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Seismic Performance of A Building Under Different Soil Type as Classified on NBC105-2020 In Plain and Sloping Ground

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Abstract- Nepal is susceptible to the potential damage that earthquakes may cause as it is located in a seismically active region. As seen by historical events, Nepal has had a number of devastating earthquakes that have destroyed homes, claimed many lives and damaged properties. This study presents a comparative seismic analysis of a multistoried reinforced concrete building situated on both plain and sloping ground under varying soil conditions, as classified by the Nepal National Building Code (NBC 105:2020). The primary objective is to assess the structural response of the building to seismic forces when subjected to different site conditions and to evaluate the influence of ground slope on seismic behavior. A regular building model was analyzed using response spectrum analysis as per NBC provisions. Key parameters such as base shear, story displacement and story drift, were examined. Results indicate that both soil type and ground slope significantly affect the seismic performance of the structure, with buildings on soft soil and sloped ground showing greater vulnerability. The study emphasizes the importance of considering local soil conditions and topography in seismic design to enhance structural safety and performance.

Keywords: Response spectrum, story displacement, story drift, story stiffness, base shear

I. INTRODUCTION

Nepal is situated in the central part of the Himalaya, which is one of the seismically most active zones in the world. Earthquakes in the Himalaya result from the cycle release of elastic stress accumulating continuously at a rate of about 2cm a year. Nepal has witnessed several mega-quakes, with magnitude above 8, and thousands of smaller earthquakes. The Kathmandu valley has been reportedly destroyed several times by destructive earthquakes in the past. The 2015 Mw 7.8 Gorkha Earthquake is the most recent destructive event in Nepal, which killed about 8979 people and injured hundreds of thousands. Small earthquakes ($Mw<4.0$) occurs every day but they are not strong enough to cause loss of lives and property. Great ($Mw \geq 8$) as well as major ($8.0>Mw>7.0$) earthquakes occur infrequently but can have a tragic impact on people and society as a whole. Earthquakes cannot be predicted reliably; therefore proper assessment of seismic hazard is important. Such assessment provides information, which is required in construction practices, national level planning, national level policy making and insurance policies and so on.

Among various factors affecting the seismic design of the building, the site-soil condition is the prominent one. 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. 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. 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. 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.

From the elastic spectrum for each soil type, it is evident that the spectral acceleration is constant for a certain time period. The softer the base soil, the more will be the amplification of the earthquake shock waves. As the seismic wave passes through the soft soil, its magnitude amplifies which increases the extent of damage to the structure. 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. Even for the isolated building, spectral acceleration and spectral displacement are maximum in soft soil i.e., soil type –D.

Some studies also indicate that depending upon the soil conditions of underlain strata, a second amplified frequency is locally revealed, which can play an important role in creating a resonance with the structures built over the ground during an earthquake.

Prediction of earthquakes, till now, is not possible. However, its effects can be minimized by assessing the probability of occurrence of large earthquakes and their probable effects in advance and working out the reduction of earthquake vulnerability. The preparation of a seismic hazard map of an area and the identification of the site-specific response of a ground motion during earthquake could be the fundamental step in mitigating the earthquake risk.

The earth's land surfaces aren't uniform, some of the earth is covered in hard rock, some of it in dense soil, and some of it in soft soil. Studies have shown that these two geologic characteristics have a large impact on the levels of ground shaking during an earthquake i.e. softness of rock or soil and total thickness of sediments above the bedrock. An earthquake's effects vary with the softness of the sediment. Seismic waves that travel through the ground move faster through hard rock than soft soil - when waves transition from hard to soft earth, they increase in amplitude (or size). A bigger wave causes stronger shaking.

The same principle also applies to sediment thickness. The deeper the sediment layer above bedrock, the more soft soil there is for the seismic waves to travel through. Soft soil means bigger waves and stronger amplification. In short, the softer and thicker the soil, the greater the shaking or amplification of waves produced by an earthquake. As a result, building damage tends to be greater in areas of soft sediments or deep basins.

Nepal has wide range of soil type from Terai to Himalayas .NBC 105-2020 has classified the site soil type in 4 category i.e. Soil type A , soil type B, soil type C and soil type D on the basis of shear strength and SPT value for which elastic response spectra has been defined. The seismic analysis parameter may differ due to the different soil type. As a result, two points located the same distance from an earthquake's epicenter can experience significantly different effects.

The economic growth & rapid urbanization in hilly region has accelerated increase in population density in the hilly region enormously. Therefore; there is popular & pressing demand for the construction of multi-storey buildings on hill slope in and around the cities. In some parts of Nepal, hilly region is more prone to seismic activity. . In hilly regions, locally available traditional material like, the adobe, brunt brick, stone masonry and dressed stone masonry, timber reinforced concrete, bamboo, etc., is used for the construction of houses. Since, the behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings, both of which vary in case of hilly buildings with irregularity and asymmetry due to step back frame and step back & set back frame configuration.

Hill buildings constructed in masonry with mud mortar or cement mortar without conforming to seismic codal provisions have proved unsafe and resulted in loss of life and property when subjected to earthquake ground motions. It is observed during the past earthquakes, buildings in hilly regions have experienced high degree of damage leading to collapse though they have been designed for safety of the occupants against natural hazards. Hence, while adopting practice of multistory buildings in these hilly and seismically active areas, utmost care should be taken for making these buildings earthquake resistant.

II. RESEARCH METHODOLOGY

Seismic analysis of buildings is crucial for understanding how they behave during earthquakes, especially under different soil types and in varying topographies, such as sloping grounds. Based on the NBC 105: 2020, here's a methodology that addresses seismic analysis of buildings under different soil types and sloping grounds.

1. Review of various literature related to research topic.
2. Seismic Analysis Methodology
    a. Structural Model Development
    b. Selection of Seismic Analysis Method i.e. Equivalent Static Method, Response Spectrum Method, Time History Analysis

c. Response Spectra Generation
d. Load Combinations and Seismic Forces
3. Building Modal on Sloping Ground and varying soil type
4. Seismic Analysis and Results Interpretation
5. Design Modifications
6. Report and Documentation

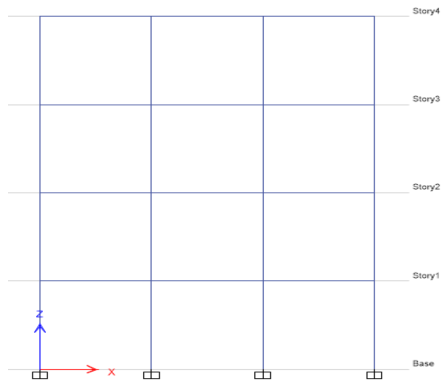
2.1 Explanation of methodology

a) Identify the problem
There is a lack of comprehensive understanding of how buildings perform seismically on different NBC 105:2020 soil types, especially when comparing plain ground to sloping ground conditions. This gap leads to challenges in choosing safe, cost-effective design strategies for buildings in varied terrain and soil conditions, common throughout Nepal.
b) Set research question and objective
After the problem identification, the objectives of the study was set with some research question.
c) Literature review
This step involves reviewing existing research, journals, papers, articles and guidelines relevant to this topic.
d) Modelling of structure
Structure are modeled using ETABS software on different slope i.e. 10 degree, 20 degree, 30 degree and 40 degree slope and in plain ground .Building on each slope was again modelled on different soil type as per NBC 105: 2020 .Thus 20 model prepared for this study.
e) Analysis of structure
Out of several method of seismic analysis, response spectrum method of analysis was used in this study.
f) Evaluation of different seismic parameter
After the model fulfill the design criteria, different seismic parameter such as displacement, drift and base shear were evaluated.
g) Result comparison and suggestions
The results are compared with each other and suggestion are provided for the improvement.

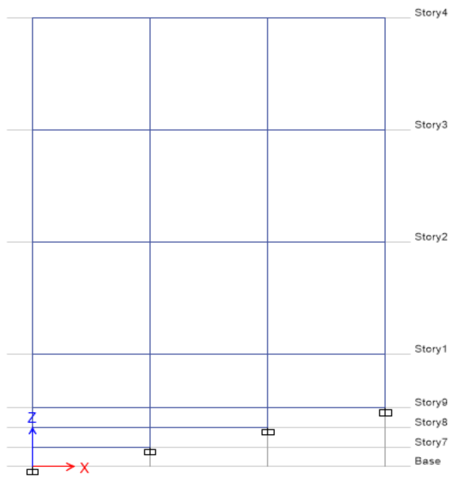
2.2 Description of Building

The building details used for the study is summarized below:-
a) Grade of concrete=M25
b) Grade of steel =HYSD-500
c) Type of Building =Residential Building
d) Height of building =12m
e) Dimension of Building = Along X-axis-9m and along Y axis – 7.5m
f) Structural System = Moment resisting framed Structure
g) Beam size= (300*400)mm
h) Column size = (500*500)mm
i) Slab thickness = 150mm

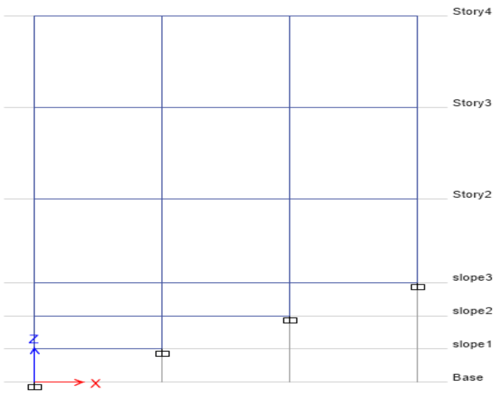
In this study 5 model of Moment resistant RCC building is selected situated in varying slope i.e plain ground, 10 degree, 20 degree, 30 degree and 40 degree slope. These all model are analyzed by Response spectrum method of analysis. The result for Drift, Displacement, and Base shear are taken for further analysis. Similarly, these all model are analyzed in different soil type as classified in NBC 105:2020 i.e soil type A , soil type B, soil type C and soil type D by Response spectrum method of analysis. The models are shown below:



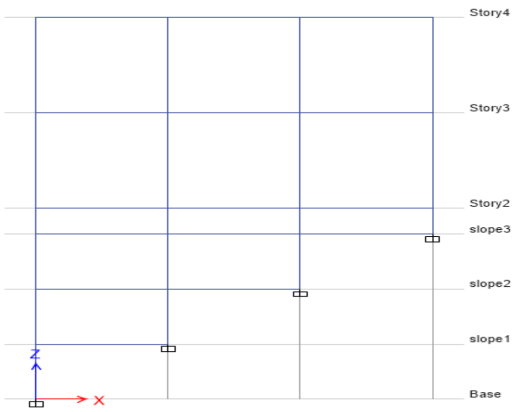
Model 1: Building in plain ground



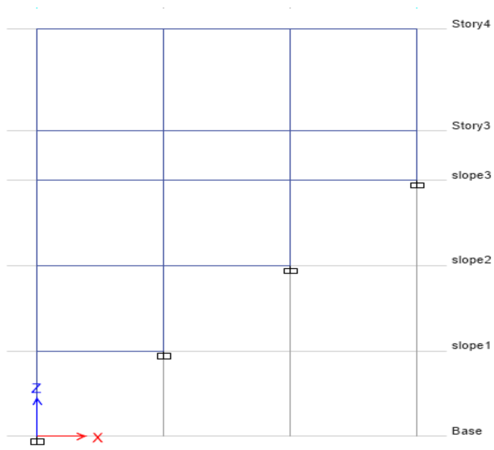
Modal 2:- Building in 10 degree slope



Modal 3:-Building in 20 degree slope



Modal 4:-Building in 30 degree slope

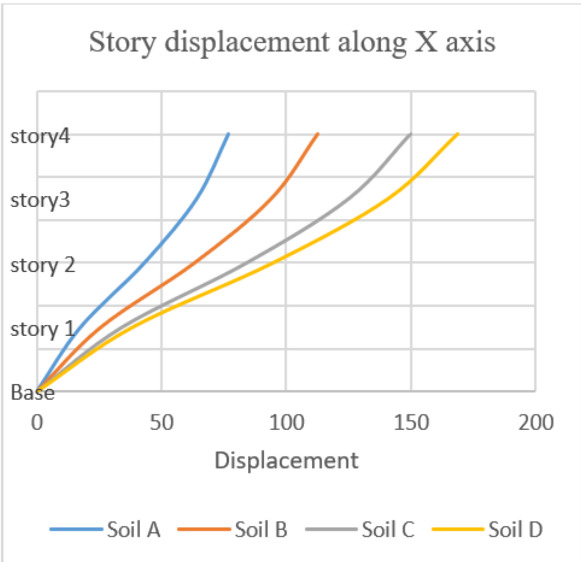


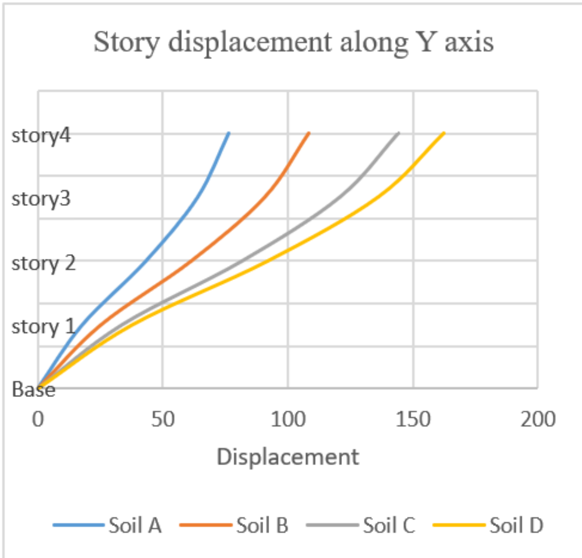
Modal 5:-Building in 40 degree slope

III. RESULT AND DISCUSSION

These models were analyzed by using response spectrum analysis on ETABS software as per NBC 105:2020. Considering the seismic parameters story displacement, story drift and story shear various results were obtained which are shown below.

3.1 Story Response of a building in a plain ground under different soil type





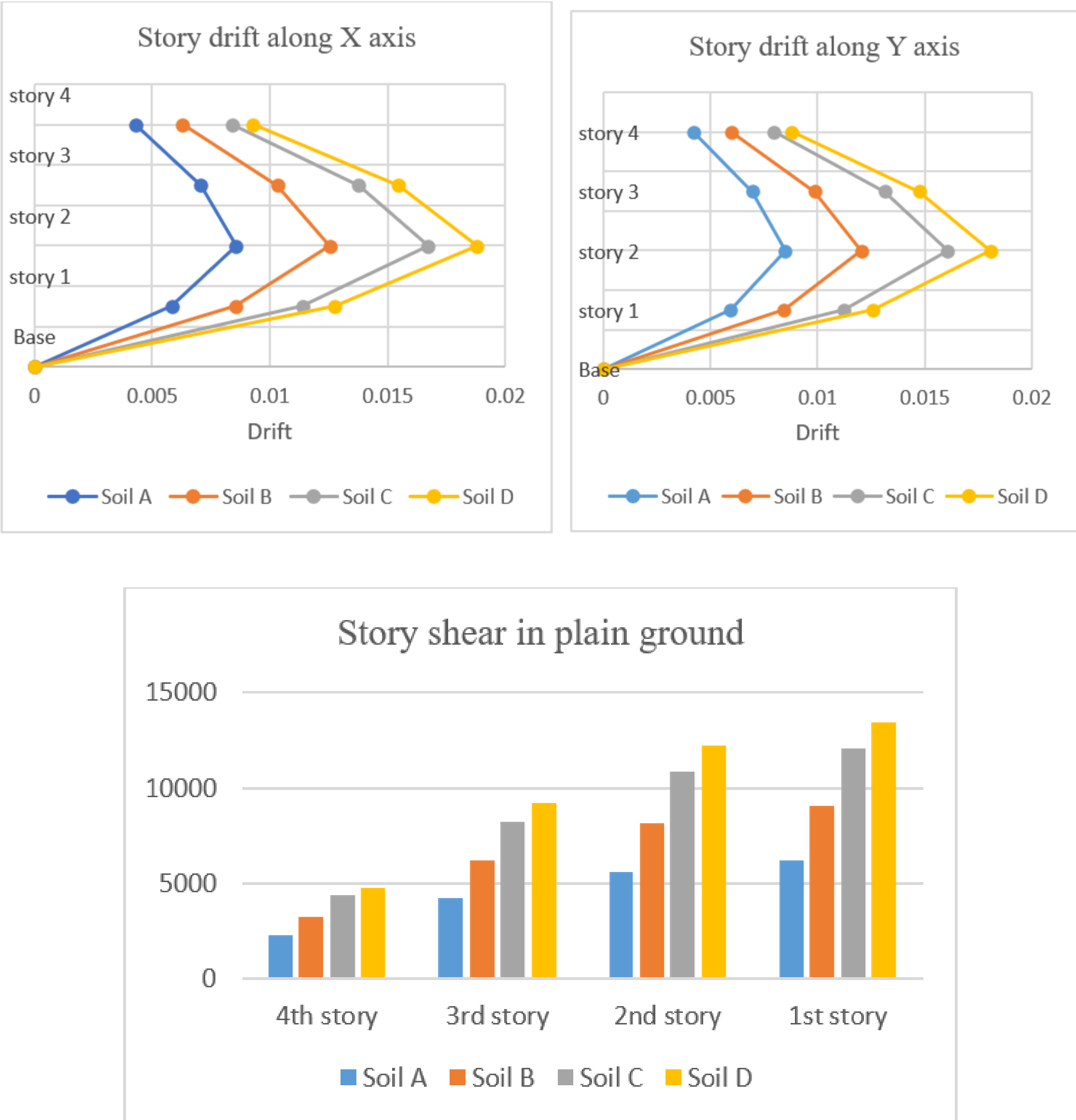
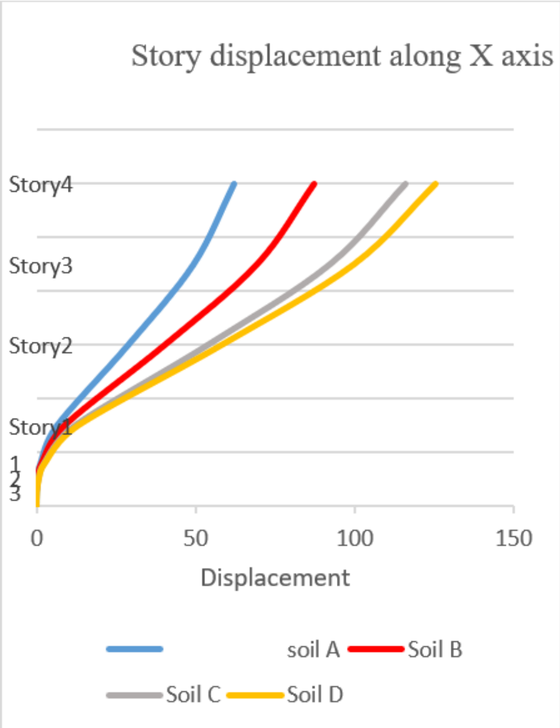
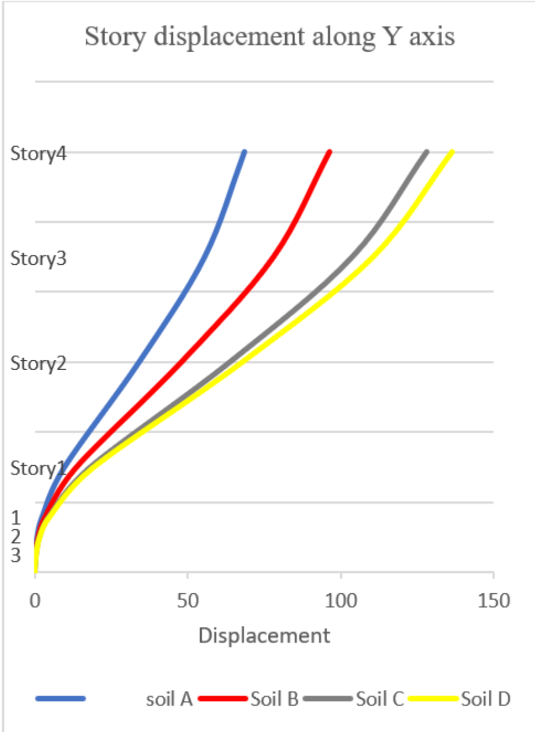


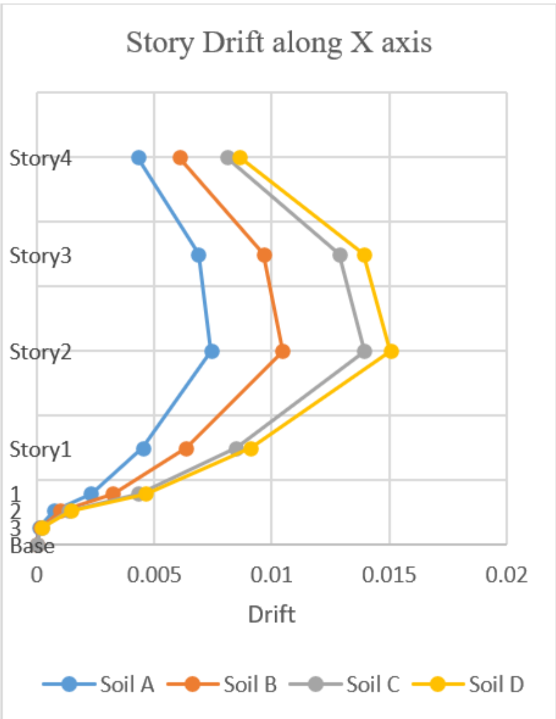
Figure 1: Comparison of story displacement, drift and base shear for a building in plain ground for EQX and EQY.

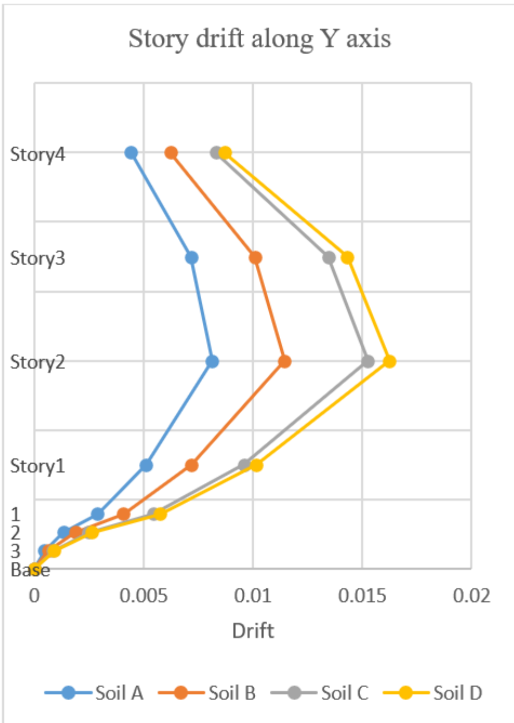
From the figure1, it is observed that the maximum story displacement occurs in soil type D. For soil type C the top story displacement decreases by 11.034%, for soil type B 33.27% and for soil type A the story displacement decreases by 54.41% as compared to displacement for D type soil .Similarly the story drift is also maximum for soil type D. For soil type C the story drift deceases by 9.76%, for soil type B 32.32% and for soil type A the story drift decreases by 53.67% as compared to drift for D type soil. Similarly the story shear is also maximum for soil type D. For soil type C the story shear deceases by 8.01%, for soil type B 31% and for soil type A the story shear decreases by 52.65% as compared to story shear for D type soil.

4.2 Story Response of a 10 degree sloping building under different soil type









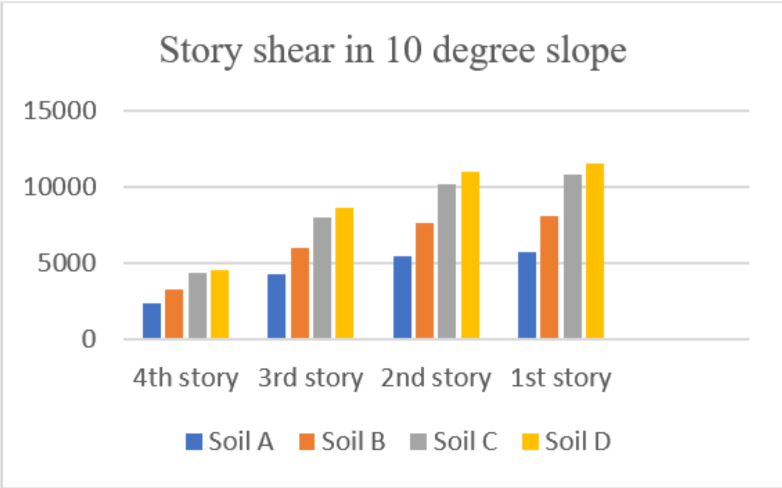
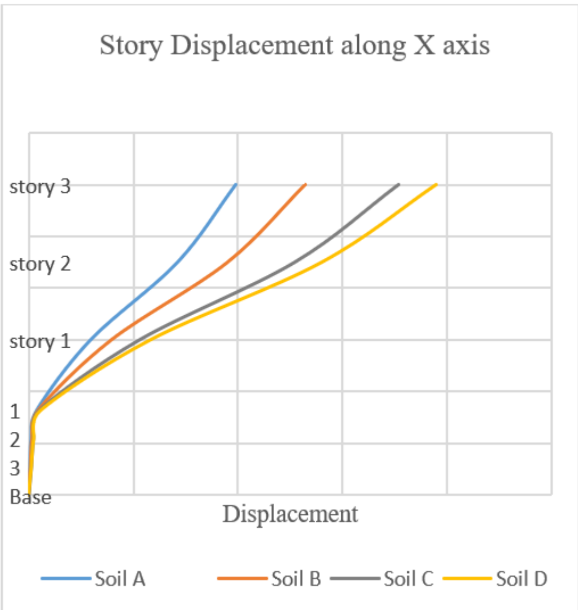


Figure 2: Comparison of story displacement, drift and base shear for a building in 10 degree slope ground for EQX and EQY.

From the figure 2, it is observed that the maximum story displacement occurs in soil type D. For soil type C the top story displacement decreases by 7.41%, for soil type B 30.56% and for soil type A the story displacement decreases by 50.62% as compared to displacement for D type soil .Similarly the story drift is also maximum for soil type D. For soil type C the story drift deceases by 6.29%, for soil type B 29.72% and for soil type A the story drift decreases by 50% as compared to drift for D type soil. Also, the story shear is also maximum for soil type D. For soil type C the story shear deceases by 4.42%, for soil type B 28.31% and for soil type A the story shear decreases by 49% as compared to story shear for D type soil.

3.3 Story Response of a 20 degree sloping building under different soil type



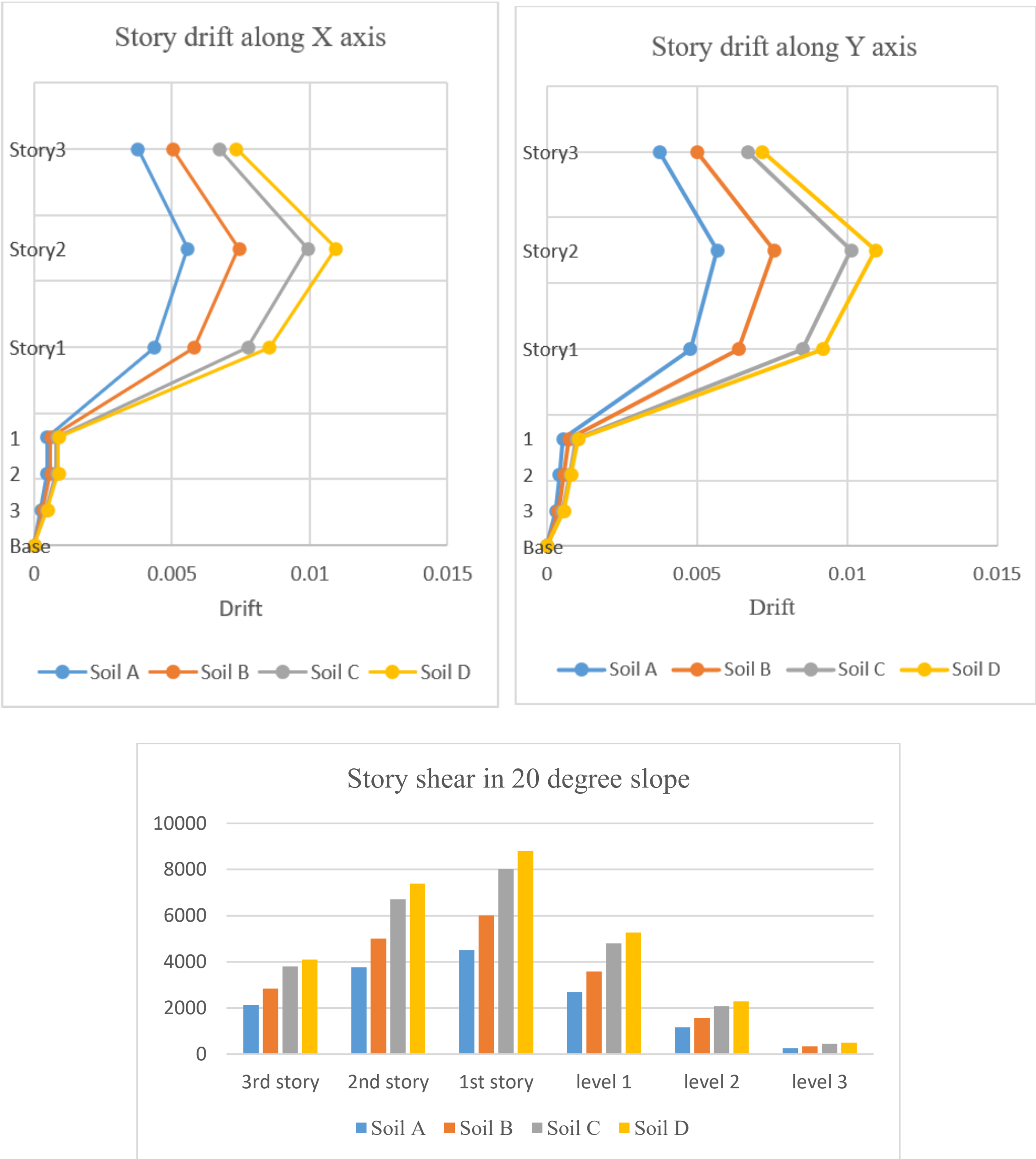
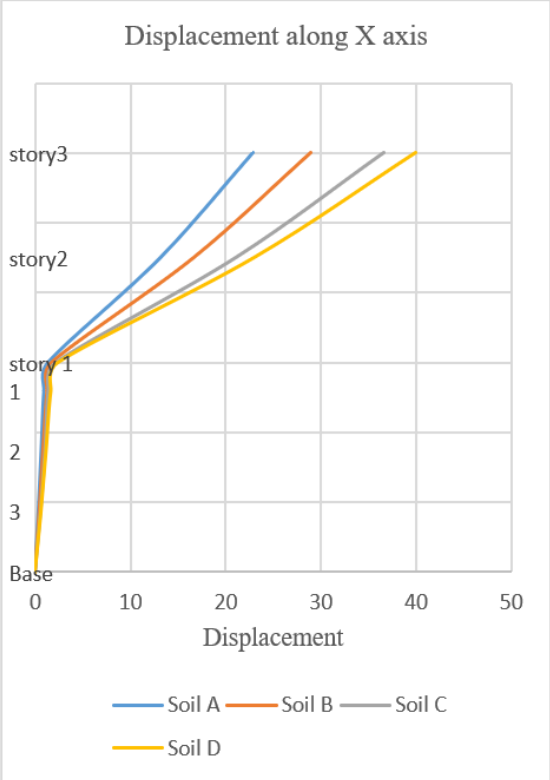
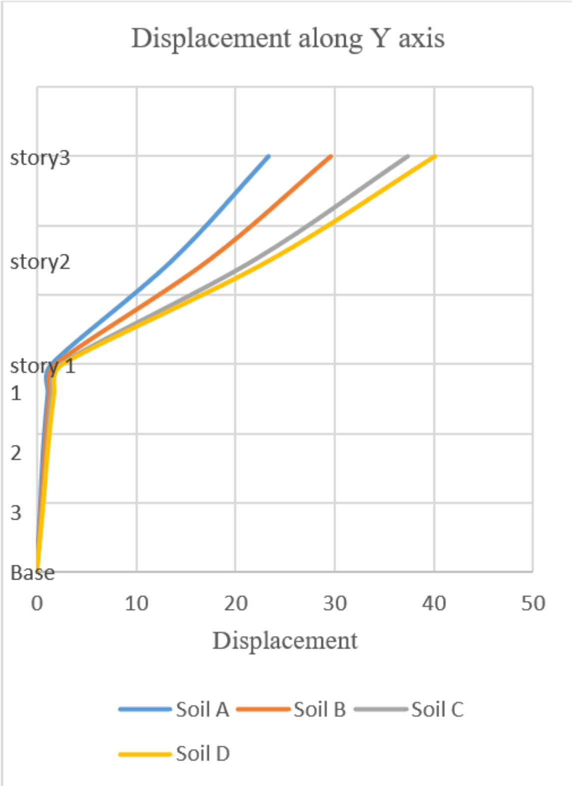


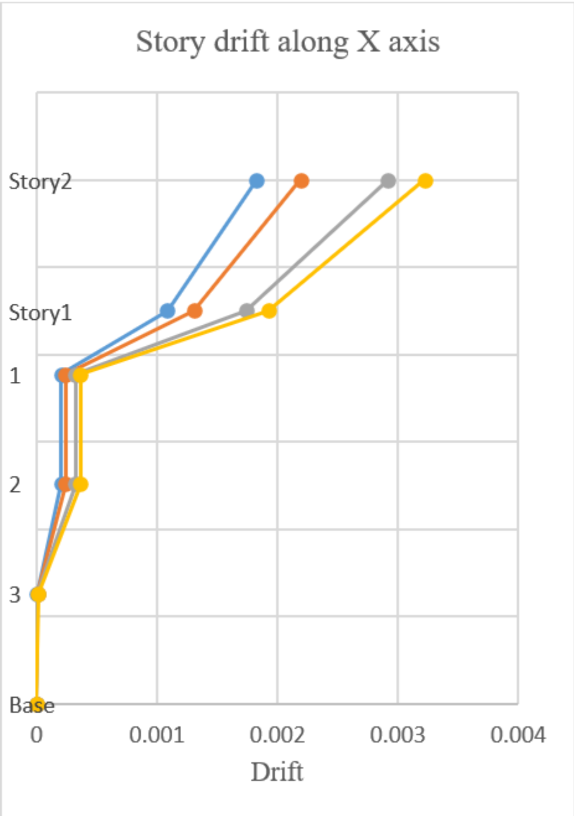
Figure 3: Comparison of story displacement, drift and base shear for a building in 20 degree slope ground for EQX and EQY.

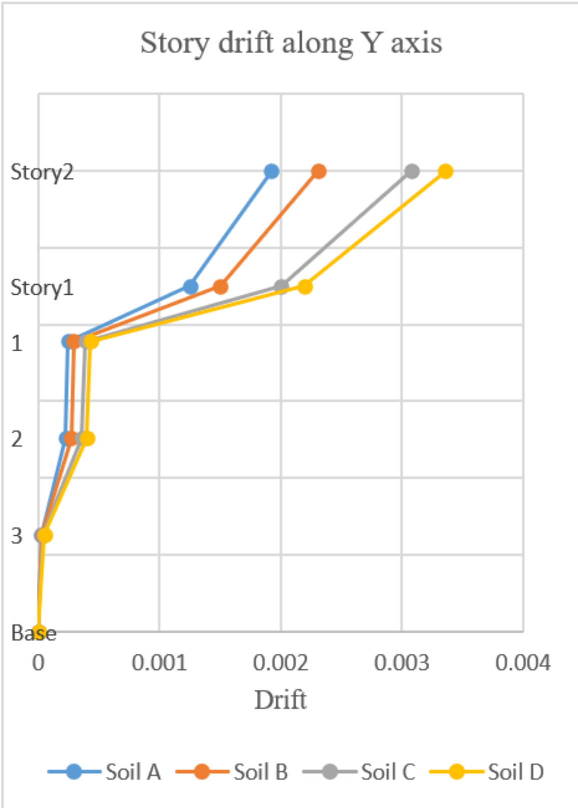
From the figure 3, in 20 degree sloping building, it is seen that the minimum story displacement occurs in soil type A. For soil type B the top story displacement increases by 33.33% as compared to soil A, for soil type C 33.74% as compared to soil B and for soil type D the story displacement increase by 10.18% as compared to displacement for C type soil. Similarly the story drift is also minimum for soil type A. For soil type B the story drift increases by 31.62%, for soil type C 36.28% as compared to soil B and for soil type D the story drift increases by 15.33% as compared to drift for C type soil. Similarly the story shear is minimum for soil type A. For soil type B the story shear increases by 32.65%, for soil type C it increases 78.2% as compared with B and for soil type D the story shear increases by 92.38% as compared to story shear for A type soil.

3.4 Story Response of a 30 degree sloping building under different soil type









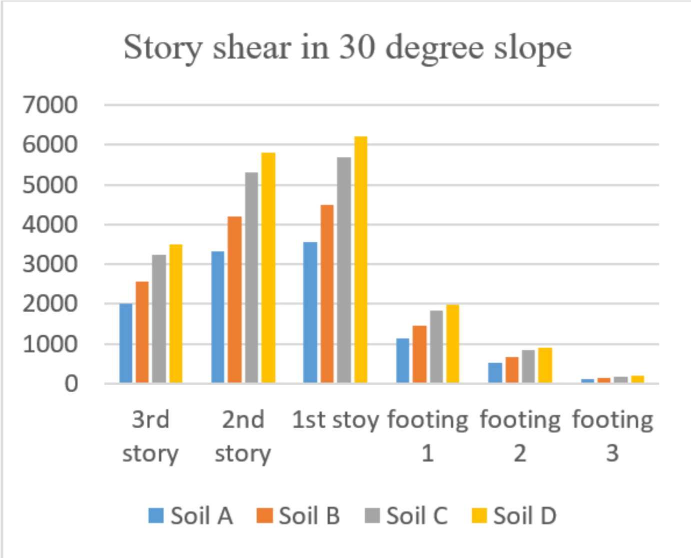
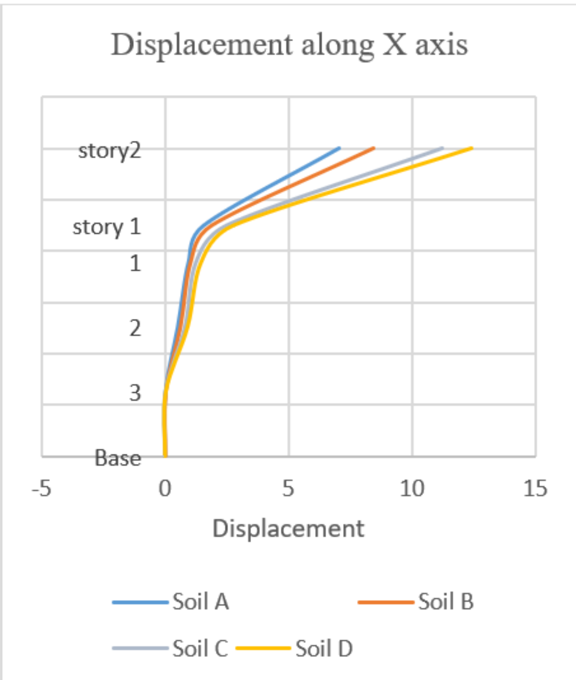
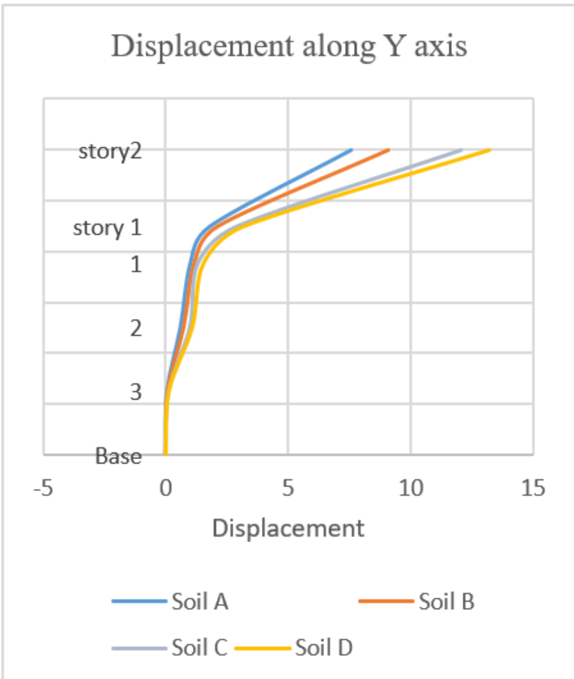


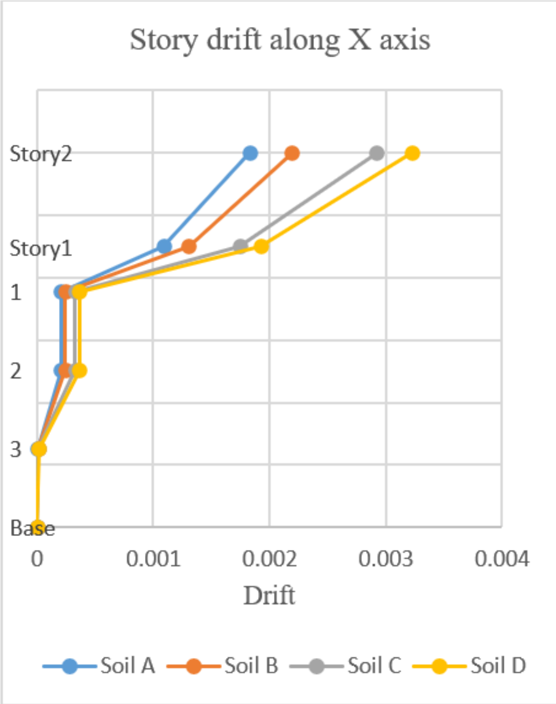
Figure 4: Comparison of story displacement, drift and base shear for a building in 30 degree slope ground for EQX and EQY.

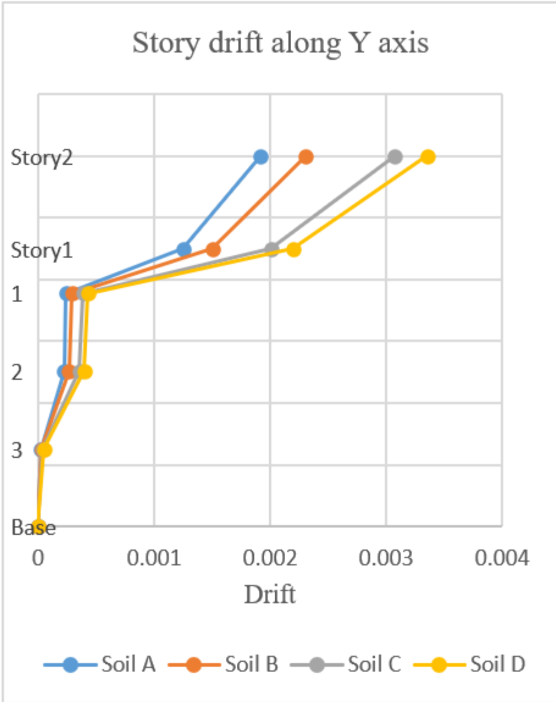
From figure 4, in 30 degree sloping building, it is seen that the minimum story displacement occurs in soil type A. For soil type B the top story displacement increases by 26.668% as compared to soil A, for soil type C 60% and for soil type D the story displacement increase by 74.56% as compared to displacement for A type soil. Similarly the story drift is also minimum for soil type A. For soil type B the story drift increases by 26.64%, for soil type C 58.87% and for soil type D the story drift increases by 72.51% as compared to drift for type soil A. Also story shear is maximum for soil type D. For soil type C the story shear decreases by 8.46%, for soil type B it decreases 27.53% and for soil type A the story shear decreases by 42.79% as compared to story shear for D type soil.

4.5 Story Response of a 40 degree sloping building under different soil type









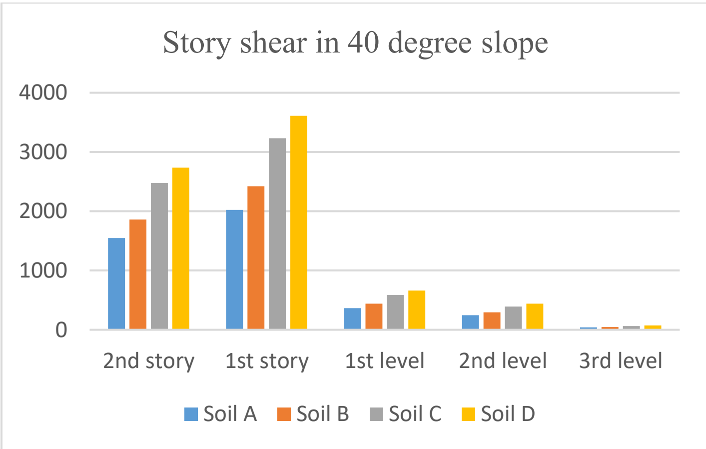


Figure 5: Comparison of story displacement, drift and base shear for a building in 40 degree slope ground for EQX and EQY.

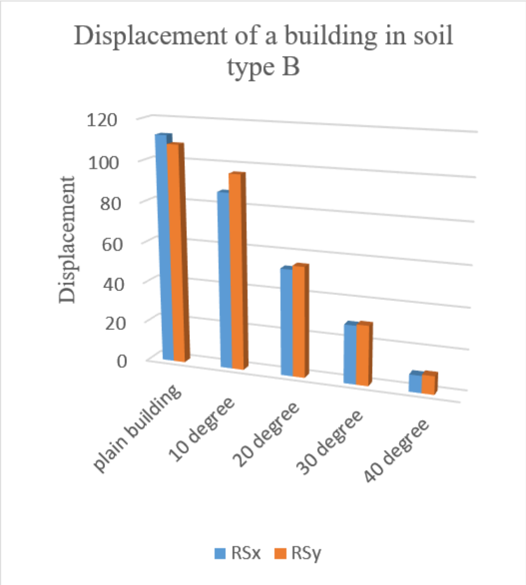
It is observed that the maximum story displacement occurs in soil type D. For soil type C the top story displacement decreases by 9.3%, for soil type B 31.97% and for soil type A the story displacement decreases by 43.31% as compared to displacement for D type soil .Similarly the story drift is also minimum for soil type A. For soil type B the story drift increases by 20%, for soil type B 60.21% and for soil type D the story drift increases by 76.45% as compared to drift for A type soil. Also, from the figure story shear is maximum for soil type D. For soil type C the story shear decreases by 10.41%, for soil type B it decreases 32.81% and for soil type A the story shear decreases by 44.01% as compared to story shear for D type soil.

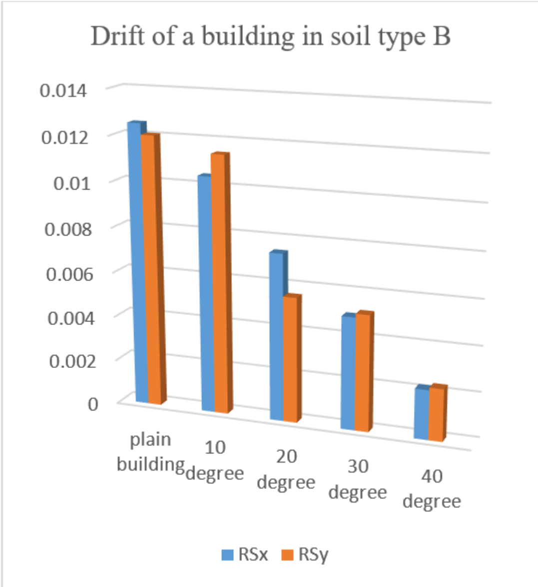
4.6 Response of a building constructed on different slope in soil type A

Figure 6: Comparison of story displacement, drift and base shear for a building in soil type A for EQX and EQY.

From figure 6, it is observed that the maximum story displacement occurs in plain building. For 10 degree building the top story displacement decreases by 19.4%, for 20 degree slope building 48.45%, for 30 degree slope building 70.25% and for 40 degree slope the story displacement decreases by 90.84% as compared to displacement for plain building. Similarly the maximum story drift occurs in plain building. For 10 degree building the top story drift decreases by 13.1%, for 20 degree slope building 35% ,for 30 degree slope building 54.28% and for 40 degree slope the story drift decreases by 78.66% as compared to drift for plain building. Also, the maximum base shear occurs in plain building. For 10 degree building the top base shear decreases by 6.85%, for 20 degree slope building 27.13% , for 30 degree slope building 42.53% and for 40 degree slope the base shear decreases by 67.311% as compared to base shear for plain building.

4.7 Response of a building constructed on different slope in soil type B





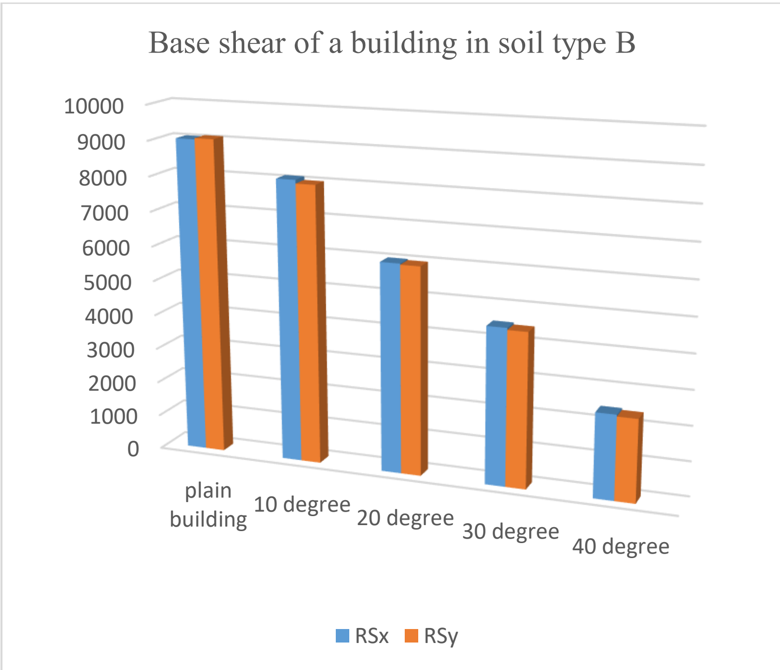
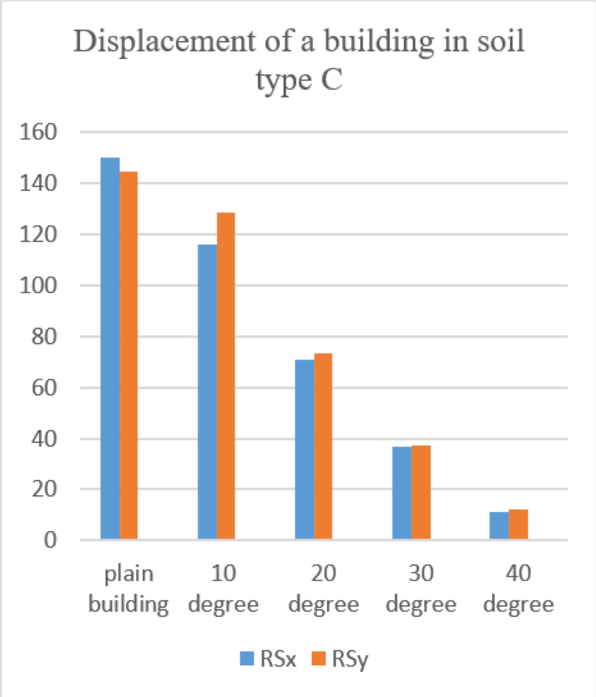
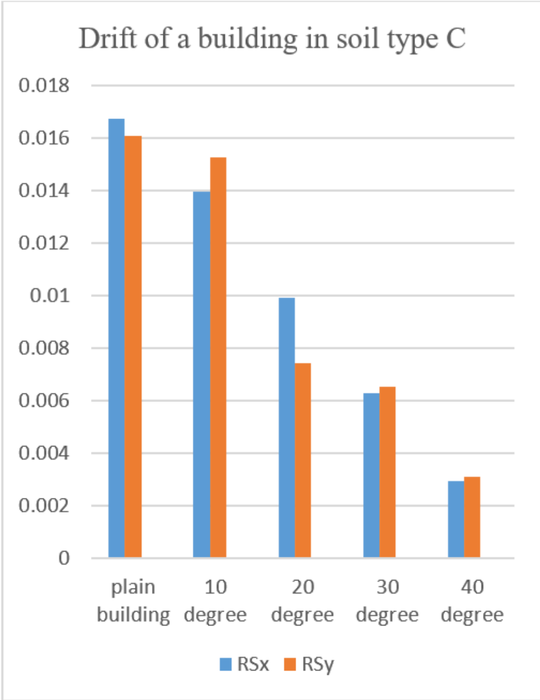


Figure 7: Comparison of story displacement, drift and base shear for a building in soil type B for EQX and EQY.

From figure 7, it is observed that the maximum story displacement for soil type B occurs in plain building. For 10 degree building the top story displacement decreases by 22.56%, for 20 degree slope building 53%, for 30 degree slope building 74.25% and for 40 degree slope the story displacement decreases by 92.49% as compared to displacement for plain building. Similarly the maximum story drift occurs in plain building. For 10 degree building the top story drift decreases by 16.57%, for 20 degree slope building 40.8% ,for 30 degree slope building 60.28% and for 40 degree slope the story drift decreases by 82.51% as compared to drift for plain building. Also, the maximum base shear occurs in plain building. For 10 degree building the top base shear decreases by 10.43%, for 20 degree slope building 33.56%, for 30 degree slope building 50.23% and for 40 degree slope the base shear decreases by 73.17% as compared to base shear for plain building.

4.8 Response of a building constructed on different slope in soil type C





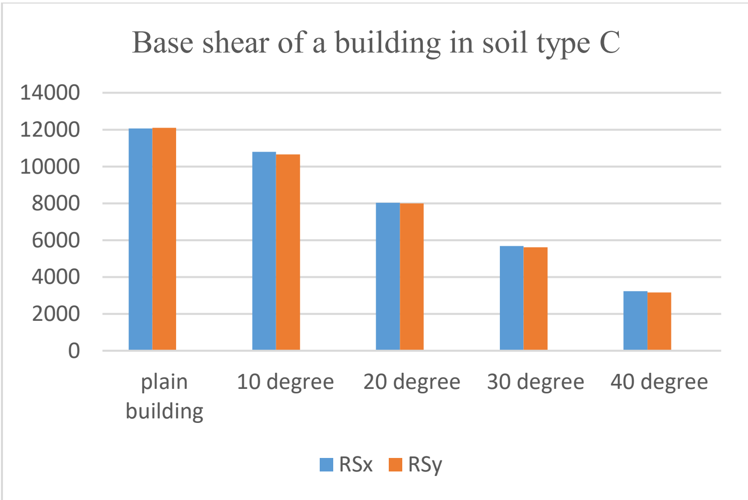
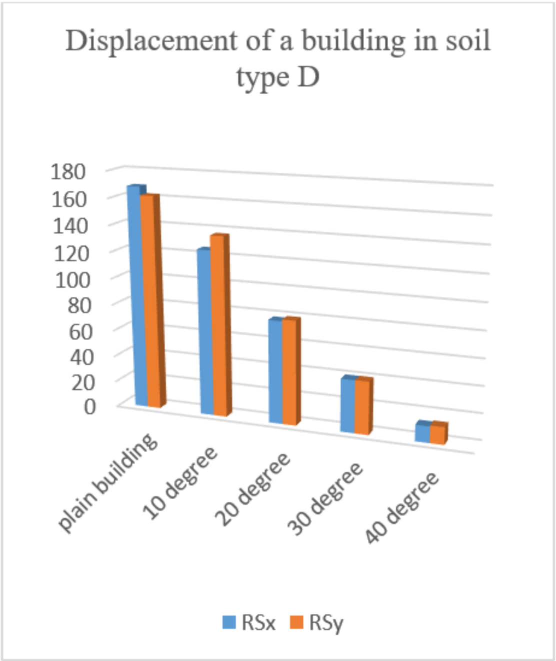
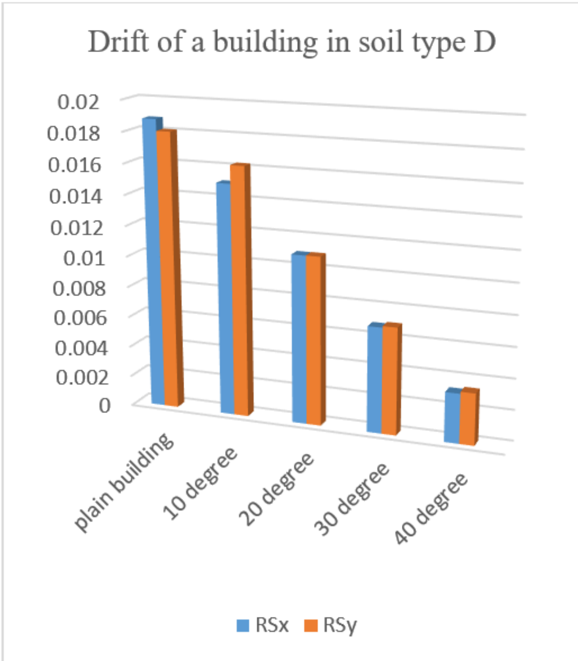


Figure 8: Comparison of story displacement, drift and base shear for a building in soil type C for EQX and EQY.

As from figure 8, the maximum story displacement occurs in plain building. For 10 degree building the top story displacement decreases by 22.56%, for 20 degree slope building 52.43%, for 30 degree slope building 75.61% and for 40 degree slope the story displacement decreases by 93% as compared to displacement for plain building. Similarly the maximum story drift occurs in plain building. For 10 degree building the top story drift decreases by 15.83%, for 20 degree slope building 40.65% ,for 30 degree slope building 62.38% and for 40 degree slope the story drift decreases by 83.53% as compared to drift for plain building. Also, the maximum base shear occurs in plain building. For 10 degree building the top base shear decreases by 11.36%, for 20 degree slope building 33.36%, for 30 degree slope building 52.84% and for 40 degree slope the base shear decreases by 75.7% as compared to base shear for plain building.

4.9 Response of a building constructed on different slope in soil type D





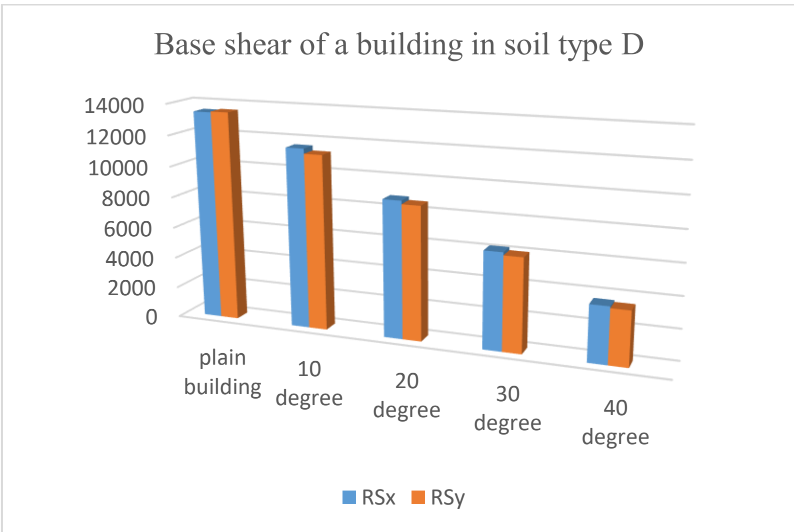


Figure 9: Comparison of story displacement, drift and base shear for a building in soil type D for EQX and EQY.

From the figure 9, it is observed that the maximum story displacement for soil type D occurs in plain building. For 10 degree building the top story displacement decreases by 25.58%, for 20 degree slope building 53.82%, for 30 degree slope building 76.32% and for 40 degree slope the story displacement decreases by 92.64% as compared to displacement for plain building. Similarly the maximum story drift occurs in plain building. For 10 degree building the top story drift decreases by 19.9%, for 20 degree slope building 41.82% ,for 30 degree slope building 63.5% and for 40 degree slope the story drift decreases by 83.85% as compared to drift for plain building. Also, the maximum base shear occurs in plain building. For 10 degree building the top base shear decreases by 14.17%, for 20 degree slope building 34.65%, for 30 degree slope building 53.89% and for 40 degree slope the base shear decreases by 71.19% as compared to base shear for plain building.

4.1 Recommendations

The following recommendations are proposed for further study to obtain more through and improved results.

a) Analyze multi-story building and impact of building height in relation to slope and soil properties.
b) Examine the effect of different lateral force resisting structural system such as shear wall, bracing on different position of building for damage control and durability of structure.
c) Seismic analysis through nonlinear time history analysis for better understanding of damage mechanism.
d) Variation of number of bays in either direction of building can be for better seismic analysis in sloping building.

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