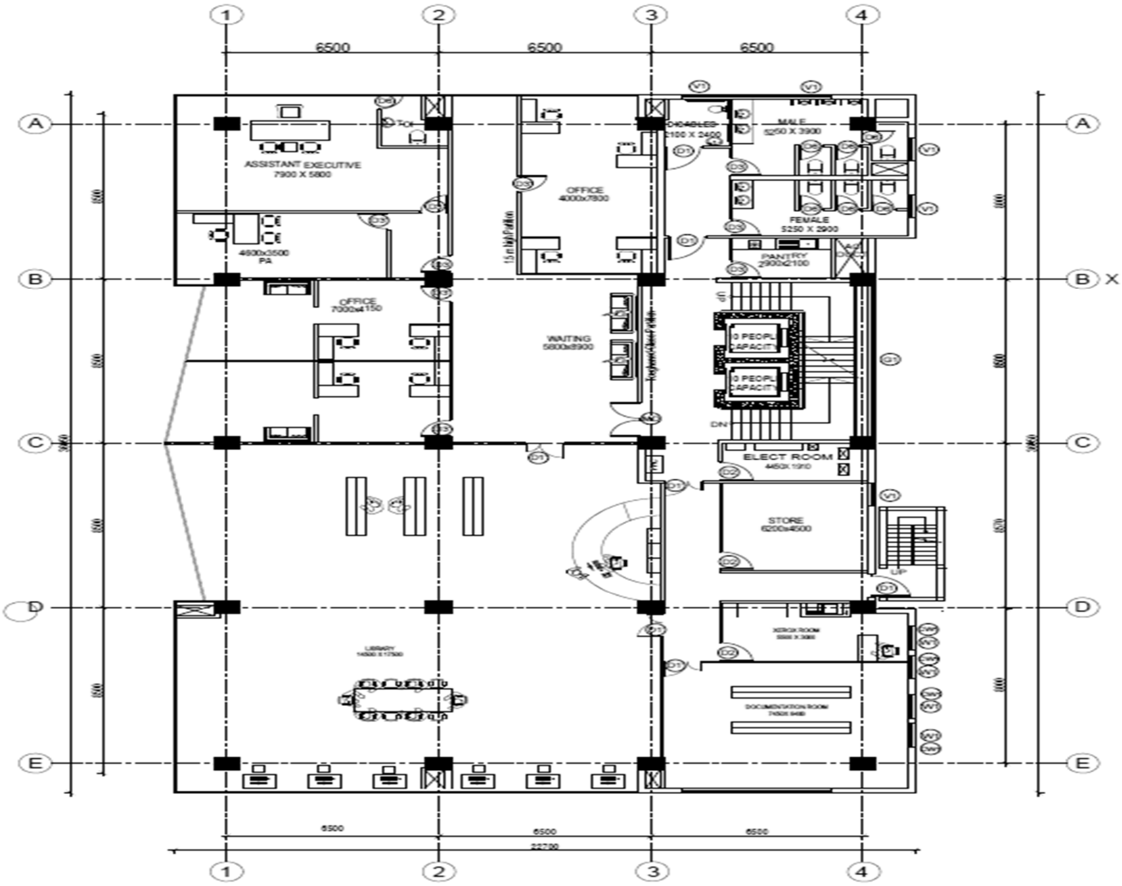

Figure 2 -Typical Building Plan

3. Result and Discussion

3.1 Size of structural elements

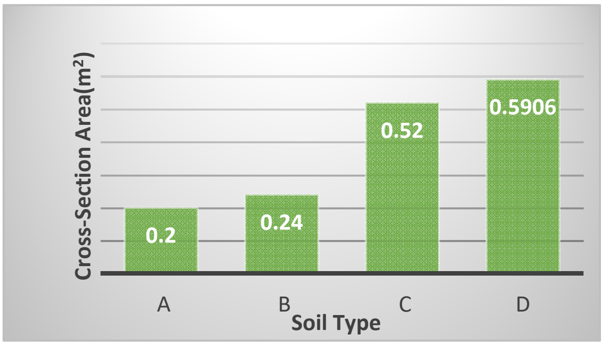

Figure 3- Beam Size Requirement

Soil Type	Beam Size(mm^2)
A	500×400
B	600×400
C	800×650
D	875×675

Table 2- Beam Size Requirement

From the bar chart above, it is clear that the required beam size is minimum in soil type-A and maximum in soil type-D.

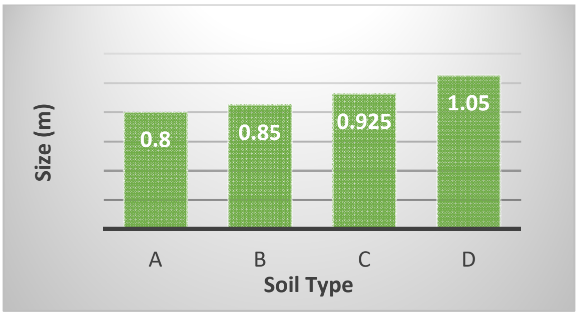

Figure 4- Column Size Requirement

Soil Type	Column Size(m)
A	0.8
B	0.85
C	0.925
D	1.05

Table 3- Column Size Requirement

The above bar chart shows that the column size requirement is maximum for soil type-D and minimum for soil type-A.

3.2 Base Shear in the Buildings

Base shear variation was analyzed for ultimate limit state (ULS) and serviceability limit state (SLS) in two different conditions:

1. When size of the structure is constant and soil type is varied.

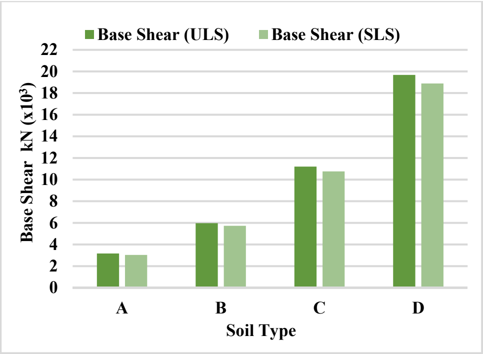

Figure 5- Base Shear Variation with Change in Soil Type

Soil Type	Base Shear (ULS) (x10^3)	Base Shear (SLS) (x10^3)
A	3.1657	3.0338
B	5.9718	5.7319
C	11.2001	10.7564
D	19.6782	18.8867

Table 4- Base Shear in Buildings

Above bar chart suggests that the base shear is maximum in soil type-D and minimum in soil type-A when the soil type is varied for same structure.

2. When size of the structure and the soil type both are varied.

Soil Type	**Eqx (ULS) (analysis) (10^3)**	**Eqx (ULS) (Design) (10^3)**	**Eqx (SLS) (analysis) (10^3)**	**Eqx (SLS) (Design) (10^3)**
A	3.1657	3.1657	3.0338	3.0338
B	5.9718	5.9718	5.7319	5.9715
C	11.2001	13.9662	10.7564	13.4075
D	19.6782	26.3810	18.8867	25.3200

Table 5- Base Shear Comparison with size variation and no size variation

The above table shows the variation in base shear when the size is constant in different soil type and when the size is different in different soil type in ULS & SLS.

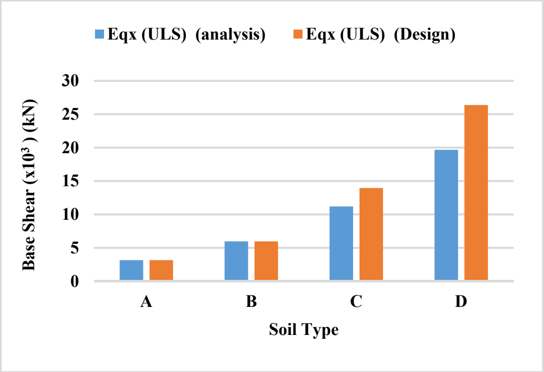

Figure 6- Base Shear Comparison in ULS

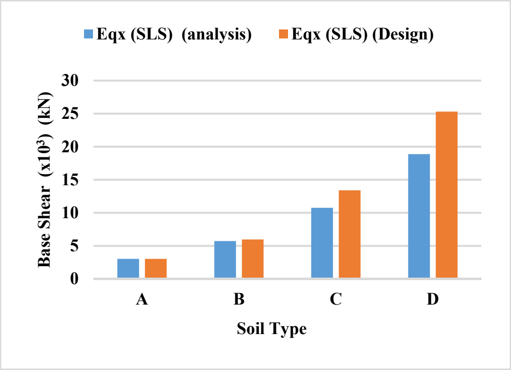

Figure 7- Base Shear Comparison in SLS

Here, soil type-A is considered as a reference. From the above graphs, it is evident that the base shear increases with increase in weight of the structure and found to be maximum in soil type D and minimum in soil type A.

Here, analysis refers to the base shear when size is constant and design refers to the base shear when size is varied.

3.3 Storey Shear Comparison

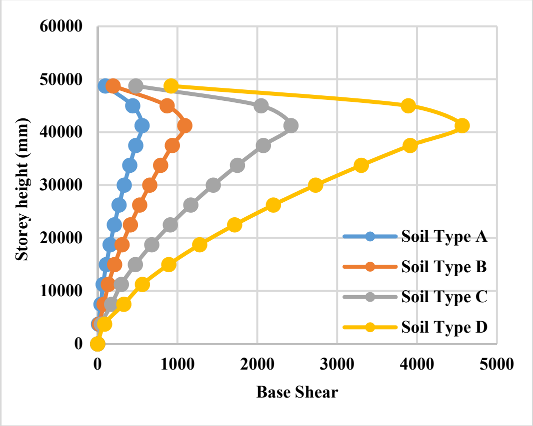

Figure 8- Storey Shear Variation in ULS for Eq_x

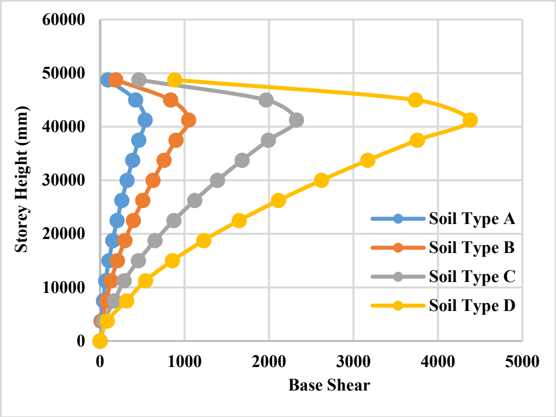

Figure 9- Storey Shear Variation in SLS for Eq_x

From the above graph, it can be concluded that the base shear is maximum in 11th floor at the height of 41.25m from the ground level.

It was found that the base shear is equal in X & Y direction.

3.4 Storey displacement comparison

The graph below represents the comparison of displacement in each storey for soil type A, B, C & D.

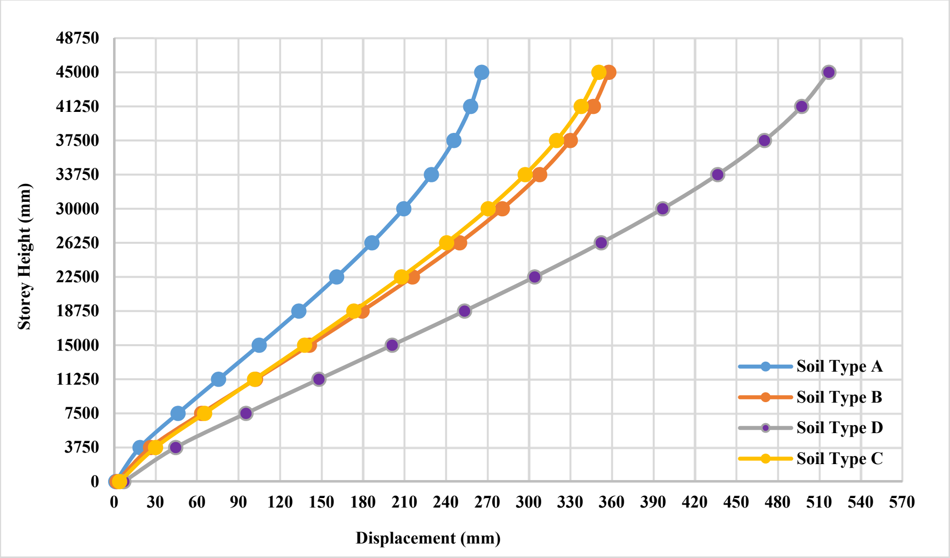

Figure 10- Displacement Comparison in ULS for Eqx

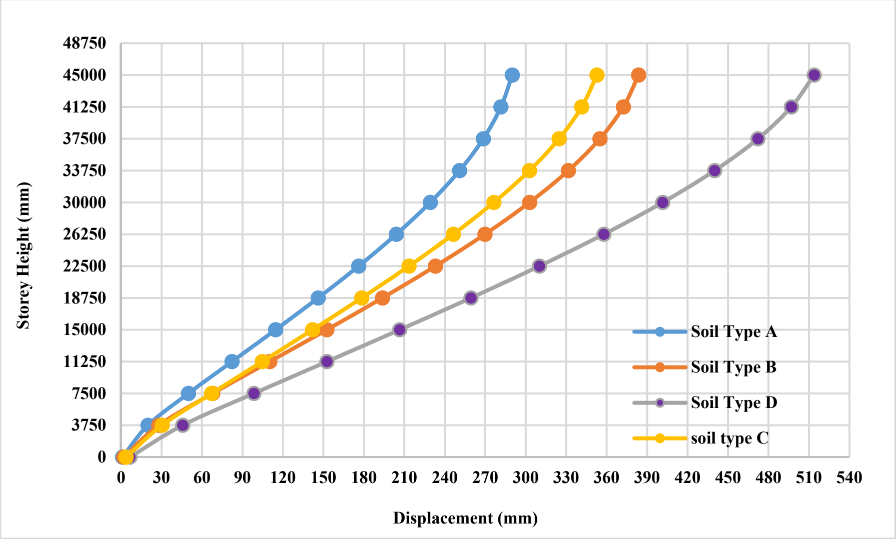

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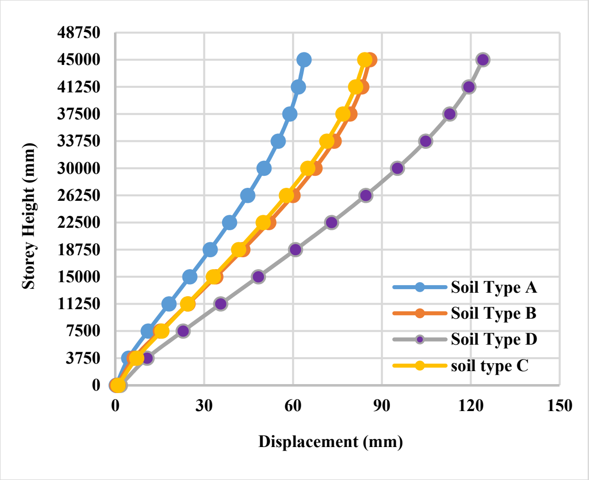
Figure 11- Displacement Comparison in ULS for Eq_y



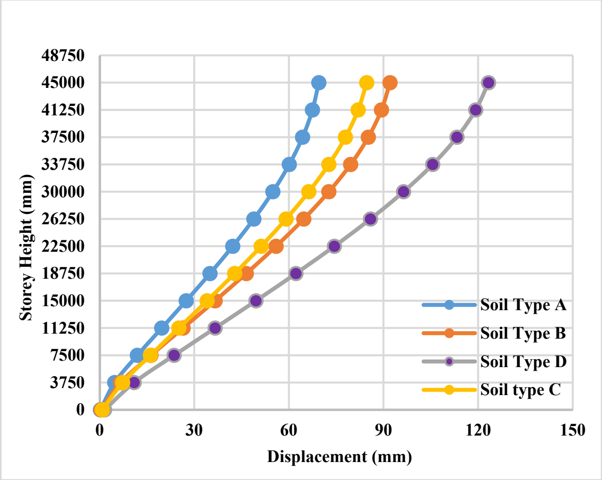
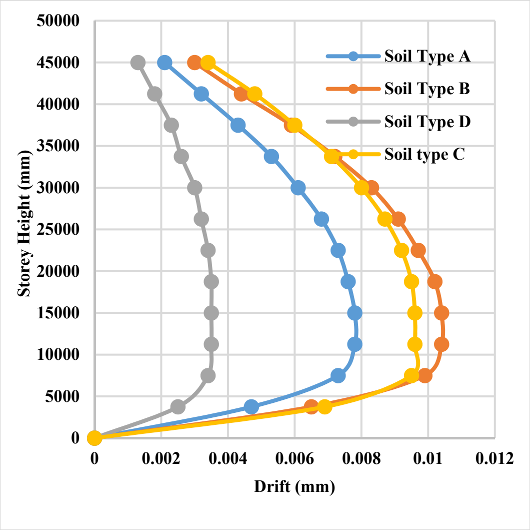


Figure 12 -Displacement Comparison in SLS for Eq_x

Figure 13 - Displacement Comparison in SLS for Eq_y

3.5 Inter-Storey Drift Comparison

Following graph represents the variation in inter-storey drift in ULS and SLS for earthquake loading in X & Y axis. Inter- storey drift should not exceed 0.025 at ultimate limit state and 0.006 at serviceability limit state. From the analysis, it was observed that the inter-storey drifts are within limit.



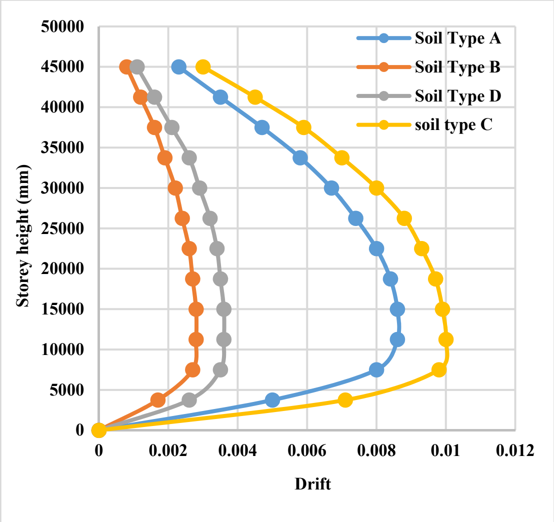
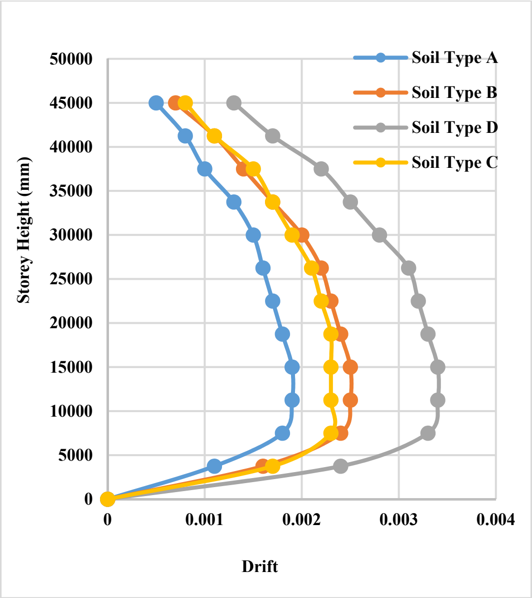


Figure 14- Inter- storey drift in ULS for Eq_x

Figure 15- Inter-Storey Drift in ULS for Eq_y



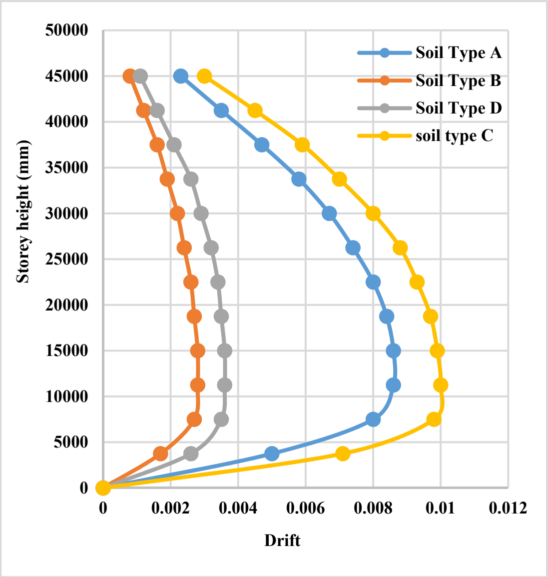


Figure 16- Inter-Storey Drift in SLS for Eq_x

Figure 17- Inter- storey Drift in SLS for Eq_y

4. Conclusion and Recommendations:

According to the study, soil type D is found to be most vulnerable in comparison to A, B and C whereas the soil type A is most suitable for safe seismic design for the case of moderately tall building. The base shear is maximum in soil type D and minimum in soil type A and hence the size of the structural components are in soil type D and goes on decreasing for the soil type C, B and A. The size of beam was found to be 500x400mm^2, 600x400mm^2, 800x650mm^2 and 875x675mm^2 in soil type A, B, C and D respectively. Similarly, the column size was found to be 800x800mm^2, 850x850mm^2, 925x925mm^2 and 1050x1050mm^2 in soil type A, B, C and D respectively. The storey displacement goes on increasing with the increase in height of the structure and was found to be maximum in top storey in soil type D.

This observation definitely shows that the seismic design of tall building is safer and economical in soil type A and vulnerable in soil type D. To improve the seismic performance of the structure in soil type B, C and D, various soil improvement techniques can be adopted. The recommendation is made on the study of one particular structure height. To quantify the effect, it is advisable to analyze the building of different storey.

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