Effect of Soil Modelling on Structural Response

FINAL YEAR PROJECT UG-2017

By

ARSLAN AMIR (G.L)	202293
USAMA KHURRAM	225662
ALI ZAFAR	215301
MUHAMMAD HASNAIN HAIDER	208229

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Science and Technology Islamabad, Pakistan

This is to certify that the

Final year project Titled

EFFECT OF SOIL MODELLING ON STRUCTURAL RESPONSE

Submitted By

ARSLAN AMIR (G.L)	202293
USAMA KHURRAM	225662
ALI ZAFAR	215301
MUHAMMAD HASNAIN HAIDER	208229

Has been accepted towards requirements for
the undergraduate degree in
CIVIL ENGINNERING

Dr. Fawad Ahmed Najam
Assistant Professor
NUST Institute of Civil Engineering (NICE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST), Islamabad,
Pakistan.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our Project Supervisor, Assistant Professor Dr. Fawad Ahmed Najam, for his continuous support for our Undergraduate (U.G.) research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped us in all times of research and writing of this thesis. His utmost efforts and guidance enabled us to develop a deep understanding of not only our project but also its associated topics.

ABSTRACT

The mechanical properties and characteristics of the ground on which the structure is based can remarkably influence the structural response. However, in current general design office practice, the effect of soil is neglected in structural modelling and response of structure is evaluated against an idealized structural model having a fixed or hinge base. But, in some cases, this effect may significantly modify the response of super-structure The present study aims to assess the effect of soil modelling by comparing the local and global responses of case study building models (with and without modelling the effects of foundation and local soil) under gravitational load analysis and seismic Analysis. For this we selected two case study buildings (4-Story Luxury Residence and 7-Story Commercial Building). These buildings are Frame Structures with RCC Walls to resist lateral loads and are representative of other buildings in our scope of work. Then we created models of selected buildings in ETABS. 3 different models for each building were created.

1. Baseline model (No foundation + No soil effect)
2. Model with actual geometry of foundations (No soil effect)
3. Model with actual geometry of foundations + Soil effect using modelling approach.

For modelling soil, we used Winkler soil modelling Approach.

For each model created, we preformed modal analysis, Gravitational load analysis and seismic analysis (ELF procedure). We extracted Global and local responses of every model of each building. When we compared these responses, we observed that the responses for both buildings, the base model results and plots differ significantly from either the foundation model, soil model or both. Hence, it can be safely concluded that the inclusion of foundation and soil modelling into the basic design approach is important to obtain a better and improved design.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

Chapter 1 Introduction

1.1 Background

In Structure Analysis while predicting structural response various methods are used to determine the stresses and displacements of the structure under the loading. These responses of the structure under loading are significantly influenced by the super-structure, type of foundation it is resting upon, and the ground or soil medium which surrounds the foundation of the structure (Vijaya & Lavanya, 2018). The mechanical properties and characteristics of the ground on which the structure is based can remarkably influence the structural response. Consider the following failure case studies:

Transcona grain elevator (1913): On September 1913, when elevator construction completed, it was put into function. The bins of elevator were filled with grain. The filling was as evenly as possible. However, On October 18, 1913, when 31,500 cu m (875,000 bushels) of wheat was placed in the elevator, settling commenced and it steeped uniformly to about 0.3 m (1 ft) per hour. Following it, elevator began to tilt. Tilting continued for a day and by then an inclination of approximately 26 degrees had occurred. In 1951 after a comprehensive study, it was revealed that the incident happened due to a bearing failure of underlying soil. (Bosela, Brady, Delatte & Parfitt, 2013).

Figure 1.1 Failure of the Transcona Grain Elevator in October 1913 at North Transcona, Manitoba, Canada. (0binna,2021).

Fargo grain elevator (1913): During the start of summer in 1954 a grain elevator with a reinforced concrete structure was constructed near Fargo, North Dakota. When major filling of the elevator commenced, the elevator experienced a classic, full-scale bearing capacity failure, and was destroyed. (Bosela, Brady, Delatte & Parfitt, 2013).

Figure 1.2 Failure of Fargo Grain Elevator 1956. (Olson,1955).

Niigata Earthquake (1964): A remarkable ground failure occurred due to the 1964 Niigata earthquake. It can be seen in the picture that an apartment (named kawagishi-cho) has suffered soil failure and has tilted severely to the left. (Wikipedia, 2021).

Figure 1.3 ground failure occurred due to the 1964 Niigata earthquake. (Wikipedia,2021)

Hence it may be significant to account the soil behavior in the structural analysis of building and thus the structural behavior may not be predicted accurately if it is not accounted. Additionally, Pakistan is a seismically active region which could further contribute to failures due to insignificant soil behavior consideration in superstructure design phase.

1.2 Problem Statement

However, in current general design office practice, the effect of soil is neglected in structural modelling and response of structure is evaluated against an idealized structural model having a fixed or hinge base. (Anwar, Najam & Uthayakumar, 2019). Underlaying soil is assumed to be totally rigid (like solid rock), which is a false assumption. It is well known that the soil is flexible medium and even if the base is considered pinned instead of fixed, it will still fail to properly depict the structural response. Neither the fixed geometry of foundation nor the soil is modelled while performing the gravity seismic analysis of building structures. However, in some cases, this effect may significantly modify the response of super-structure. The present study aims to assess this effect by comparing the local and global responses of case study building models (with and without modelling the effects of foundation and local soil) under gravitational load analysis and seismic Analysis.

1.3 Methodology

To meet the desired objectives, following workflow has been put into effect:

- Selection of typical case study buildings. Which will be representative of other buildings in our scope. These buildings include a 7-story commercial building and a 4-story luxury residence.
- Modelling of selected buildings in ETABS 2017. There will be 3 different models for each building:
  - Baseline model (No foundation + No soil effect)
  - Model with actual geometry of foundations (No soil effect)
  - Model with actual geometry of foundations + Soil effect using modelling approach.
- Modal analysis of the building.
- Carrying out Gravitational load Analysis for every model of each building.
- Carrying out seismic Analysis of each building. For this Equivalent lateral force procedure has been used.
- Compilation of results. Results will include local and Global responses of every model of each building. Local and global responses include following responses:
  - Global responses:
    - Story shear.
    - Story moment.
    - Inter story drift ratio.
    - Story displacement.
    - Peak floor acceleration.

        - Local Responses:
            - Shear forces in beams, columns and shear wall.
            - Bending moments in beams, columns and shear wall.
            - Rotation and strain in beams, columns and shear wall.
- Conclusion.

1.4 Objectives

The following objectives are set in order to achieve the research aims:

- To perform the gravity load analysis and seismic analysis of selected case study buildings with and without modeling the effects of foundations and local soil - (Comparison of seismic demands).
- To propose a simplified modeling approach for including the soil effects in prediction of seismic behavior and performance of typical buildings in Pakistan.
- To study some practical approaches for the modeling of soil for typical RC buildings in Pakistan - (2 case study buildings of different heights located on sites with different soil profiles).

1.5 Scope and Limitations

1.5.1 Scope

The scope of this study is limited to Reinforced concrete building, having frame structure, resisting on strip and Mat foundation of 4-story and 7-story building.

1.5.2 Limitations

Buildings of subject include a low rise and mid-rise building. High rise buildings are not analyzed under this study. Secondly, while modelling soil, a very basic approach i.e., area spring method has been used. Various others complex methods are also available. In addition to that for seismic analysis only the linear static procedure i.e., Equivalent lateral procedure has been applied.

To make this study more mature and effective, the same work criteria can be used to demonstrate the structural response of high-rise buildings, have underlying soil modelled through a more complex and detailed approach, and using non-linear dynamic analysis procedure.

Chapter 2 Literature Review

2.1 Soil Constitutive Models

Soils are very complicated and multiphase materials. They contain grains of minerals, air voids and water. They are neither linearly elastic nor completely plastic under loading. Stating factually, Soil behavior is extremely complicated and significantly varies under different conditions. In past few years, numerous studies have been conducted on soil-structure interaction, and soils because of their complex behavior have been modelled in number of ways based on the elasticity, plasticity and visco-elasticity classical theories. A spring, slider and dashpot are used to represent elastic, plastic and viscous property of soil. These are the basic components of soil models. (Kavitha, Narayanan & Beena, 2011).

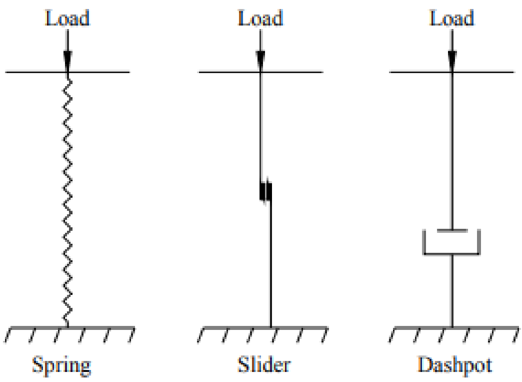

Figure 2.1 Basic components of soil models. (Kavitha, Narayanan & Beena, 2011).

2.1.1 Elastic Models

Soils exhibiting purely elastic behavior are considered in this type of model. Most basic way to idealize soil response is to assume underlaying soil medium as linear elastic continuum. Under this assumption deformation will be assumed as linear and reversible. (Vasani,2003). The simplest elastic models are Winkler model and continuum model. (Datta and Roy ,2002). Which are discussed in the following section.

2.1.1.1. The Winkler's Model

Winkler model is the most basic elastic soil model. It can be used with ease because of its simplicity. Moreover, hypothesis under which Winkler model works performs reasonably. (Kavitha, Narayanan & Beena, 2011). Numerous studies in soil-structure interaction area have been ran using Winkler's hypothesis as base. To model soil for present study this approach has been used too.

Underlying soil in Winkler model is inferred as an arrangement of uniform but independent of each other, closely knit, distinct, linearly elastic springs. This model characterizes soil as a medium having discontinuous surface displacement when subjected to loading. Under this idealization, soil deformation under load is only limited to loaded regions only. (Datta and Roy ,2002). It presumes that Deformation of underlying soil at each point is in a direct relation with the applied stress at that point and has no influence of the stresses or displacements at other or even the first neighboring point of the structure-soil interface.

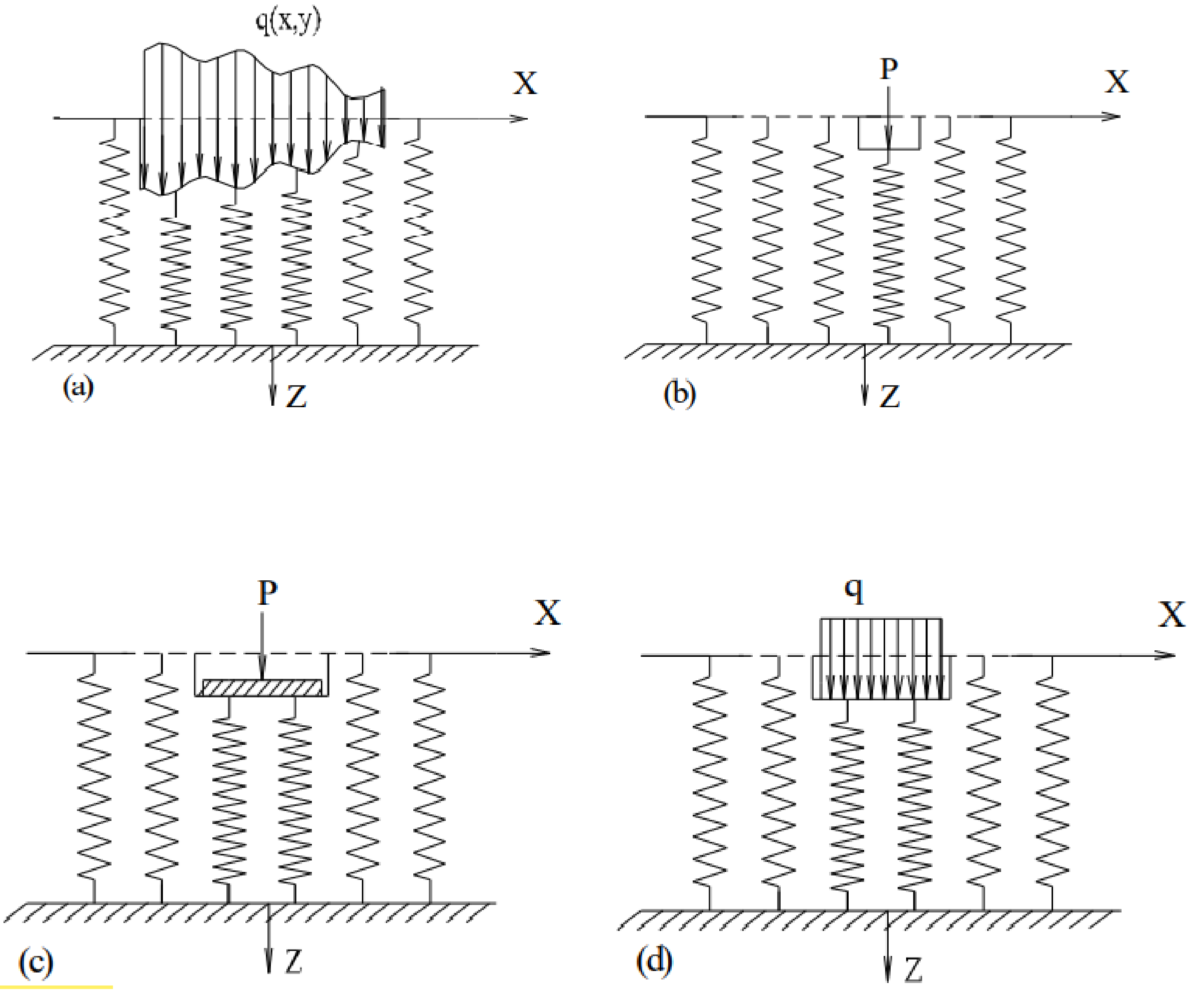

Figure 2.2 Surface displacements of the Winkler model due to (a) non-uniform, (b) A concentrated load, (c) A rigid load, (d) A uniform flexible load. (Vasani,2003).

Working function for Winkler model is,

$$p(x, y) = k\, w(x, y)$$

In which $p(x, y)$ represents stress applied at point, $w(x, y)$ represents deflection at the same point due to the applied stress and k shows the subgrade modulus reaction ($stress/length$).

Soil properties in the Winkler model are determined using a single parameter k, it shows the subgrade modulus reaction and is representative for the stiffness of elastic springs which have been used in place of underlying soil medium (Singh, Jha, n.d.). Coefficient of subgrade reaction is dependent on both subgrade nature and loaded area dimensions. (Datta and Roy ,2002). As k is the only representative parameter to idealize the soil properties in the Winkler model, one must be cautious while numerical calculating the value of k. Number of methods are available to determine the coefficient of subgrade reaction. For the present study we have used Bowles approach to calculate the value of subgrade reaction.

2.1.1.2. The Elastic Continuum Model

Elastic continuum model uses a more conceptual approach to physically represent the continuity of soil media. Soil body contains distinct particles held as a mass by intergranular forces. A very common problem faced in soil mechanics is related to loaded regions and boundary distinctions. Loaded areas and boundary distances are much greater comparing to individual grains of soil. Because of which soil media becomes ‘statistical macroscopic equivalent’ and needs to be put under mathematical analysis. (Singh, Jha, n.d.). Thereby making it reasonable to use continuum mechanic theory to idealize it.

To constitute the continuous behavior of soil media in this model, soil is ideally represented as a 3D elastic continuous solid. Surface displacements in this model will be occurring below and around the loaded region. (Kavitha, Narayanan & Beena, 2011). In result the surface deformation distributes continuously under loading in this model.

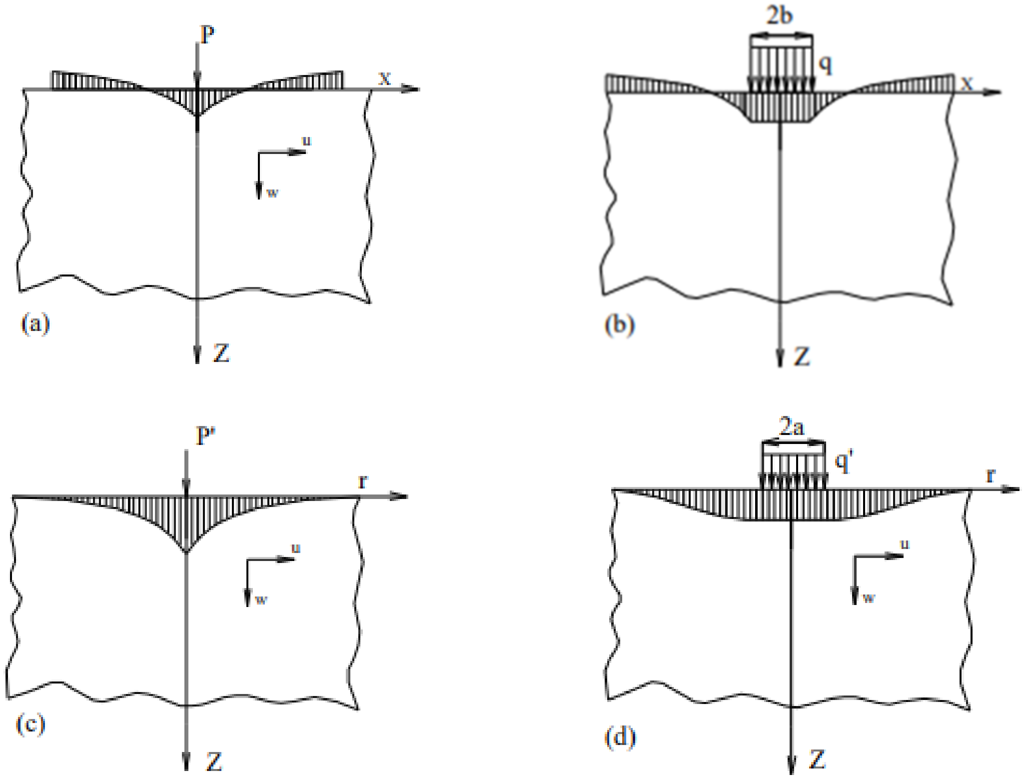

Figure 2.3 Typical surface displacement profiles of an elastic Continuum model subjected to (a) A line load P, (b) A uniform load q of width 2b, (c) A concentrate d load P', (d) A uniform load q' of radius 'a'. (Vasani,2003).

For reducing complexity, this model presumes soil as a semi-infinite and isotropic media. Nevertheless, the influence of layering of soil and soil anisotropic properties can be conveniently handled in this approach. In contrast to Winkler model, Elastic continuum model dispenses greater amount of knowledge regarding stresses and displacements in the soil body. (Datta and Roy ,2002).

However, this approach comes with complexities from mathematical viewpoint. This markedly restricts the use of this approach in common practice. One of the main flaws in this idealization is inaccuracy in calculating the reactions at foundation peripheries. Moreover, it has been observed that, in soil media, the surface deformations reduce more rapidly away from the loaded region than what is predicted by this idealization. (Singh, Jha, n.d.).

2.1.1.3. Improved Versions of Elastic Models

For encountering the limitations of Winkler's model and Continuum model, some improved soil models have been offered in the literature. Two alternate approaches have been adopted to bring about these improvements. In the first approach, using some structural elements the springs elements in Winkler model are made interactive to represent the continuity of the infinite soil. While in second approach, continuum model complexity has been reduced in order to obtain a realistic picture about expected deformations and stresses. These modified models have been discussed below.

a. Modified Versions Using First Approach (Improved Versions of Winkler Model)

i. Filonenko-Borodich Model

Filonenko–Borodich Model is a modified form of the Wrinkle model. Like Winkler model, the first parameter in this model corresponds to the spring constant. A second parameter has been introduced to account the interactions of these and thereby represent the soil continuity. The second parameter corresponds to the coupling effect of the linear elastic springs. The second parameter also makes it possible to consider the effect of soil on both sides of the loaded region. Even after using a second parameter, this approach still offers less tedious mathematical computation of problem. (Singh, Jha, n.d.). In this version, a thin smooth elastic membrane which is undergoing a constant tension T, connected at vertical springs top ends, is used as to model the continuity of deformation in the soil. This model is less limited than Winkler model and at the same time it is also less complex than continuum model. (Datta and Roy ,2002).

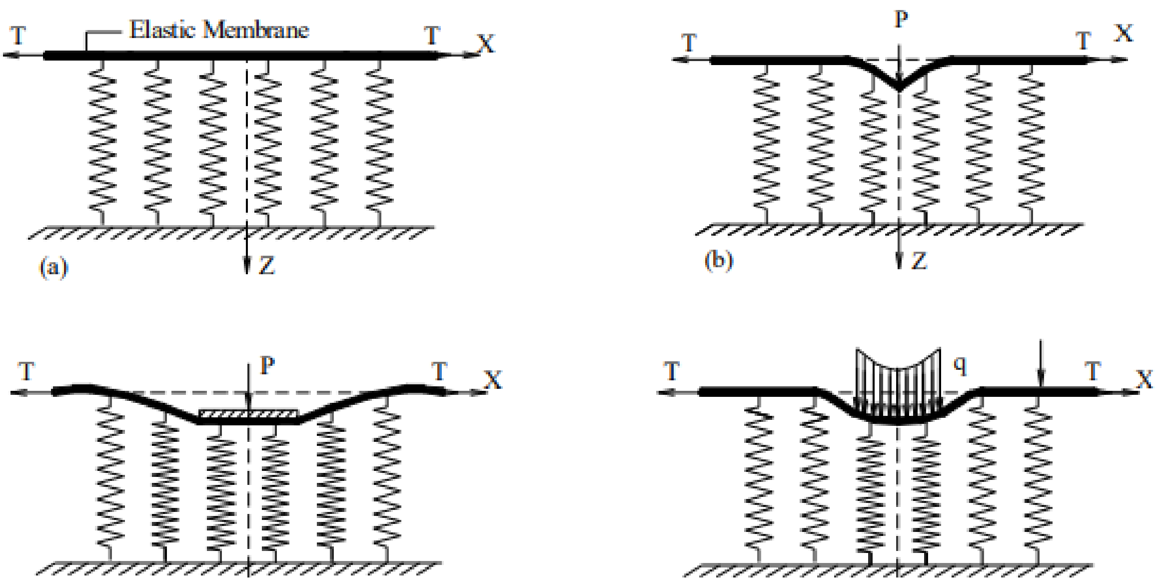

Figure 2.4 Surface displacements of the Filonenko-Borodich model. (a) Basic model, (b) Concentrated load, (c) Rigid load, (d) Uniform flexible load. (Vasani,2003).

Mathematically this model's response is expressed as follows.

$$p = kw - TV^2, For\ rectangular\ or\ circular\ foundation$$

$$p = kw - Td^2wdx^2\ , \qquad for\ strip\ foundation$$

ii. Hetenyi's Model

Hetenyi's Model is also a modified version of Winkler model. Moreover, it can be said that this model is a fair compromise between the Winkler and continuum model.

In this approach, interaction between distinct and independent vertical spring elements is included by introducing an elastic plate in case of 3D problems, whereas an elastic beam in case of 2D problems. The elastic beam or elastic plate having a flexural rigidity of EI is only subjected flexural deformations. (Vasani,2003).

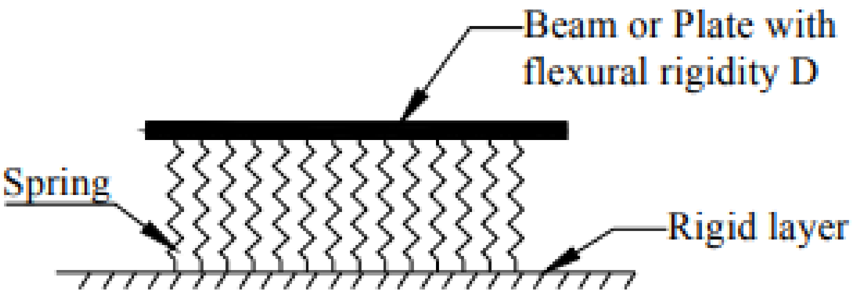

Figure 2.5 Hetenyi's Model. (Datta and Roy ,2002).

Mathematically the response of this model is represented as follows.

$$q(x, y) = \ k\, w(x, y) - \ D\, V^4\, w(x, y)$$

$$where\ D = \frac{EPh^3}{12(1 - \mathrm{Vp}^2\ )}\ is\ the\ flexural\ rigidity\ of\ the\ plate$$

For 2D,

$$q(x) = kw(x) - \left(\frac{Dd^4\, w(x)}{dx^4}\right)$$

iii. Pasternak Model

One of Winkler model's modified version is Pasternak model. In this approach, to represent the continuity of soil deformation in model, a shear elastic layer of unit thickness is connected at the top ends of Winkler's vertical springs. This shear layer incorporates both shear stiffness and compressibility of the soil, thereby forming a model representing continuity of soil. (Singh, Jha, n.d.).

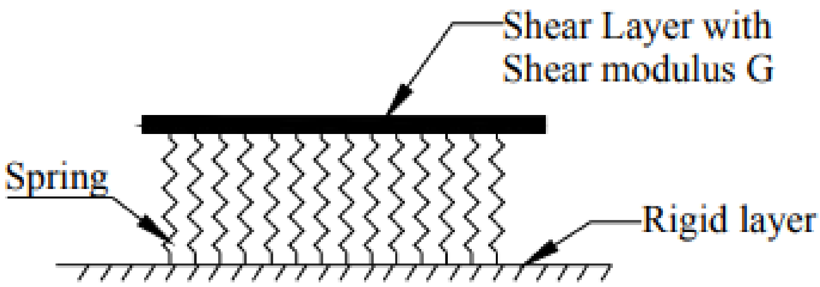

Figure 2.6 Pasternak Model. (Datta and Roy ,2002).

iv. Kerr Model

Kerr Model another improvised version of Winkler model and it introduces a three-parameter approach. It introduces dual layers of elastic vertical springs, which are interconnected by an elastic shear layer between them. Kerr model makes it more feasible and convenient to determine the extent of continuity of vertical deformations between the loaded and unloaded surface boundaries. This enables this **model** to distribute stresses more accurately in case of both cohesive and non-cohesive soil. (Singh, Jha, n.d.).

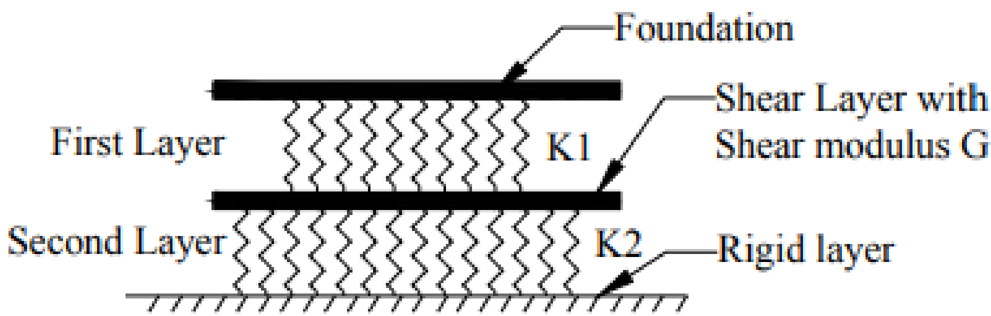

Figure 2.7 Kerr Model. (Datta and Roy ,2002).

Differential equation that Governs this model is as follows.

$$1 + k_2 k_1 p = G k_1 V^2 p + k_2 w - G v^2 w$$

where, k1 is the spring constant of the first layer; k2 is the spring constant of the second layer; w is the deflection of the first layer.

b. Modified Versions Using Second Approach (Improved Versions Of Continuum Model)

i. Vlasov Model

This model uses variation approach to introduce certain restrictions on the possible surface displacement of an elastic layer. This step simplifies the simplify the basic equations of linear theory of elasticity for a continuum model. (Datta and Roy ,2002).

ii. Reissner Model

This is also an improved version of Reissner model. For making the equation for Continuum model more simplified this approach introduces certain restrictions on both displacements and stresses.

2.1.2 Models Application

In current times, minimal amount of evidence is available to assess the accuracy of computation of various models studied for representation of soil media. Many models available in literature make use of numerous parameters for constituting a soil model. Thus, the basic requirement to constitute a model is to determine the parameters. Among all parameters, Modulus of subgrade reaction is one the that can be determined easily. The value obtained for Modulus of subgrade reaction then can be easily modified for the actual size of foundation. Among all models studied in literature, Winkler model is the one that utilizes only a single parameter and that is Modulus of subgrade reaction. The basal limitation in Winkler approach is the independent and distinct behavior of vertical springs. Which fails to idealize the continuity of the soil media. However, the degree of continuity of the structure is sufficiently greater than the soil media. Therefore, this approximation is close to reality. (Datta and Roy ,2002). In addition to that when the solution of Winkler approach for a beam on elastic foundation was compared to classical solution and finite finite-difference solution, it displayed a considerable similarity. Moreover, its very tough to calculate an accurate value of young's modulus, which is an essential parameter in continuum approach, therefore Modulus of subgrade reaction approach finds more appreciation. Further, even if someone encounters a large error in the computation of Modulus of subgrade reaction, it has an insignificant effect on the response of superstructure. In this context, the Winkler model, though oversimplified, seems adequate and suitable for computational purpose for its reasonable performance and simplicity.

2.2 Analysis Procedures

The analysis procedure used in this study comprised of

- Modal Analysis (modal properties)
- Gravity load analysis (only) [Dead, live etc.]
- Seismic Analysis [Only earthquake loading]
    - ELF (static).

2.2.1 Seismic Analysis Methods

For calculation of the seismic response, the linear state of stress is commonly used. By complicated cases or by higher importance of the structure is recommended to use some

non-linear method. These are the four methods of analysis:

Static methods:

- Equivalent Lateral force method
- Response spectrum analysis

Dynamic methods:

- Linear time-history analysis
- Non-linear time-history analysis

2.2.1.1 Equivalent Lateral Force Method

This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g., force reduction factors). Following is step wise procedure ELF procedure:

1. Find out the seismic design category of the building and choose the proper seismic importance factor, I. of the structure.
2. From Table 12.2-1 of ASCE 7-05, select the appropriate response modification factor, R.
3. Calculate the elastic fundamental period of the structure, T, which is a function of the mass and stiffness of the structure. It can be found using Section 12.8.2.1 of ASCE 7-05.
4. Calculate the seismic response coefficient, Cs, from Section 12.8.1.1 of ASCE 7-05. It is equal to the design spectral response acceleration coefficient for short periods. SDS, times the seismic importance factor, IE, divided by the response modification factor, R.
5. Compute the effective weight of the structure.
6. Finding the seismic base shear, which is defined as the total seismic force acting at the base of structure during an earthquake. According to Equation 12.8-1 of ASCE 7-05, it is equal to the product of the seismic response coefficient, Cs, and the effective weight of the structure, W.
7. Determine the seismic lateral load, Fx, for each level of the structure from Equation 12.8-11 of ASCE 7-05. The lateral seismic force is equal to vertical distribution factor, Cvx, times the total design lateral force or base shear.
8. Finally, calculate the bending moments based on the story shears.

Equivalent static lateral force analysis is based on the following assumptions,

1. The structure is rigid.
2. There is perfect fixity between structure and foundation.
3. During ground motion every point on the structure experience same accelerations.
4. Dominant effect of earthquake is equivalent to horizontal force of varying magnitude over the height.
5. Approximately determines the total horizontal force (Base shear) on the structure.

2.2.1.2 Response Spectrum Analysis

The method requires the determination of a response spectrum from measured seismic activity. This data was then reduced into a spectrum of seismic action versus natural frequency. The seismic action could be displacement, velocity, or acceleration. The independent results were then combined using an appropriate technique to determine the response of the overall structure. The response spectrum is a function of period, the reciprocal of circular natural frequency, and damping ratio. A typical response spectrum is with the advancement in personal computers and improved structural analysis techniques, the use of more precise methods increased. One of the most popular was response spectrum shown below in Figure:

2.2.1.3 Linear Time History Analysis

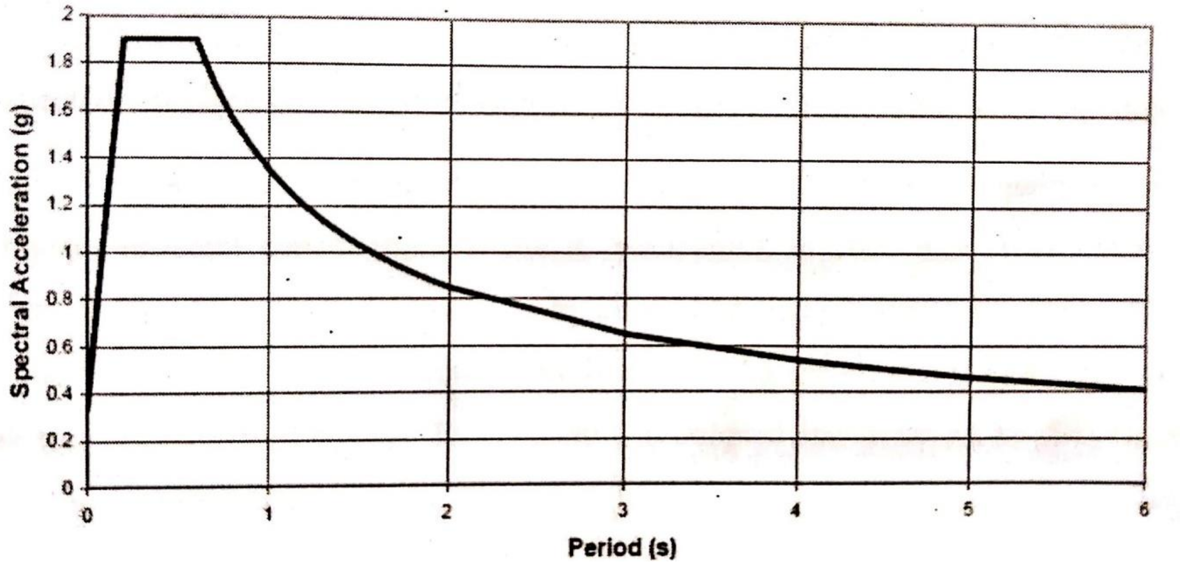

Figure 2.8 RSA typical response spectrum. (Wikipedia,2020).

LTHA provides the structural response under dynamic loading. The equation of motion for the inertial, damping and elastic restoring forces against the applied dynamic load is solved by modal or step by step direct integration methods to get the desired structural responses. In the LTHA using the step-by-step DI method, first, the mass and stiffness matrices are formed. Then the damping matrix is formed using the Rayleigh damping matrix approach. After that, the structural response at each time instance is evaluated and adjusted with the response at the previous instance which is essentially the step-by-step approach of direct integration. These resulting response vectors can be plotted against time to get the response of the structure during and even after the applied loading, which in most cases is of the earthquakes.

Chapter 3 Methodology

3.1 General Characteristics of Case Study Building:

We were required to remodel the buildings as there were modeled at the time of their construction using ETABS. Two building drawings were obtained to serve our purpose. One of the buildings was obtained from a construction company in Lahore and the other from a company in Islamabad. The building obtained from Lahore was a 7-Story commercial building while the building from Islamabad was a 3-Story residential building.

3.1.1 Salient Features of the 7-Story Case Study Building

This is a 79ft building located on MM Alam Road, Lahore which is a plain terrain. The building is used for commercial purposes. The building has a gravity and lateral load resisting structural system. To resist gravity loads, frame structure is used, and a lift well is used to resist lateral loads. All these loads are transferred to a raft foundation. To conserve the aesthetics of the building, glass partitions are used instead of masonry walls.

3.1.2 Salient Features of the 3-Story Case Study Building:

This is a 47.5 ft building taken from a site in Bahria Town which is a relatively plateaued terrain and a comparatively active region tectonically. This building has the similar structural system as the first building: frame structure to resist gravity loads and a lift well to resist lateral loads. These loads are then transferred to a strip foundation. Masonry infill walls are extensively used as it is a residential building.

3.2 Sample Building Plans:

3.2.1 7-Story Building

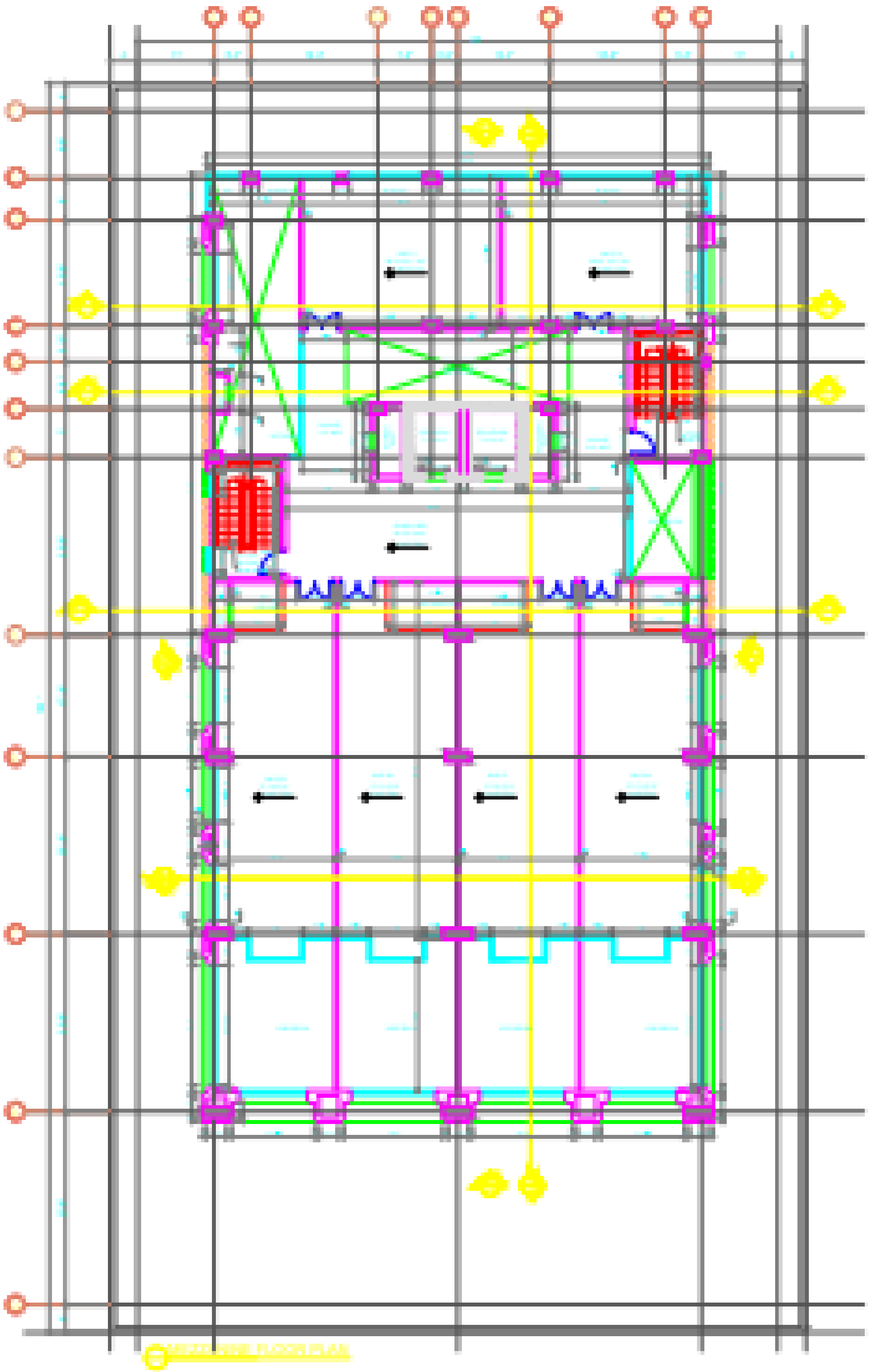

Figure 3.1 mezzanine floor plan

3.2.2 Story Building

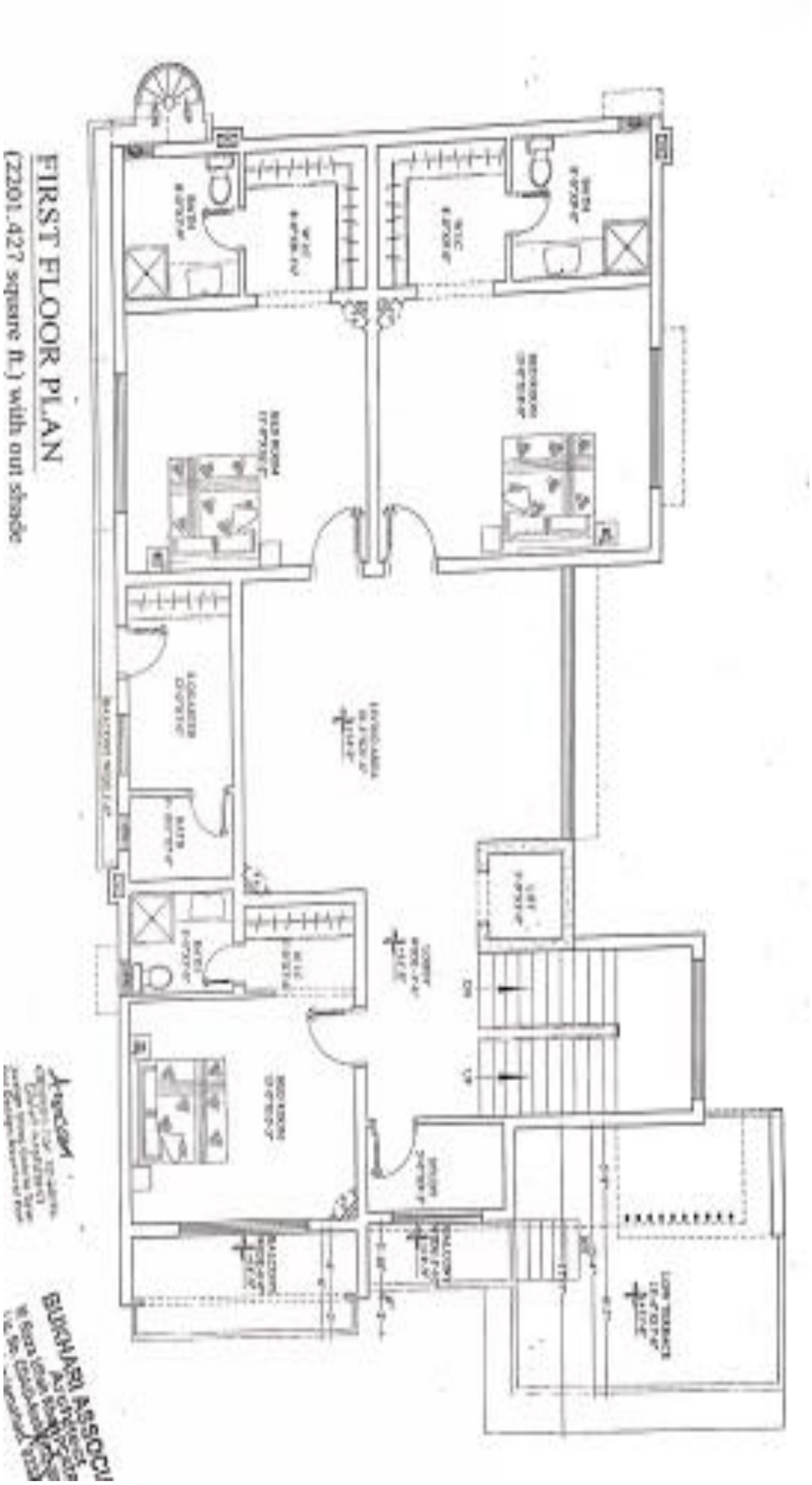

Figure 3.2 first floor plan.

3.3 Modeling In ETABS

3.3.1 Linear Elastic Modelling

In ETABS, we performed linear elastic modelling which means that all elements are modelled as linear elastic.

Linear elastic elements follow a linear mathematical model defined as those elements in which the material properties and cross-sectional properties follow fundamental linear relationships between actions and their corresponding deformations, and they obey hooks law. It is useful to compute the relation between the forces applied on the object and the corresponding change in shape. In other terms, it relates the stresses and the strains in the material.

3.3.2 Physical Model

The physical model is made up of objects that represent the physical structural members. Physical model views accurately display insertion points, member orientations, object intersections, and other geometric details captured by the object model.

3.3.3 Analytical Model

Analytical model views display the finite element model of the structure which is made up of the connectivity of the joints, frames, and shells and defined meshing. When the analysis is run, the analytical model is auto- Generated from the model and its assignments and settings.

3.4 Modelling Scheme

In ETABS, we modelled beams, columns, RCC Walls, slabs and masonry walls as follows:

3.4.1 Beams and Columns

We modelled beams and columns as one-dimensional element. So, beams and columns represent linear elements.

3.4.2 RCC Walls And Shear Walls

RCC Walls and Slabs are modelled as shell elements. Shell elements have in-plane as well as out of plane stiffness. So RCC Walls and slabs have in-plane as well as out of plane stiffness.

3.4.3 Masonry Walls

Modelling of masonry loads is included in non-elastic modelling which was out of our scope. So, we converted the masonry wall loads into uniformly distributed loads and these loads were projected onto the slabs wherever required.

3.5 7-Story While Modeling in ETABS

3.5.1 Retaining Wall/Shear Wall

Retaining wall and shear wall were defined as shell-thin elements with a strength of 3000 psi. The thickness of the wall was taken to be 12 inches as specified in the drawings.

3.5.2 Underground Water Tank Wall:

Underground water tank wall was defined the same way as the shear/retaining wall, but the thickness specified here was 9 inches.

3.5.3 Area Spring Property Data

Area springs were given a vertical stiffness corresponding to the soil properties on site. The vertical stiffness assigned was 0.0635 kip/in/in^2. Lateral stiffness was given a significantly large number, so it acts as fully restrained laterally which goes with our assumptions.

3.5.4 Story Data

All the stories were given an elevation corresponding to the building drawings which ultimately go up to 79 ft.

3.5.5 Plan View & 3D View.

A sample plan and 3D view of the 7-Story building modelled in ETABS is shown below.

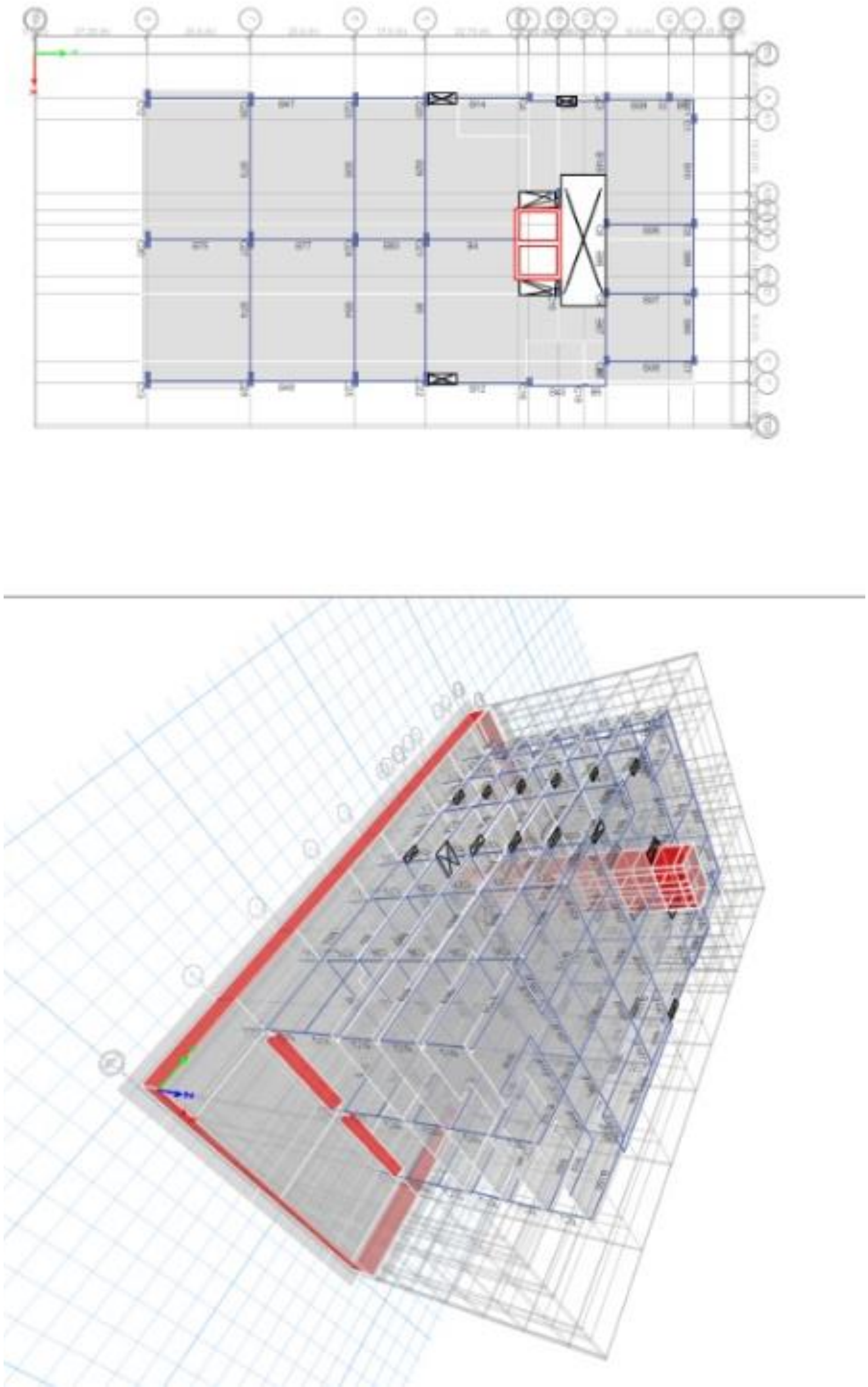

Figure 3.3 Plan View

3.5.6 Frame Properties

Frame properties were assigned by creating corresponding sized beams and columns. The stiffness modifiers were entered according to code to compensate for the faulty fixed connections in the actual field.

Beams	Columns	RCC Walls	Slabs
0’-9” x 2’-0”	0’-9” x 1’-6”	Shear/Retaining = 12”	Thickness = 6”
0’-9” x 2’-6”	2’-3” x 1’-6”	Water Tank Wall = 9”	
0’-9” x 2’-8”	3’-4.5” x 1’-6”		
1’-0” x 1’-9”	3’-6” x 1’-6”		
1’-0” x 2’-0”	4’-3” x 1’-6”		
1’-0” x 2’-6”			
1’-0” x 3’-7.5”			
1’-3” x 1’-9”			
1’-3” x 2’-0”			
1’-6” x 2’-0”			
2’-6” x 2’-0”			
2’-7.5” x 2’-0”			

Table 3.1 frame properties.

3.5.7 Frame Section Property Data

Column sections were assigned a strength of 4000 psi while the Beam sections were assigned a strength of 3000 psi.

3.6 3-Story While Modeling in ETABS

3.6.1 Plan View

A sample plan and 3D view of the 3-Story building modelled in ETABS is shown below.

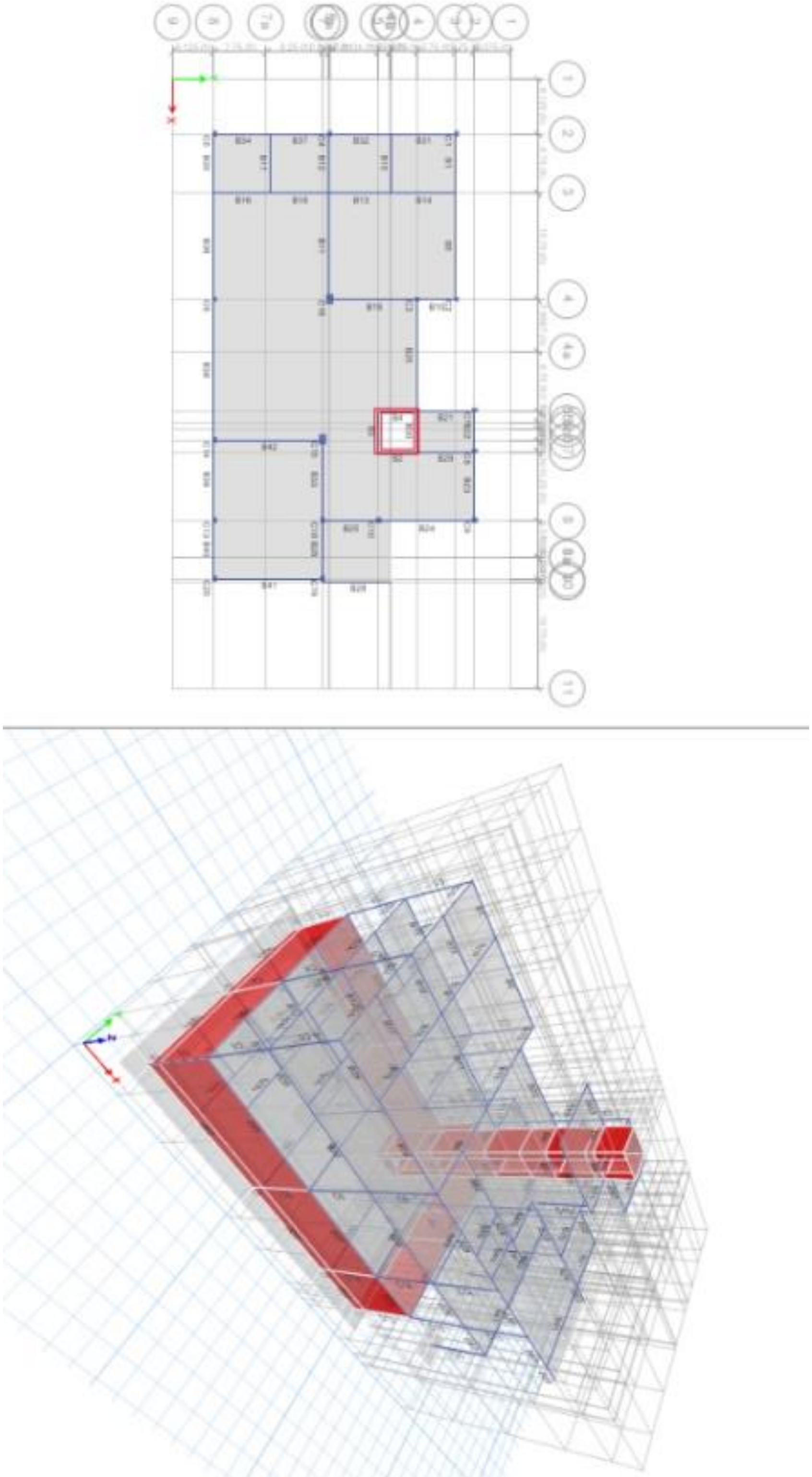

Figure 3.4 plan view

3.6.2 Frame Properties

Frame properties were assigned by creating corresponding sized beams and columns. The stiffness modifiers were entered according to code to compensate for the faulty fixed connections in the actual field.

Beams (in)	Columns (in)	RCC Walls (in)	Slabs (in)
4.5 x 9	9 x 9	9	6
9 x 9	12 x 9		
9 x 12	12 x 18		
9 x 15			
9 x 18			
9 x 24			
12 x 9			
15 x 9			
15 x 12			
18 x 9			
18 x15			

Table 3.2 frame properties.

3.6.3 Frame Section Property Data

Columns and beam sections both were assigned a strength of 3000 psi.

3.6.4 Slab Property Data

Slabs were defined as shell-thin elements of 3000 psi and were given a thickness of 6 inches.

3.6.5 Retaining/Shear Wall

Retaining wall and shear wall were defined as shell-thin elements with a strength of 3000 psi. The thickness of the walls was taken to be 9 inches as specified in the drawings.

3.6.6 Story Data

All the stories were given an elevation corresponding to the building drawings which ultimately go up to 47.5 ft.

3.6.7 Spring Property Data

Area springs were given a vertical stiffness corresponding to the soil properties on site. The vertical stiffness assigned was 0.070555 kip/in/in^2. Lateral stiffness was given a significantly large number, so it acts as fully restrained laterally which goes with our assumptions.

3.7 Types of Models Created in ETABS

We made 3 types of models for each test building in ETABS. These are:

1. Base Model
2. Foundation model
3. Soil model.

3.7.1 Base Model

It is the basic model created in ETABS as it is done in field in the normal practice. The bases of the columns were set as fixed in this model.

3.7.2 Foundation Model

We modelled the foundation of the building in ETABS as they were constructed in the field. One of the buildings selected had raft foundation while the other had isolated and strip foundations.

- In raft foundation, we fixed the corners of the foundation.
- In isolated footing, we fixed the corners of each footing. In case of strip footing, the edges were fixed where they had a change in direction.

3.7.3 Soil Model

In soil modelling, we applied area springs under the foundation. The area springs were fully restrained in lateral directions. We gave the vertical stiffness to area springs while considering the properties of soil.

3.8 Analysis Procedure

In ETABS, we used the following analysis procedures.

1. Gravitational Load Analysis
2. Equivalent Lateral Force Procedure.

3.8.1 Gravitational Load Analysis

In gravitational load analysis, Load Cases were set as Live Load and Dead Load. While running the model, responses were set as required to obtain meaningful results. Global responses and local responses were then obtained for the set live load or dead load cases which are shown in detail in the Results chapter.

Under gravitational loads, building usually displaces in the vertical direction which can be seen in the animations under these loads. Though, there may be some lateral drifts due to the non-symmetry in the building. The shear forces and moments in the local responses is a proof of that non-symmetry.

3.8.2 Equivalent Lateral Force Procedure

- In Equivalent Lateral Force Procedure (ELF), for both buildings, load patterns for earthquake loads in both x and y directions were defined separately.
- For both load patterns, the time pattern, story range, Overstrength Factor and Seismic Coefficients were entered along with the Importance factor of the respective building.
- While performing analysis, load cases for EQ in x and y direction just need to be Run and ETABS applies the adequate earthquake loads itself which can then be plotted in Excel.
- The responses from these earthquake loads can be seen in the animations which show the building swaying in x-direction, y-direction and in a twisting manner.

Modal analysis for these buildings was also performed which shows the natural behavior of the buildings under their mass and stiffnesses. These responses help in making a safe design conforming to the code.

Chapter 4 Results

As for the results, we compared the global and local responses obtained from the base model, soil model, and foundation model of the 3-Story and 7-Story building correspondingly. A hierarchal structure is shown below.

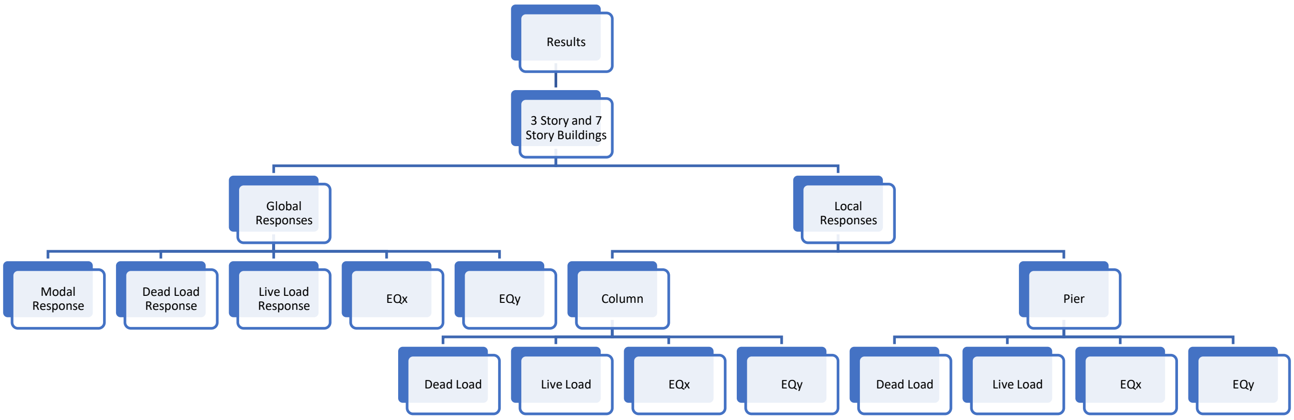

Figure 4.1 Hierarchal structure of results.

4.1 3-Story Building

4.1.1 Global Responses

Global responses were further categorized into five different responses listed below:

- Modal Response
- Dead Load Response
- Live Load Response
- EQx
- EQy

4.1.1.1 Modal Responses

Modal responses are further categorized into four different categories listed below:

- Max Story Displacement
- Max Story Drifts
- Story Shear
- Story Overturning Moment

The results obtained as a form of comparison between base model, soil model and foundation model for each category are shown below.

a) Max Story Displacement

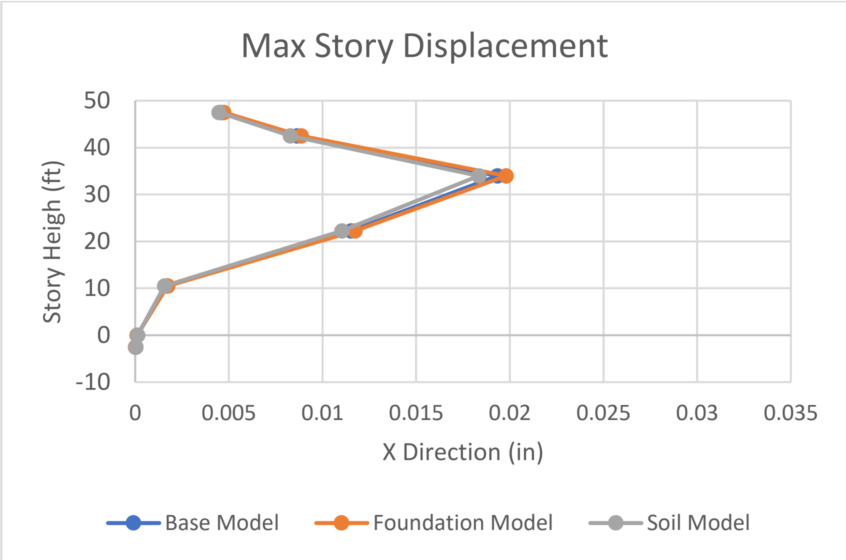

Figure 4.2 Max story displacement. (3/modal/x)

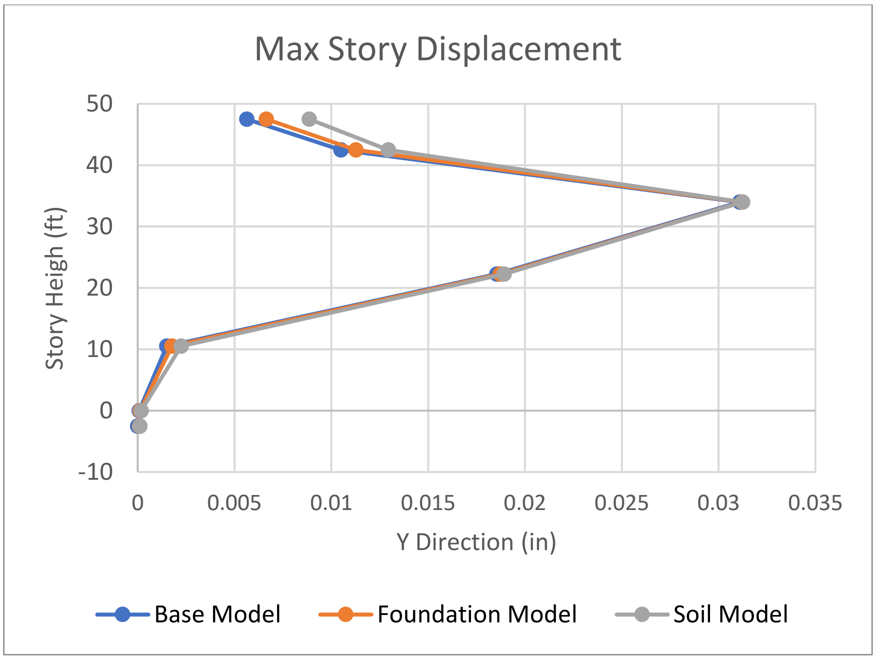

Figure 4.3 Max story displacement. (3/modal/y)

Maximum story displacement for each story under the Modal Response of 3-story building in x- and y-direction consequently is shown above. It can be seen from the responses that the top story displaces very less and against the trend which shows that it must have a very little mass.

b) Max Story Drift

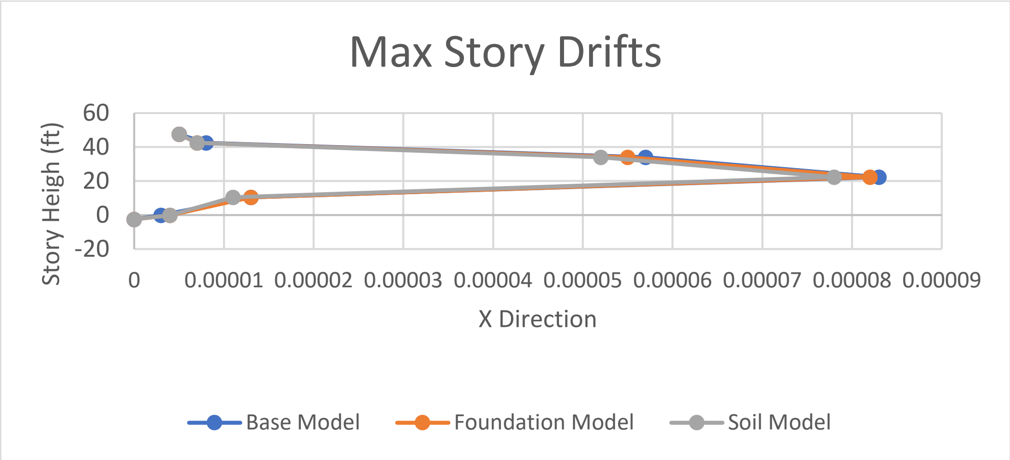

Figure 4.4 Max story drift. (3/modal/x)

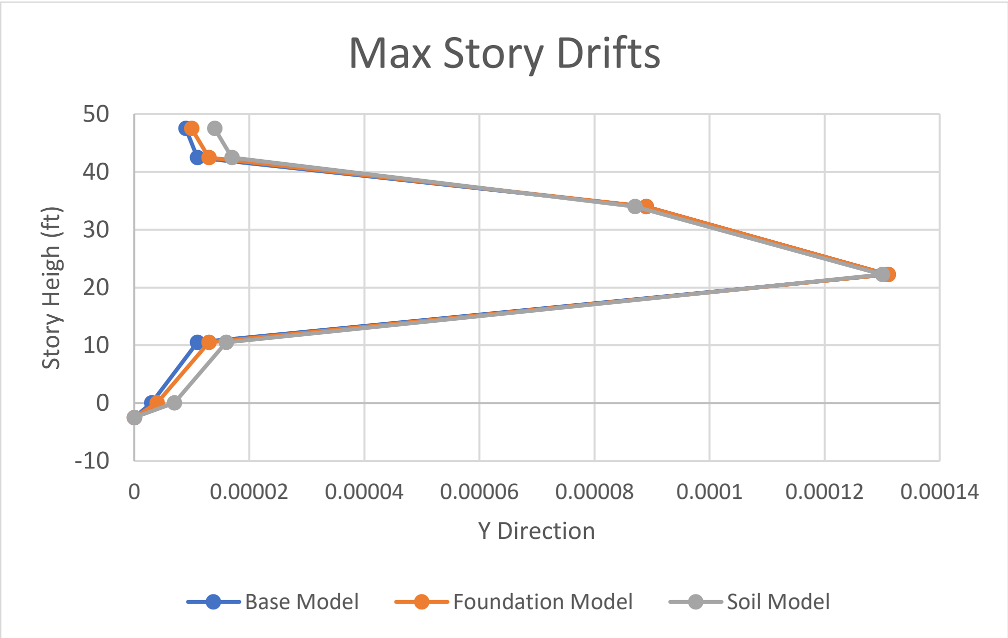

Figure 4.5 Max story drift. (3/modal/y)

Maximum story drift for the modal response is also a function of the building's mass and is similar to the maximum story displacement. Hence, it follows a similar trend.

c) **Story Shear**

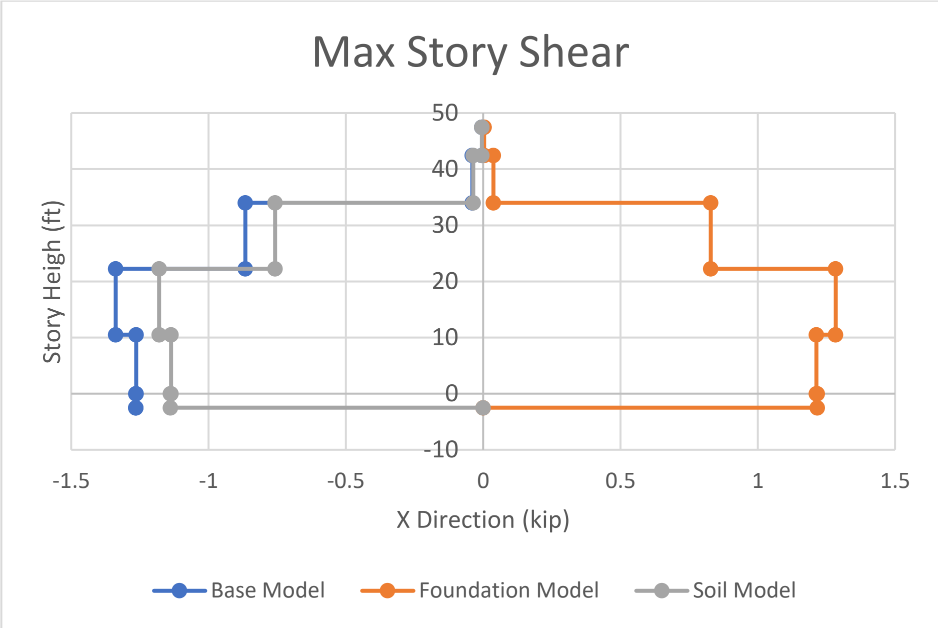

Figure 4.6 Max story shear. (3/modal/x)

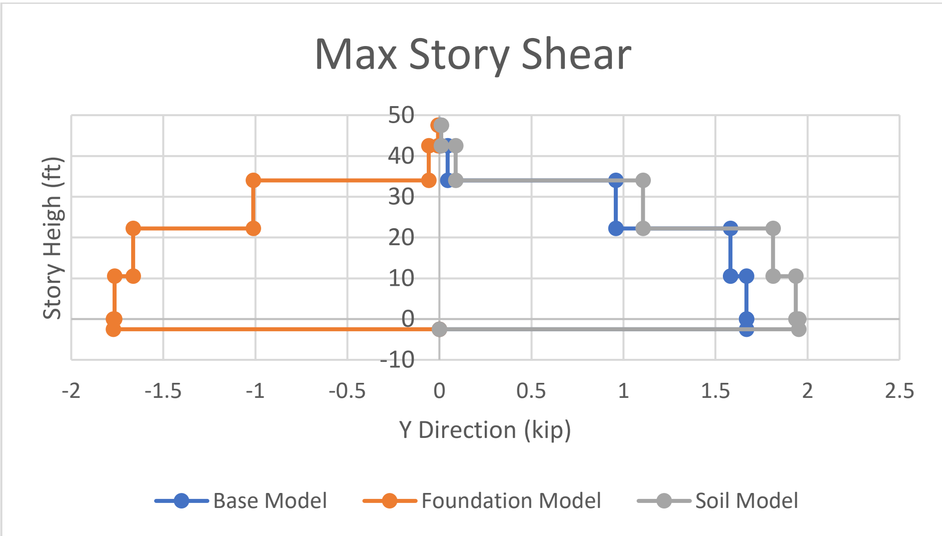

Figure 4.7 Max story shear. (3/modal/y)

Max story shears for modal responses in the x- and y-direction are shown above. It can be seen that the trends are similar regardless of the difference in values which are although significant.

d) Story Overturning Moment

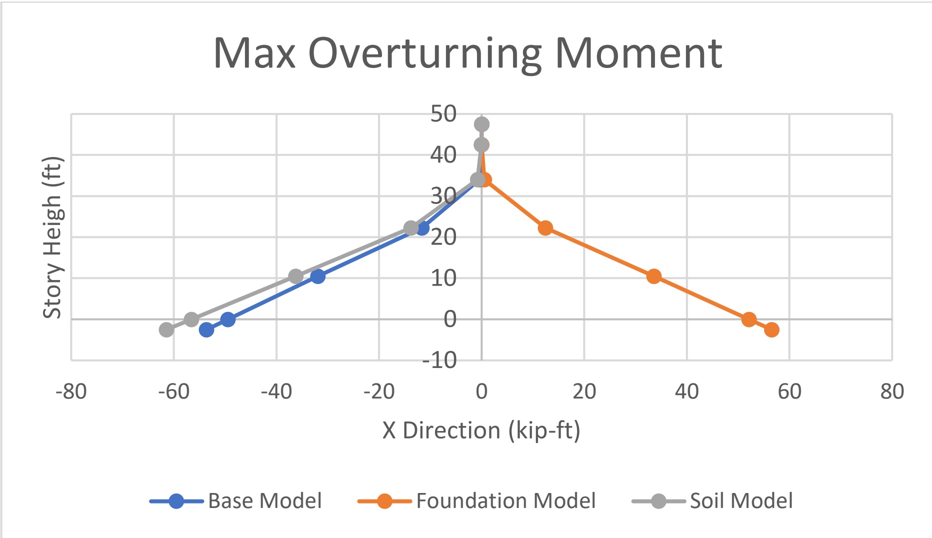

Figure 4.8 Max overturning moment. (3/modal/x)

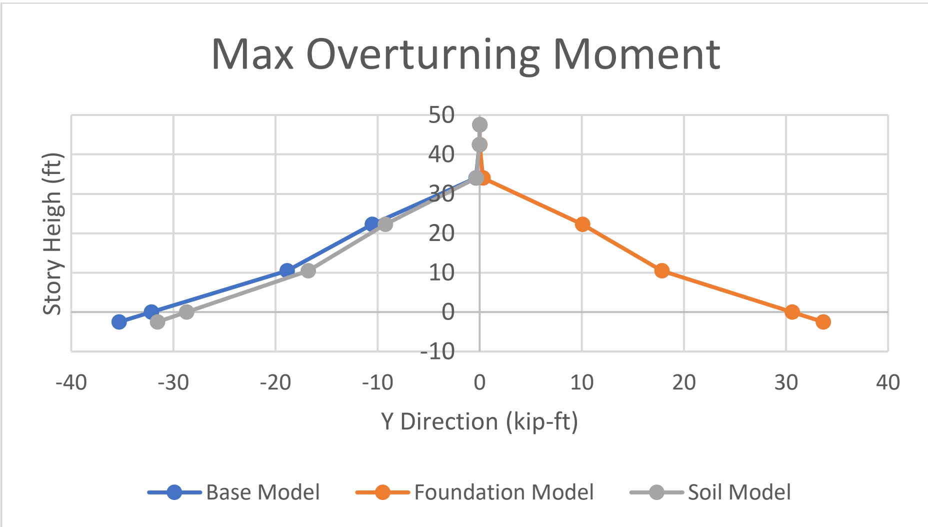

Figure 4.9 Max overturning moment. (3/modal/y)

Max overturning moment for modal responses in the x- and y-direction are shown above which are like the story shears. The plots are similar in shape regardless of the difference in their values which are although significant.

4.1.1.2 Dead Load Response

Dead Load responses are further categorized into 3 different categories listed below:

- Max Story Displacement
- Max Story Drifts
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

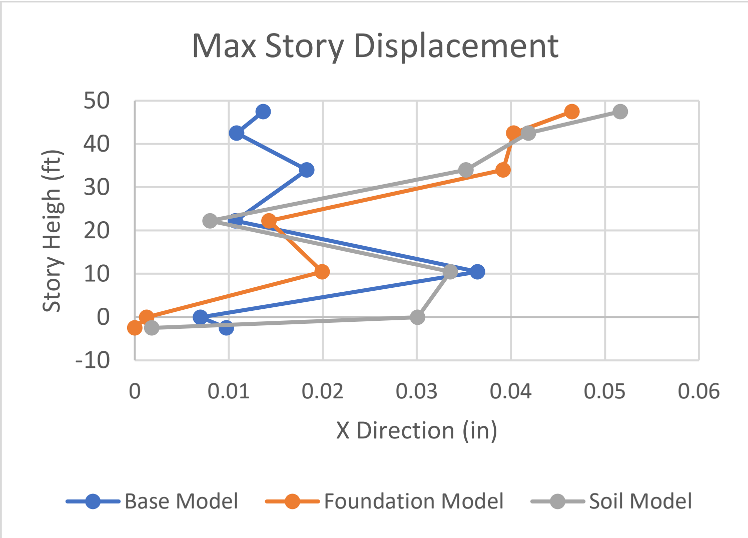

Figure 4.10 Max story displacement. (3/dead/x)

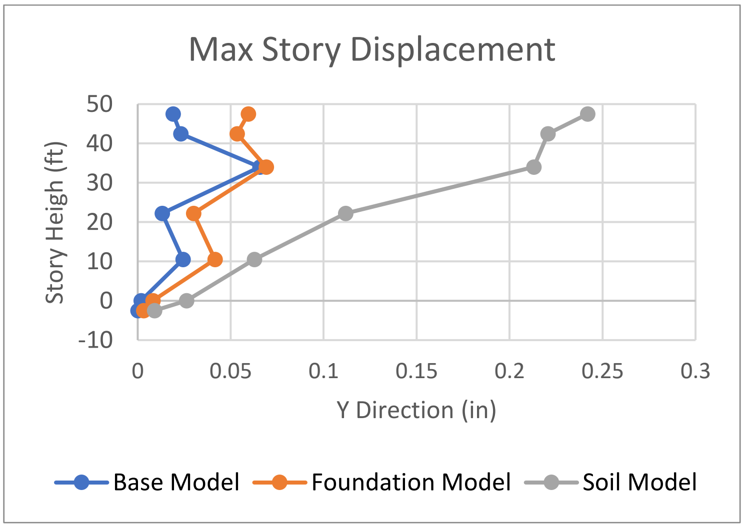

Figure 4.11 Max story displacement. (3/dead/y)

The plots above show the maximum displacements each story within each model undergoes against the dead load. It can be seen how the soil model response deviates significantly from the other two in the y-direction response.

b) Max Story Drift

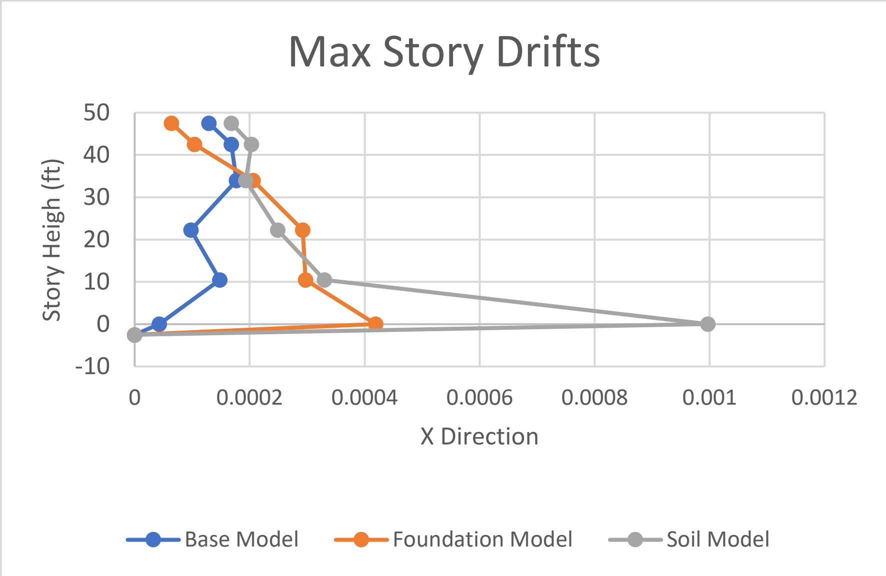

Figure 4.12 Max story drift. (3/dead/x)

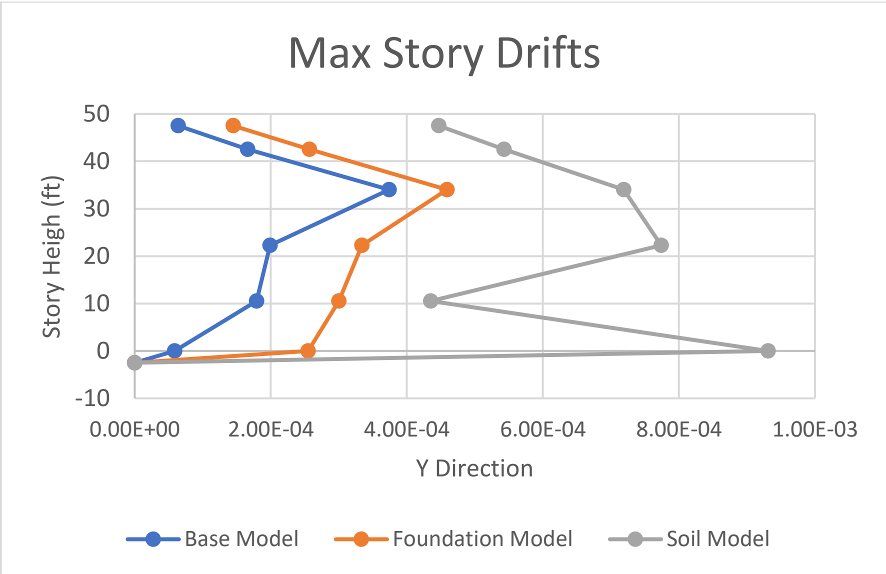

Figure 4.13 Max story drift. (3/dead/y)

Figures above show the maximum story drifts under the dead load. The significant difference in magnitudes of the three responses can be clearly seen from the plots.

c) **STORY OVERTURNING MOMENT**

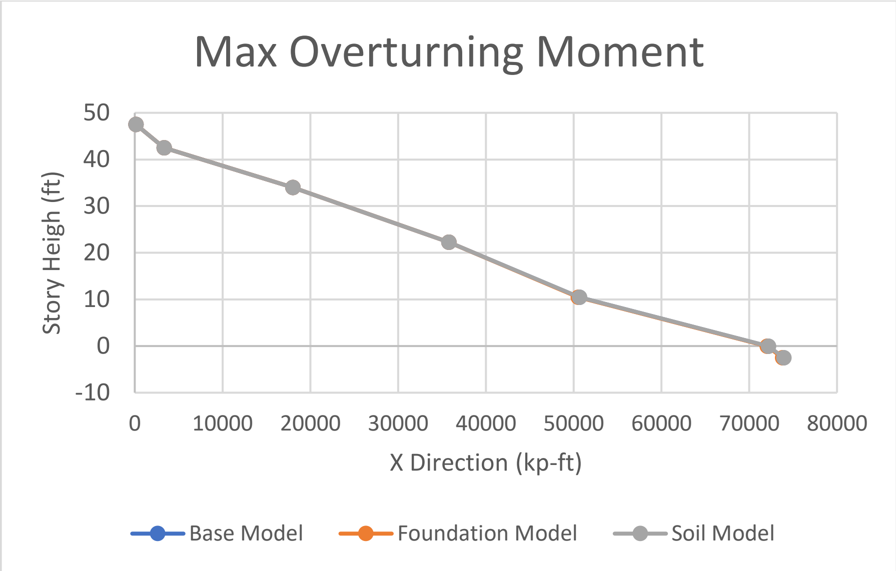

Figure 4.14 Max overturning moment. (3/dead/x)

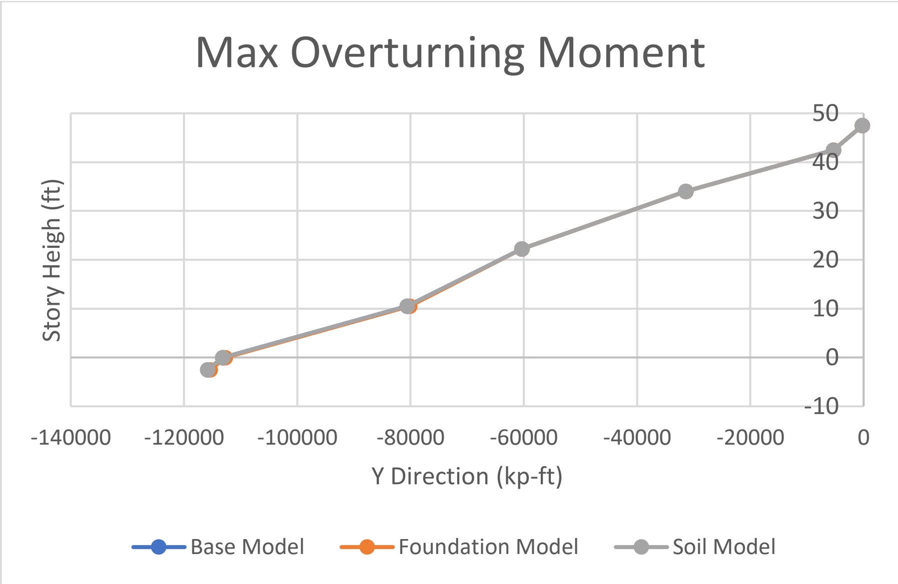

Figure 4.15 Max overturning moment. (3/dead/y)

Maximum overturning moment for each story against the dead load in the 3-story building is shown above in x- and y-direction consequently.

4.1.1.3 Live Load Response

Live Load responses are further categorized into 3 different categories listed below:

- Max Story Displacement
- Max Story Drifts
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

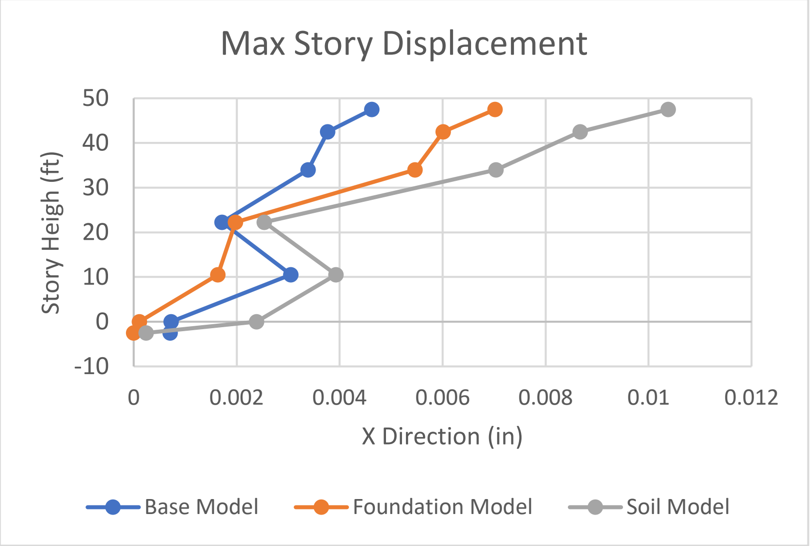

Figure 4.16 Max story displacement. (3/live/x)

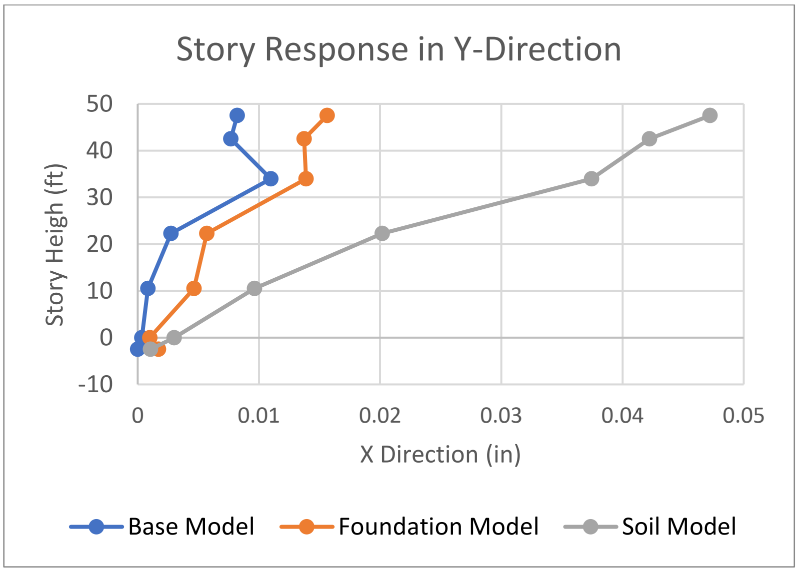

Figure 4.17 Max story displacement. (3/live/y)

The significant magnitude variation in the three max story displacement responses for the live loads in both the x- and y-direction can clearly be seen in the plots above.

b) Max Story Drift

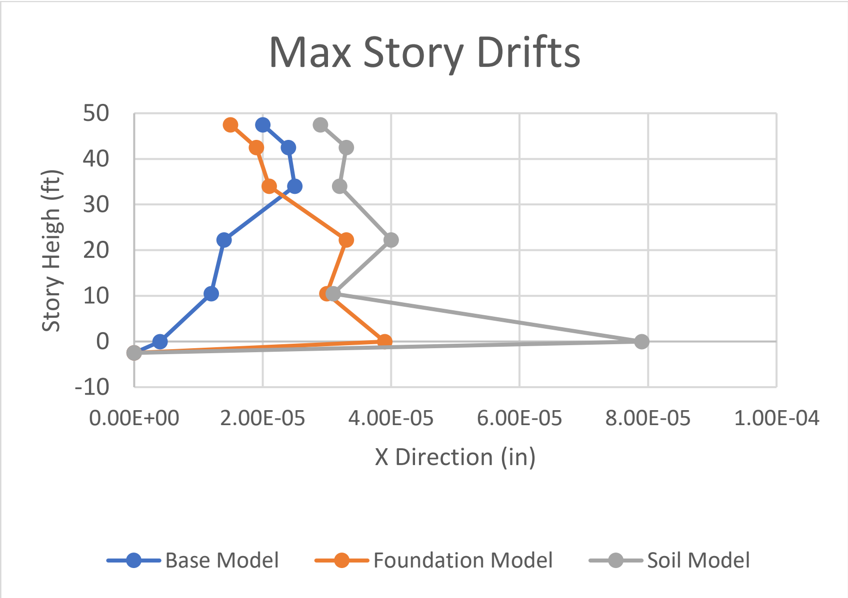

Figure 4.18 Max story drift. (3/live/x)

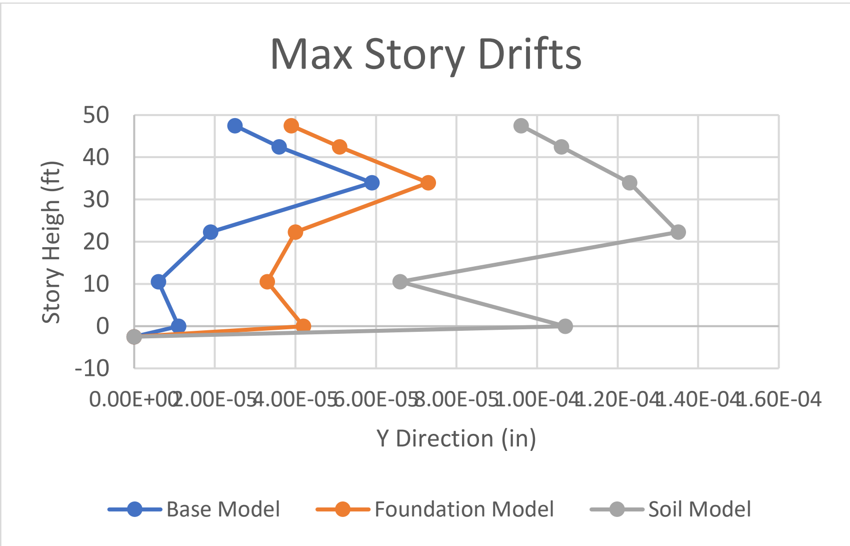

Figure 4.19 Max story drift. (3/live/y)

The similar variation as in the story displacements can be seen here in the maximum story drifts under the live loads.

c) Story Overturning Moment

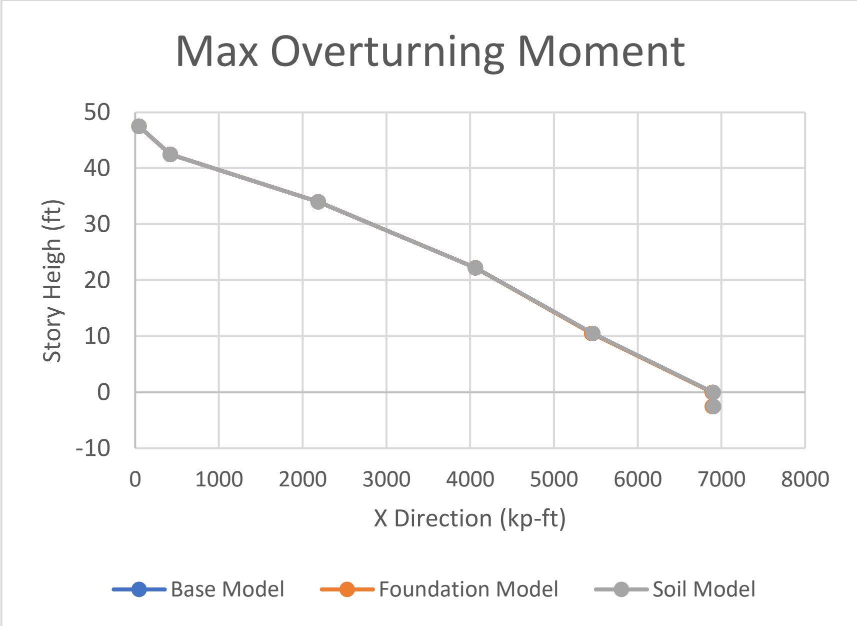

Figure 4.20 Max overturning moment. (3/live/x)

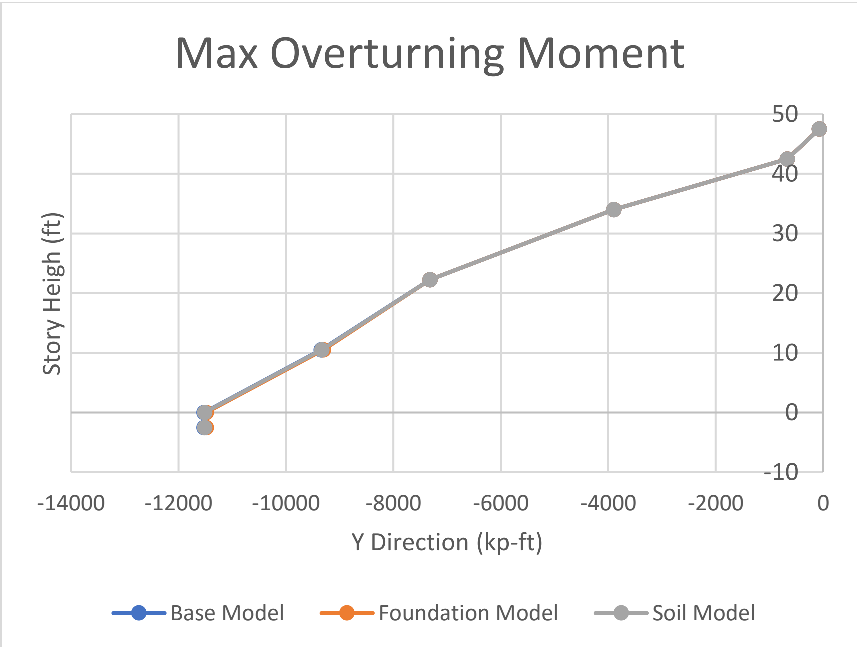

Figure 4.21 Max overturning moment. (3/live/y)

Maximum overturning moment for each story against the live load in the 3-story building is shown above in x- and y-direction consequently.

4.1.1.4 EQx Response

Eqx responses are further categorized into 4 different categories listed below:

- Max Story Displacement
- Max Story Drifts
- Story Shear
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

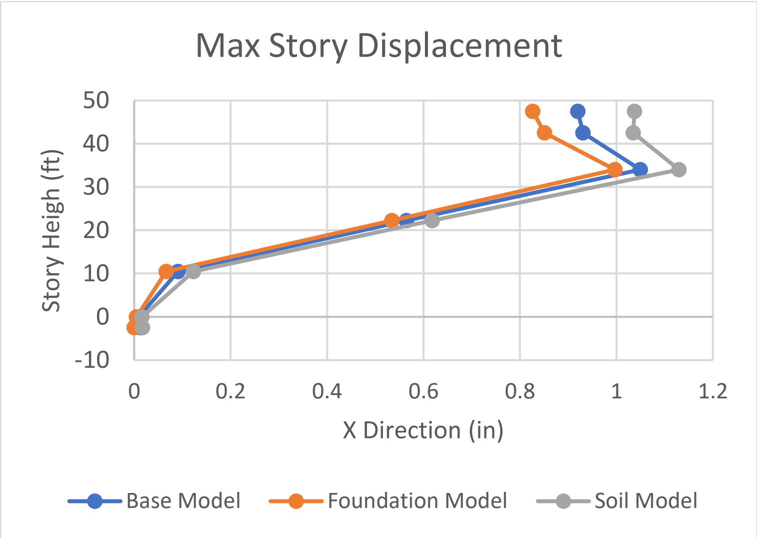

Figure 4.22 Max story displacement. (3/EQx/x)

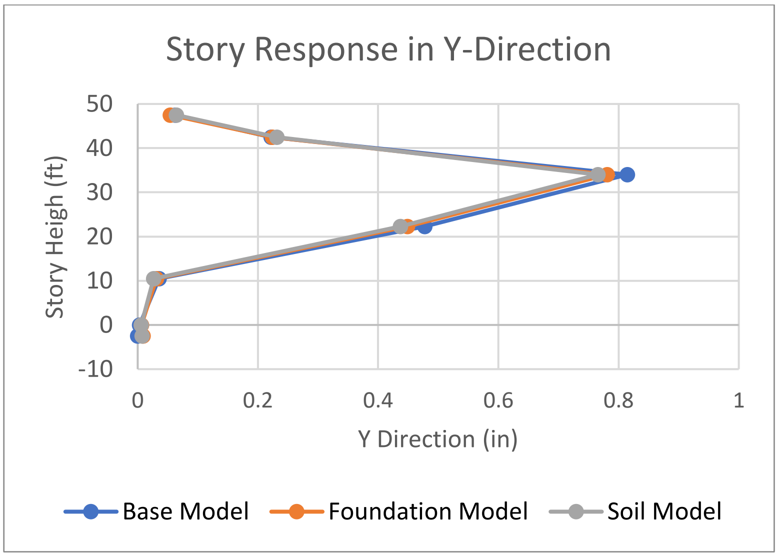

Figure 4.23 Max story displacement. (3/EQx/y)

Maximum story displacements in x- and y-direction under x-directional earthquake loading are shown above. The similar shape of the plots can be seen however, the magnitude difference for top story in x-direction is also clearly visible.

b) Max Story Drift

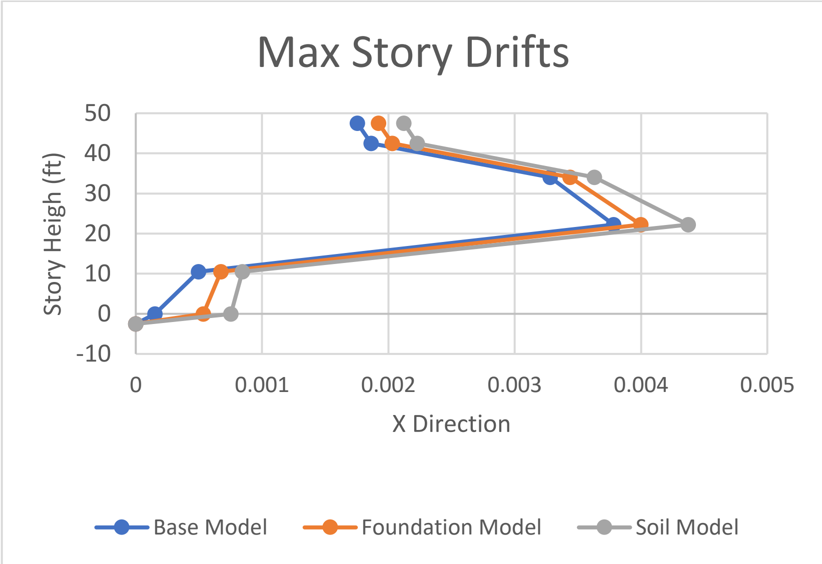

Figure 4.24 Max story drift. (3/EQx/x)

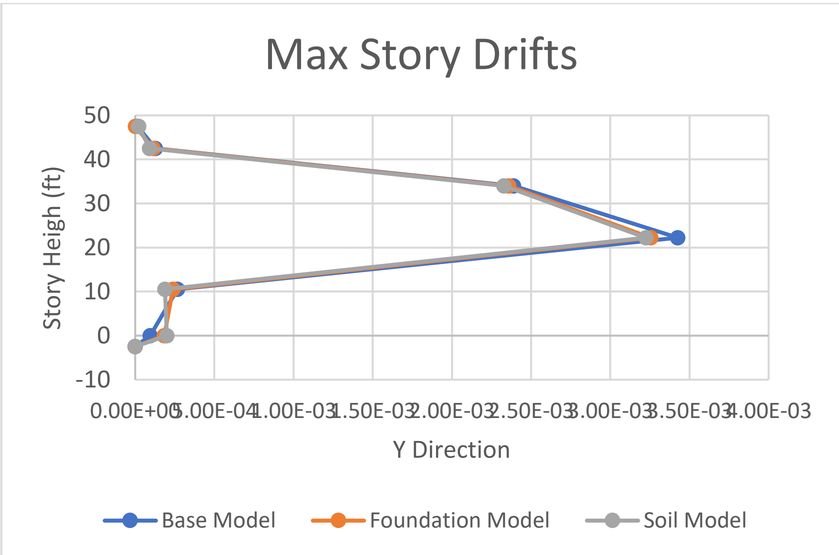

Figure 4.25 Max story drift. (3/EQx/y)

Maximum story drifts for x-directional earthquake loading are shown above. The magnitude difference in x-directional response is more than that of y-directional response.

c) Story Shear

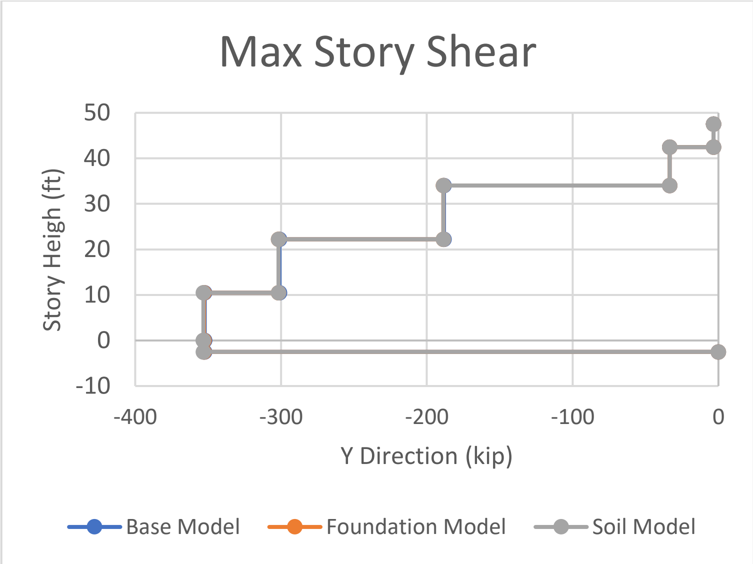

Figure 4.26 Max story shear. (3/EQx/x)

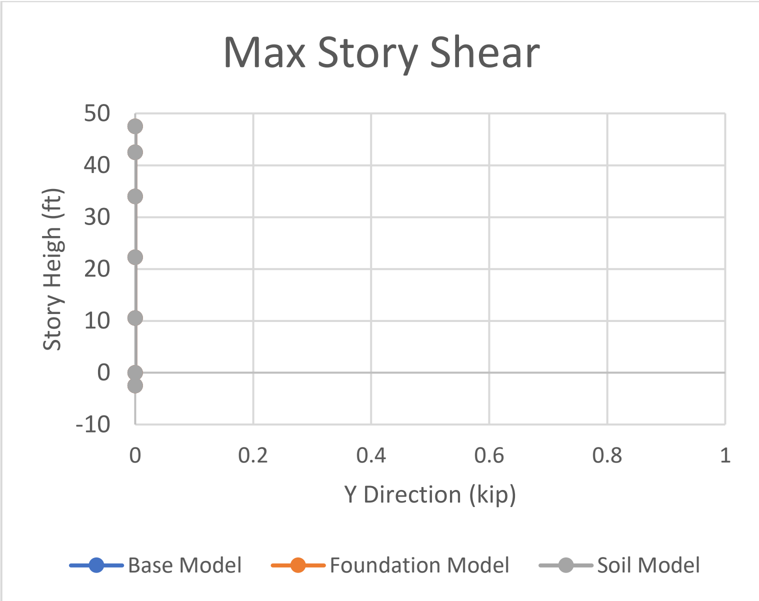

Figure 4.27 Max story shear. (3/EQx/y)

It can be seen from the above responses how the x-directional earthquake generates story shears only in the x-direction and not in the y-direction of the building.

d) Maximum Overturning Moment

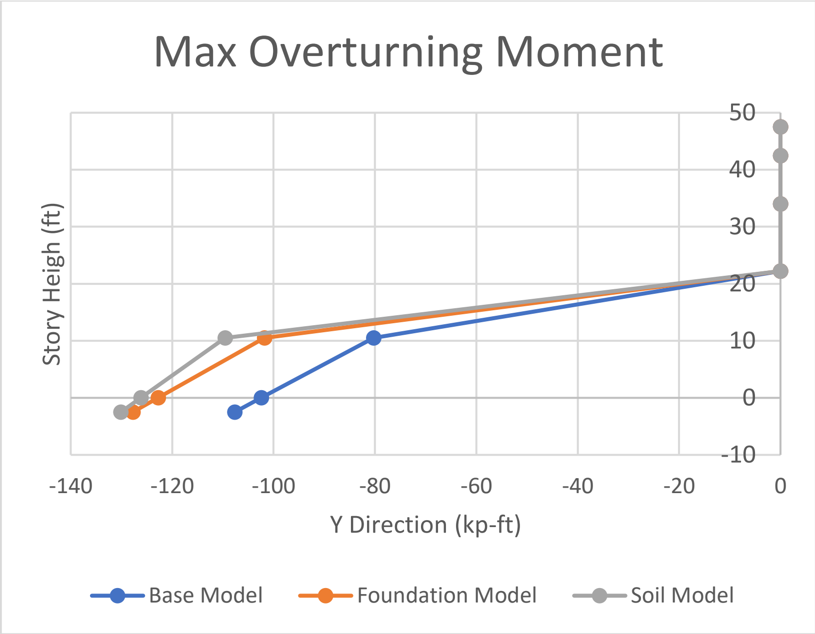

Figure 4.28 Max overturning moment. (3/EQx/x)

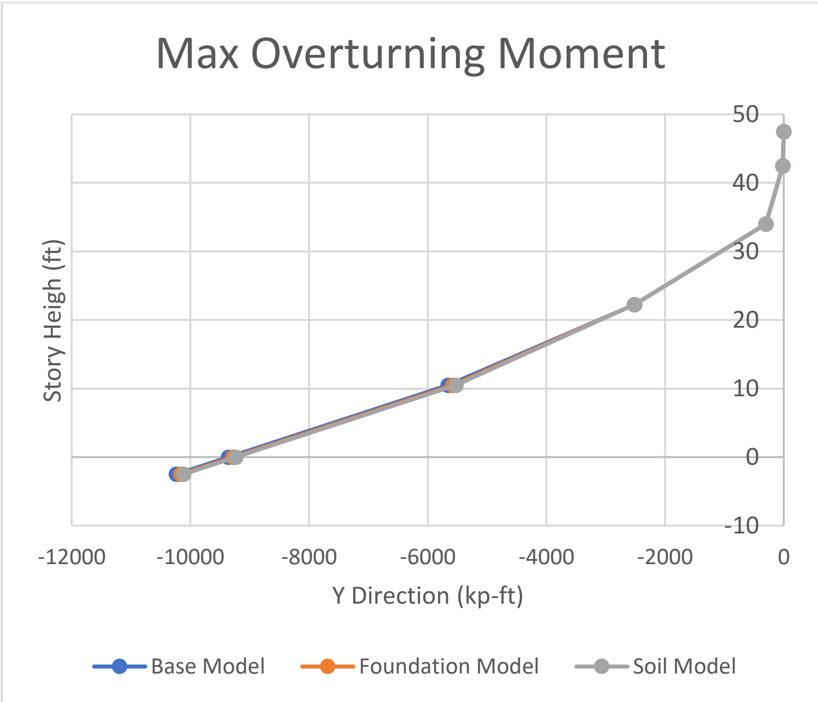

Figure 4.29 Max overturning moment. (3/EQx/y)

Maximum overturning moments under x-directional earthquake show more variation for x-direction responses than the y-direction.

4.1.1.5 EQy RESPONSE

EQy responses are further categorized into 4 different categories, listed below.

- Max Story Displacement
- Max Story Drifts
- Story Shear
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

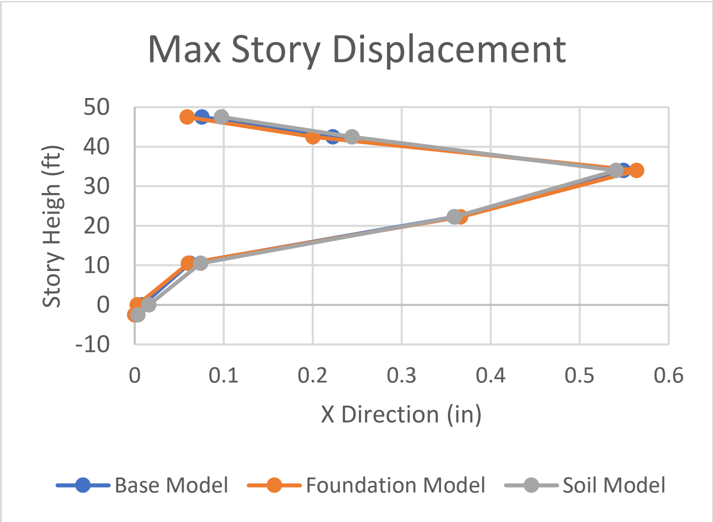

Figure 4.30 Max story displacement. (3/EQy/x)

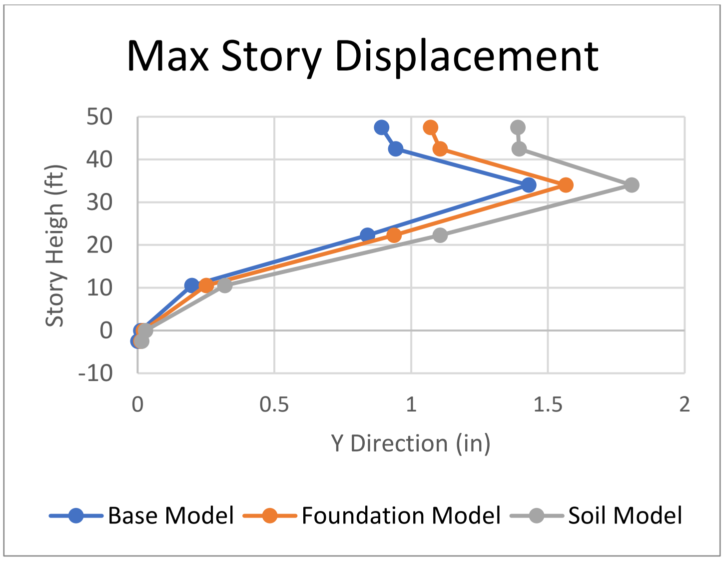

Figure 4.31 Max story displacement. (3/EQy/y)

Maximum story displacements in x- and y-direction under y-directional earthquake loading are shown above. The similar shape of the consequent plots can be seen however, the magnitude difference in the y-directional response is also clearly visible.

b) Max Story Drift

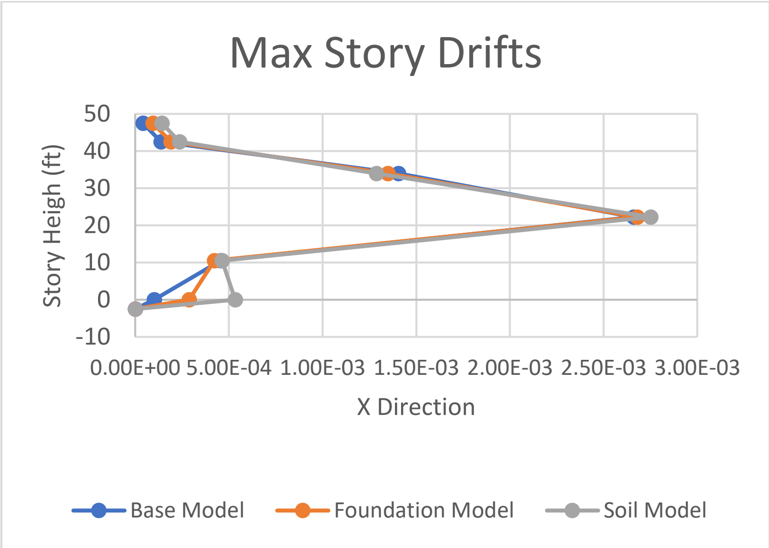

Figure 4.32 Max story drift. (3/EQy/x)

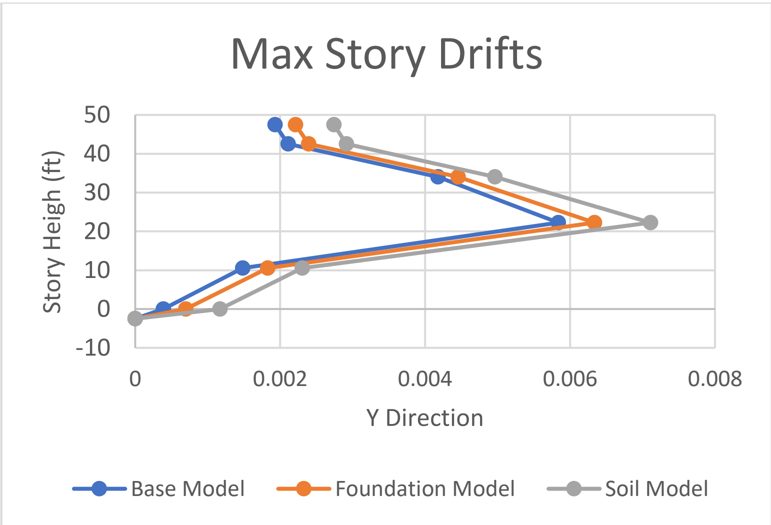

Figure 4.33 Max story drift. (3/EQy/y)

Maximum story drifts in x- and y-direction under y-directional earthquake loading are shown above. It can be seen how the building response in y-direction shows more variation in magnitude than that in x-direction.

c) **Story Shear**

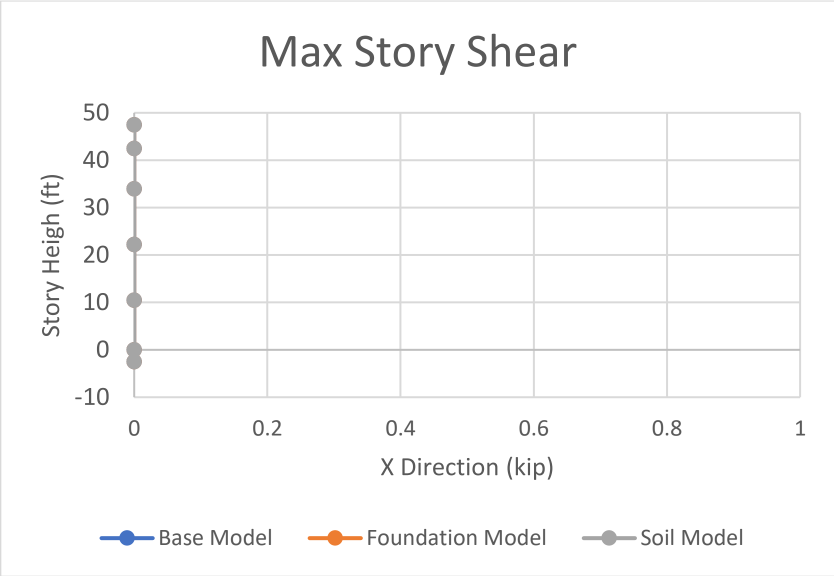

Figure 4.34 Max story shear. (3/EQy/x)

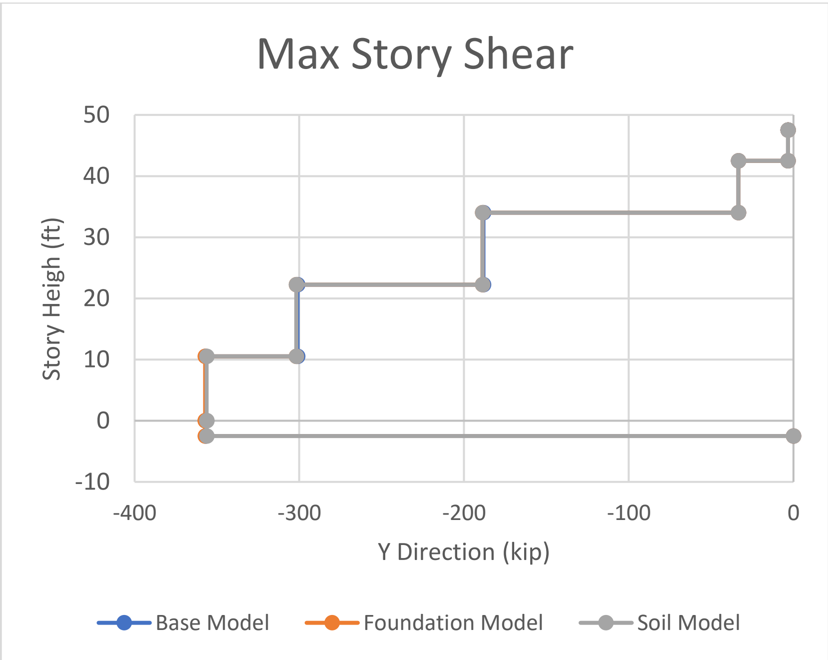

Figure 4.35 Max story shear. (3/EQy/y)

It can be seen from the above responses how the y-directional earthquake generates story shears only in the y-direction and not in the x-direction of the building.

d) Maximum Overturning Moment

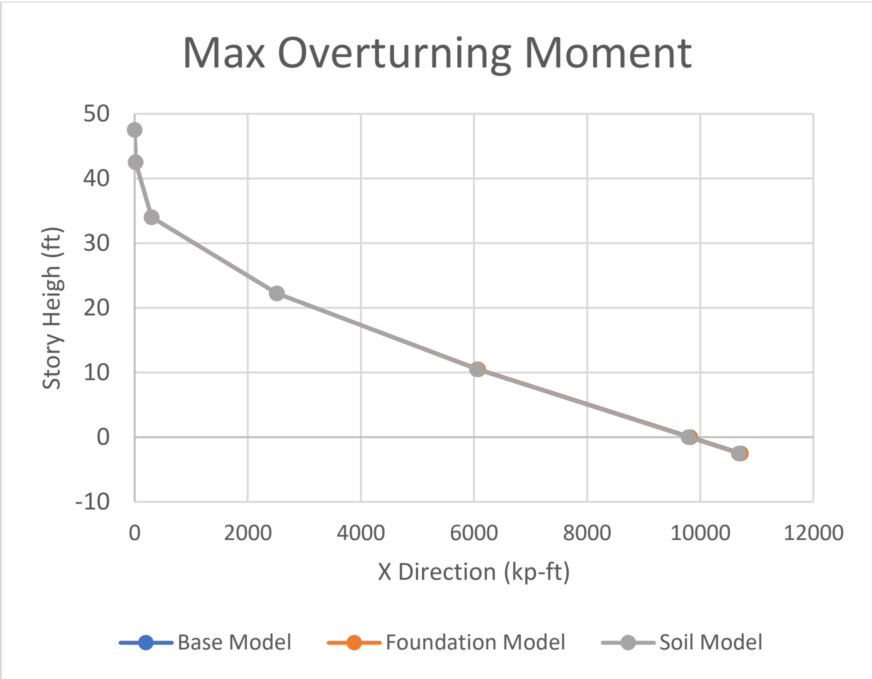

Figure 4.36 Max overturning moment. (3/EQy/x)

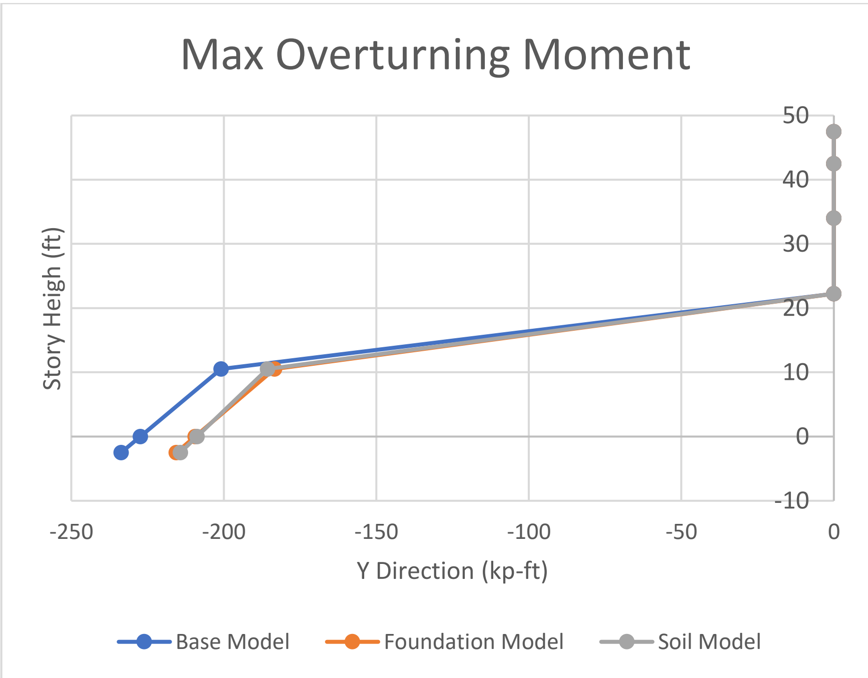

Figure 4.37 Max overturning moment. (3/EQy/y)

Maximum overturning moments under y-directional earthquake show more variation for y-direction responses than the x-direction.

4.1.2 Local Responses

In local responses we recorded different responses of Column *C5* and Pier *P3*. Here again three of the modals (Base, Soil, Foundation) were compared with each other using the shear (V2) and moment (M3) diagrams.

4.1.2.1 Column – C5

Responses recorded for column C5 are listed below:

- Dead Load Response
- Live Load Response
- EQx
- EQy

a) Dead Load Response

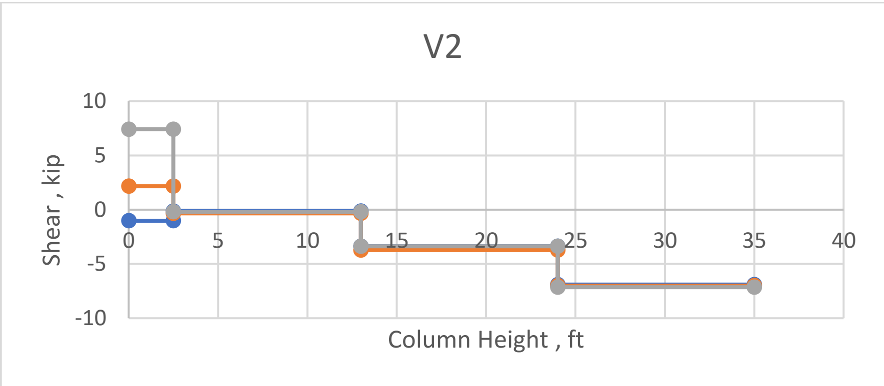

Figure 4.38 DL Shear V2. (3/C5)

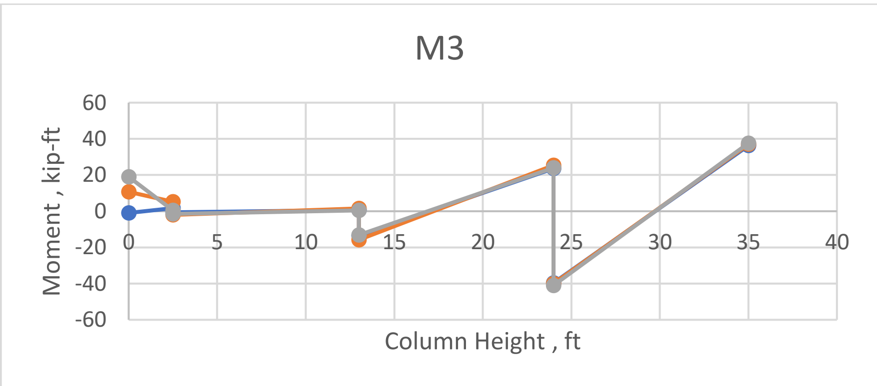

Figure 4.39 DL Moment M3. (3/C5)

Shear V2 and the corresponding moment M3 under Dead Load for the C5 column in the 3-story building is shown above.

b) Live Load Response

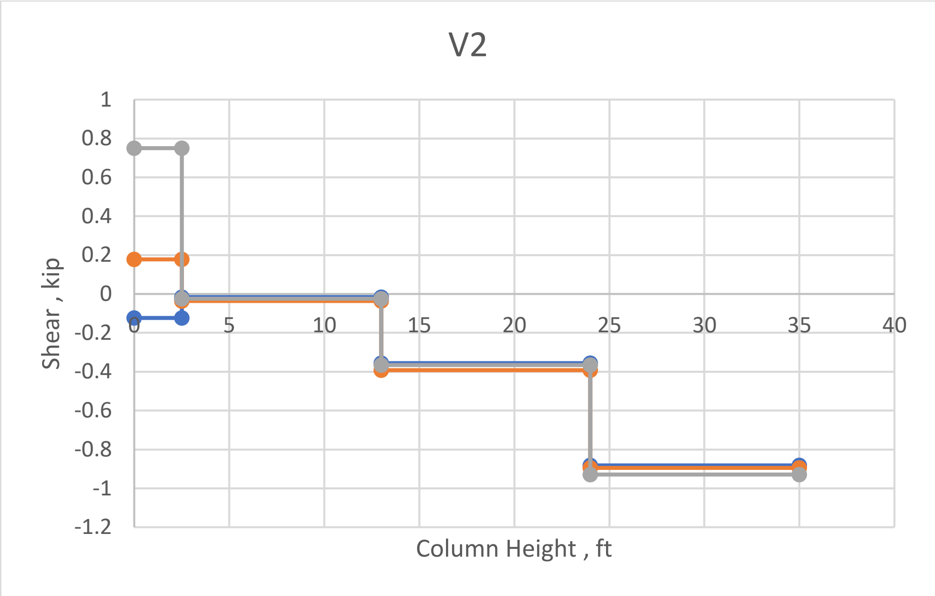

Figure 4.40 LL Shear V2. (3/C5)

Figure 4.41 LL Moment M3. (3/C5)

Shear V2 and the corresponding moment M3 under Live Load for the C5 column in the 3-story building is shown above. Similar trends with a slight difference in magnitude for these responses can be seen in the above plots.

c) EQx Response

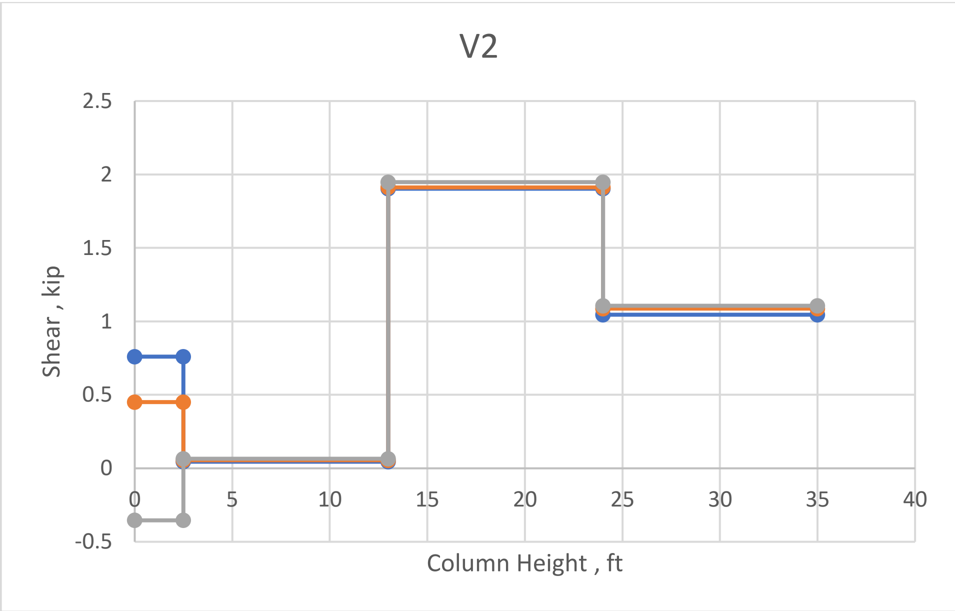

Figure 4.42 EQx Shear V2. (3/C5)

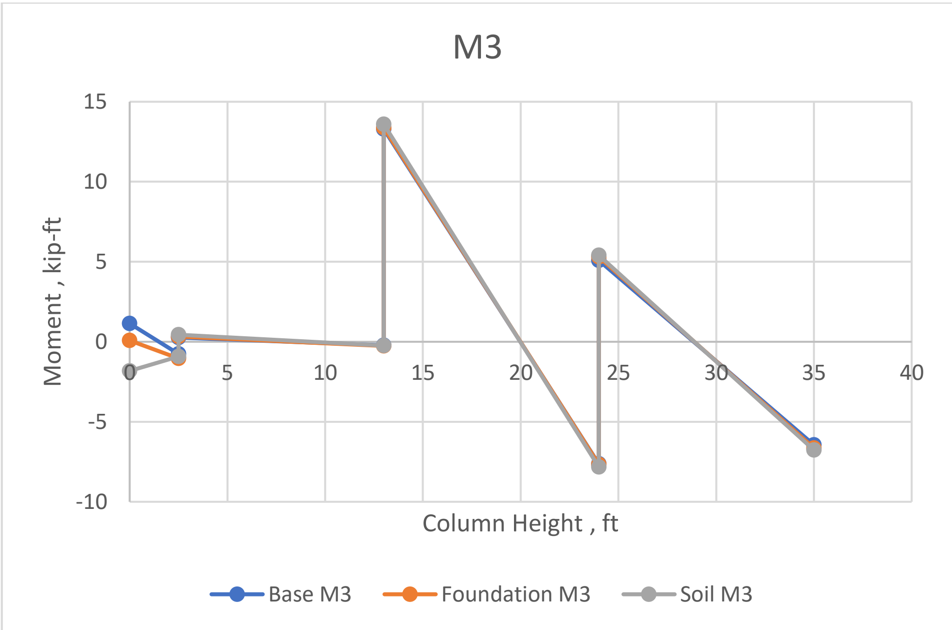

Figure 4.43 EQx Moment M3. (3/C5)

Shear V2 and the corresponding moment M3 under x-directional earthquake loading for the C5 column in the 3-story building is shown above. Similar trends with a slight difference in magnitude for these responses can be seen in the above plots.

d) EQy Response

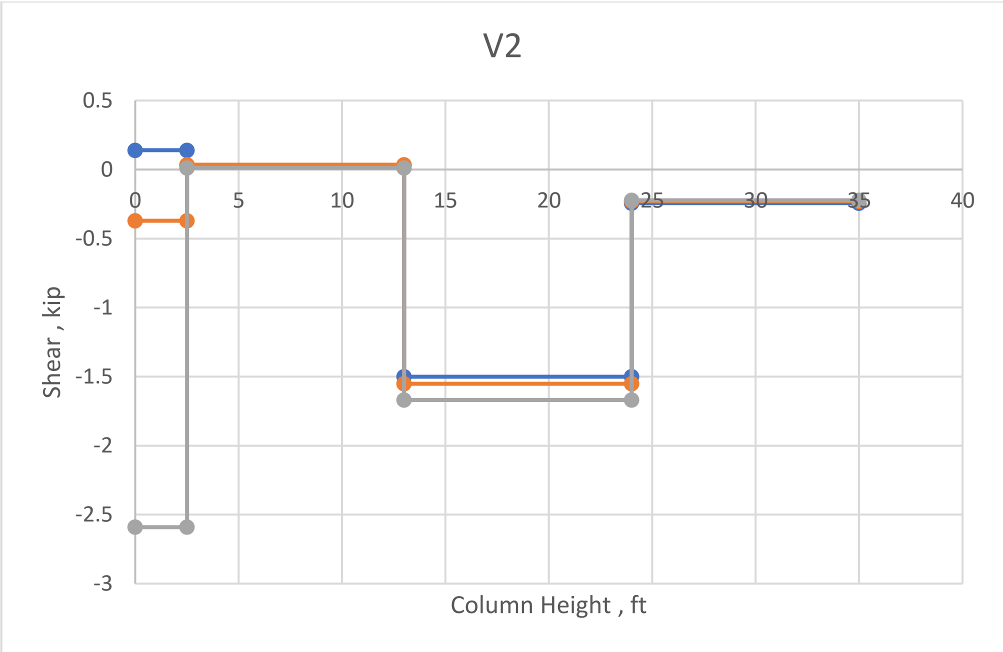

Figure 4.44 EQy Shear V2. (3/C5)

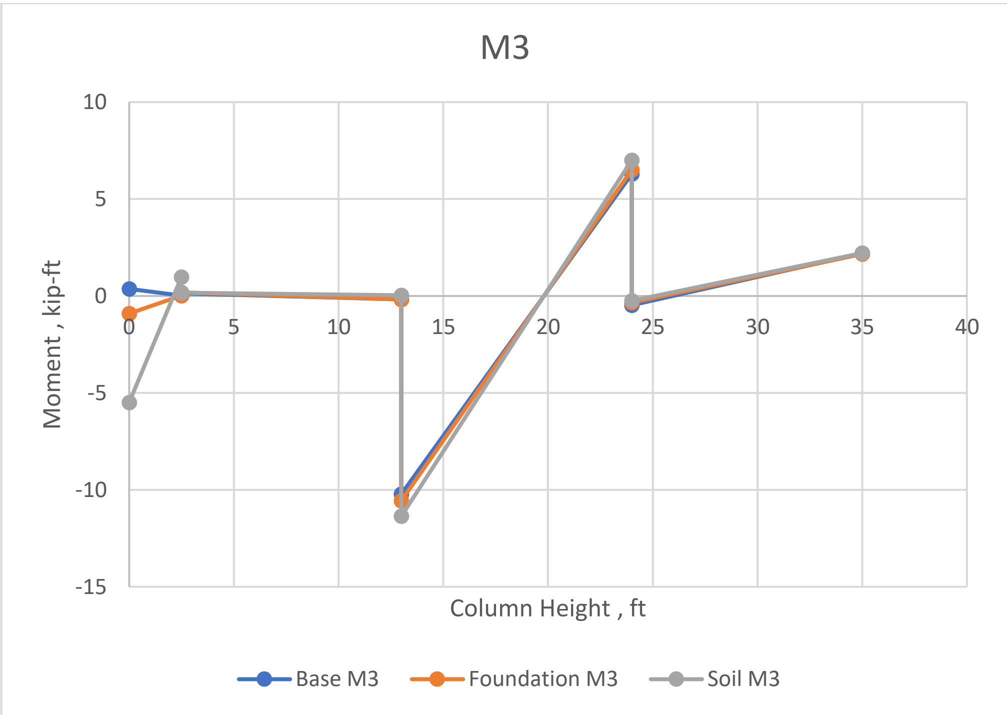

Figure 4.45 EQy Moment M3. (3/C5)

Shear V2 and the corresponding moment M3 under y-directional earthquake loading for the C5 column in the 3-story building is shown above. Similar trends with a slight difference in magnitude for these responses can be seen in the above plots.

4.1.2.2 PIER – P3

Responses recorded for pier P3 are listed below:

- Dead Load Response
- Live Load Response
- EQx
- EQy

a) Dead Load Response

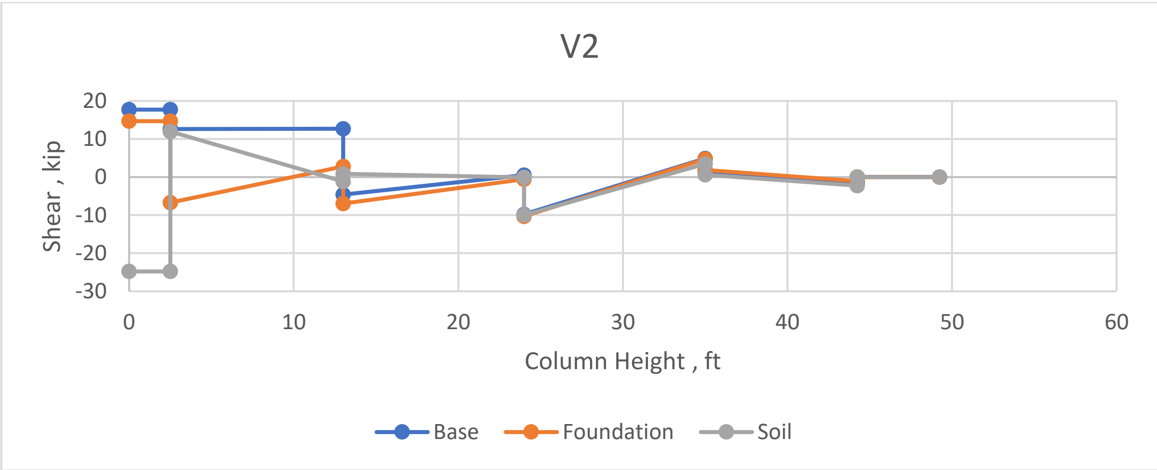

Figure 4.46 DL Shear V2. (3/P3)

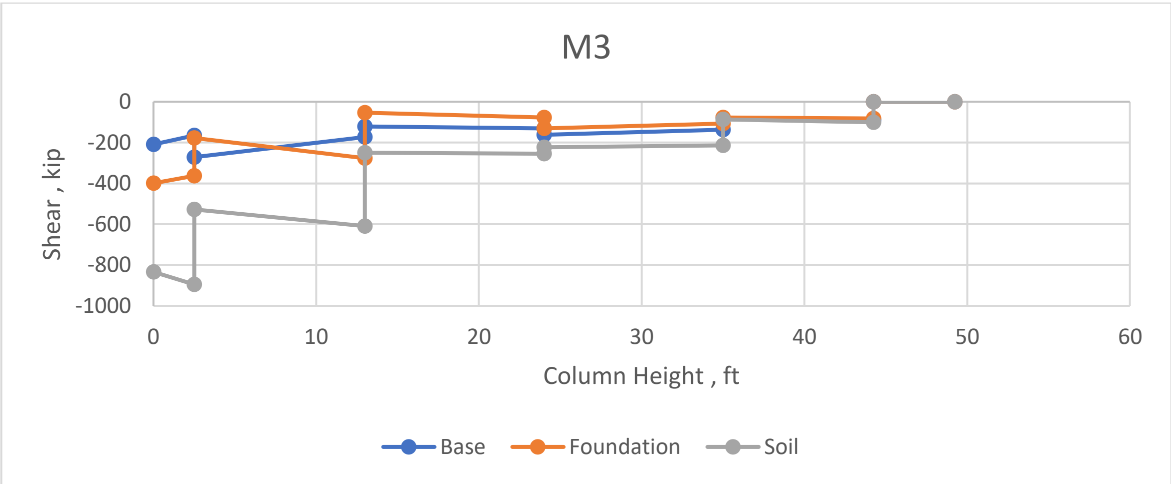

Figure 4.47 DL Moment M3. (3/P3)

Shear V2 and the corresponding moment M3 under Dead Load for the P3 pier in the 3-story building is shown above. Considerable differences in magnitude for the three consequent models in both the responses can clearly be seen.

b) Live Load Response

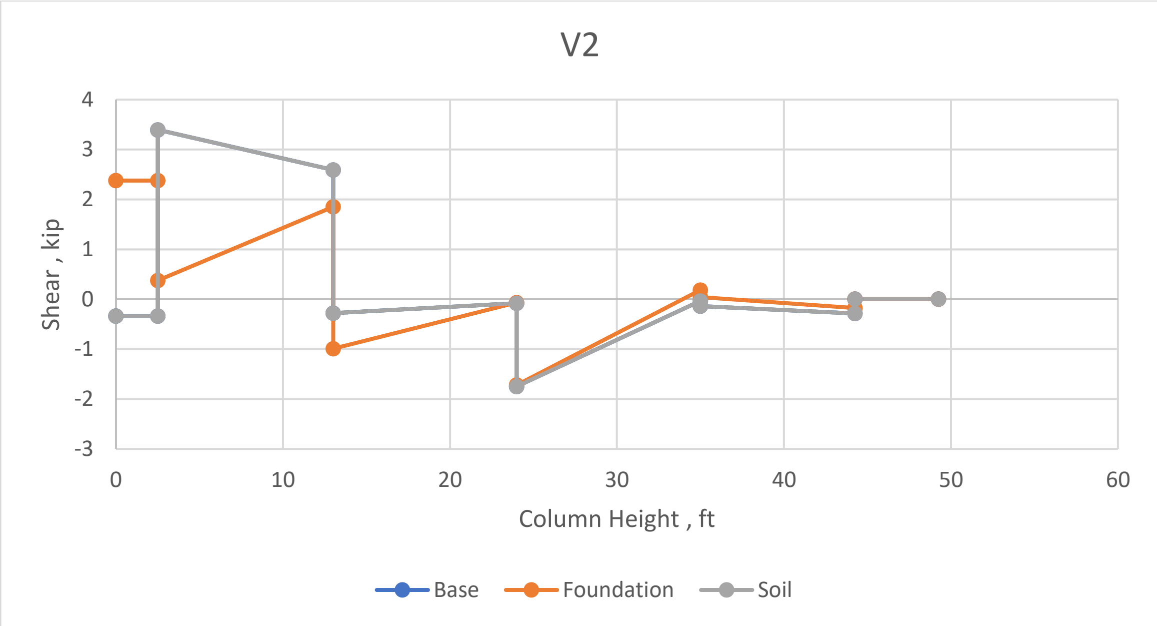

Figure 4.48 LL Shear V2. (3/P3)

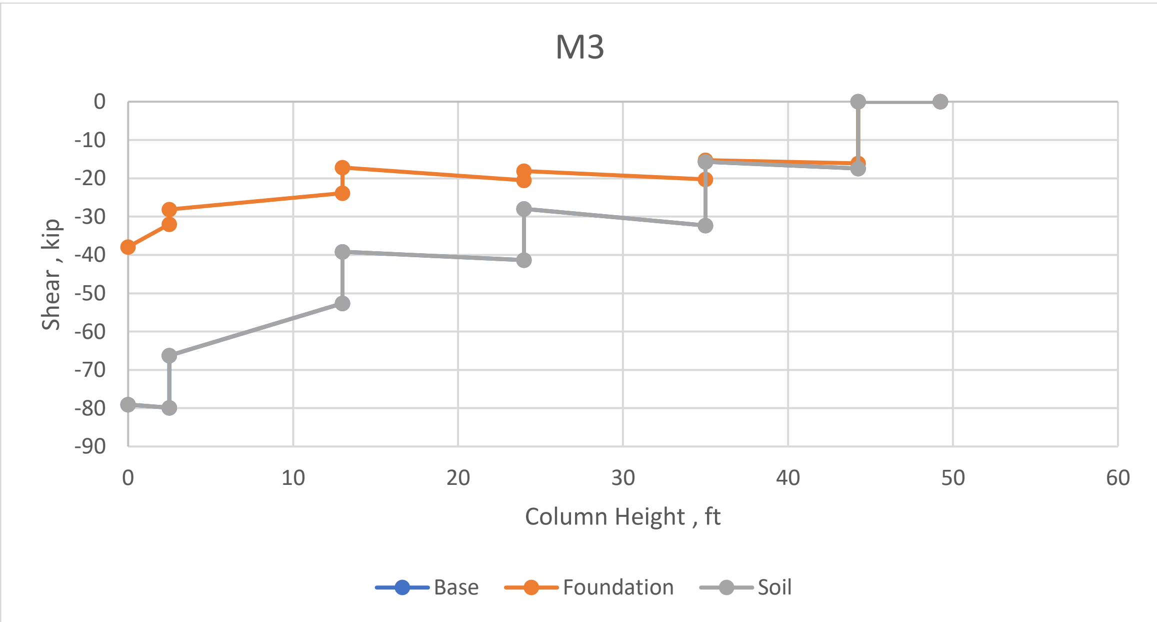

Figure 4.49 LL Moment M3. (3/P3)

Shear V2 and the corresponding moment M3 under Live Load for the P3 pier in the 3-story building is shown above. Considerable differences in magnitude for the three consequent models in both the responses can clearly be seen.

c) EQx Response

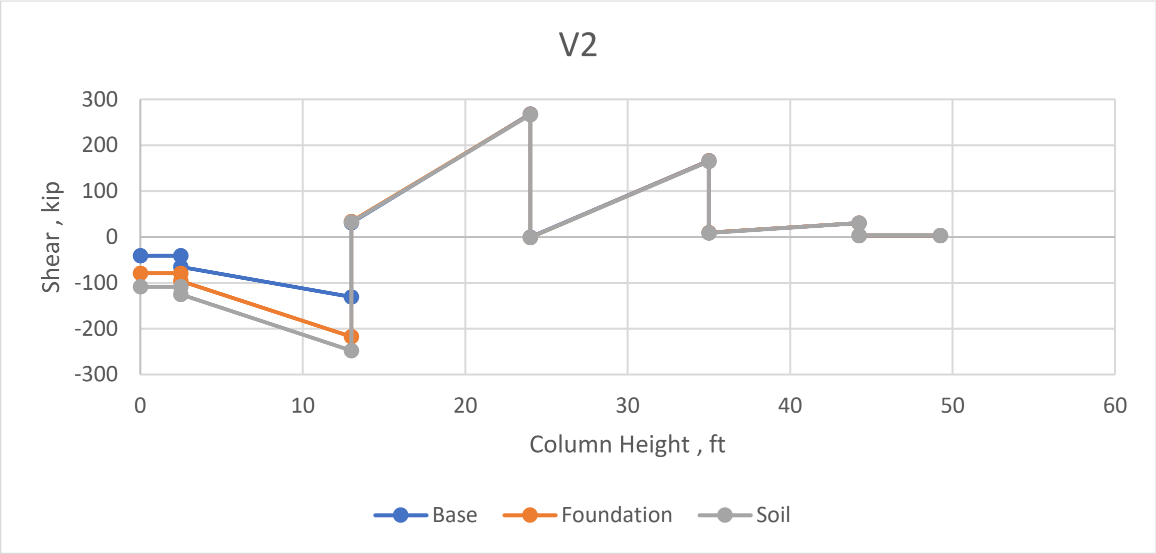

Figure 4.50 EQx Shear V2. (3/P3)

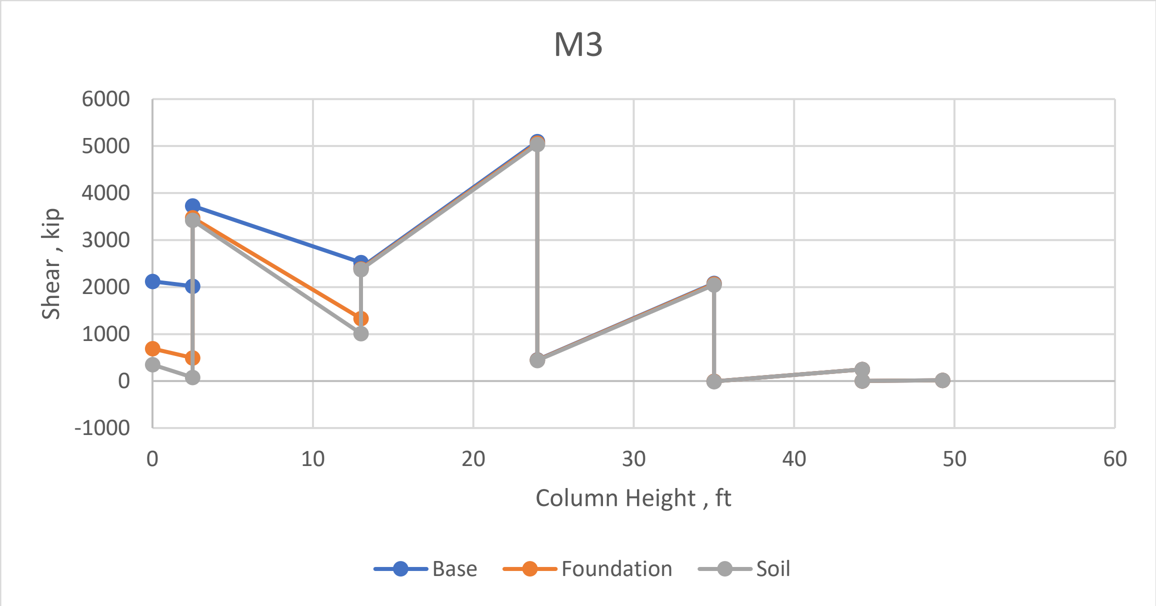

Figure 4.51 EQx Moment M3. (3/P3)

Shear V2 and the corresponding moment M3 under x-directional earthquake loading for the P3 pier in the 3-story building is shown above. It can be seen how the variations are more in the lower stories of the building and dampen down as the story height increases.

d) EQy Response

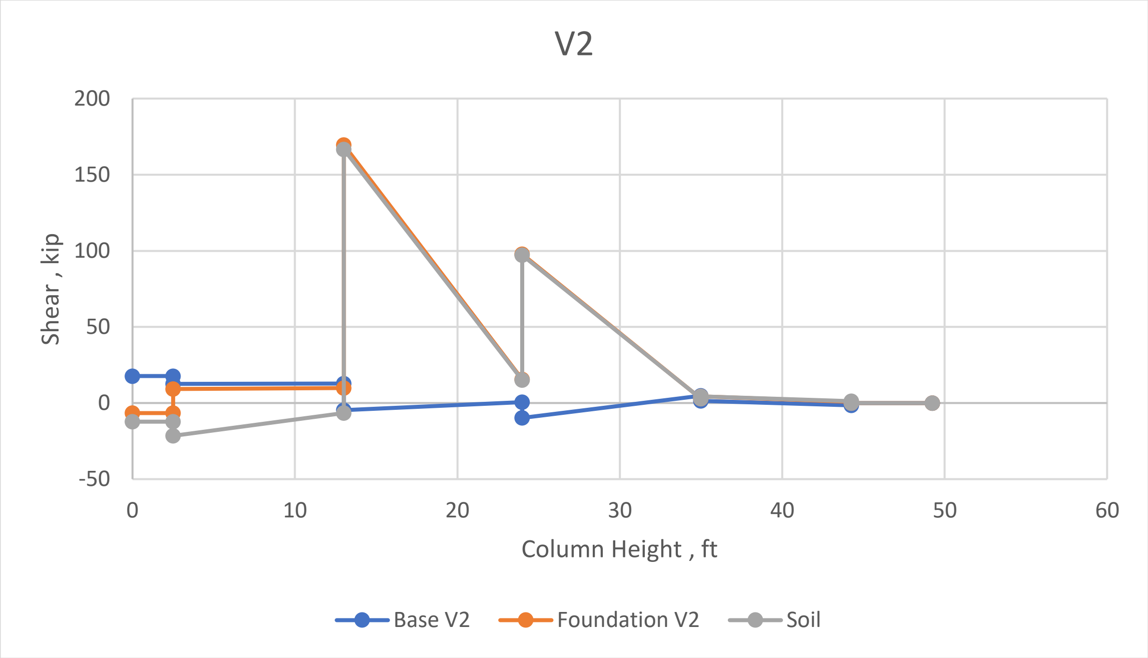

Figure 4.52 EQy Shear V2. (3/P3)

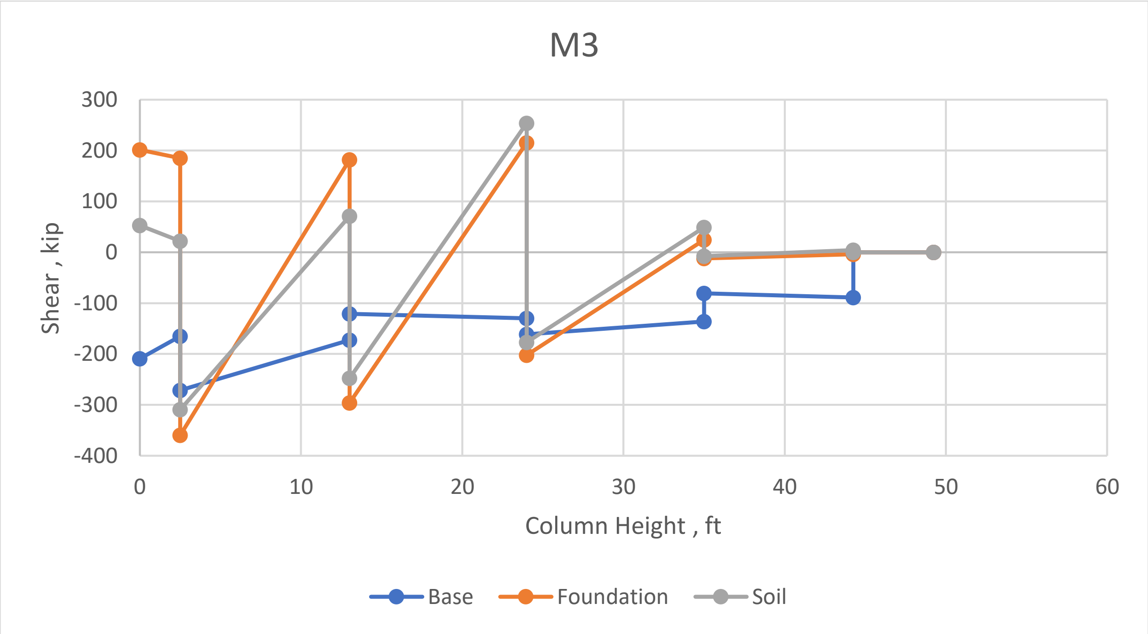

Figure 4.53 EQy Moment M3. (3/P3)

Shear V2 and the corresponding moment M3 under y-directional earthquake loading for the P3 pier in the 3-story building is shown above. Significant differences in magnitude for the three consequent models in both the responses can clearly be seen.

4.2 7-Story Building

4.2.1 Global Responses

Global responses were further categorized in to 5 different responses listed below:

- Modal Response
- Dead Load Response
- Live Load Response
- EQx
- EQy

4.2.1.1 Modal Response

Modal responses are further categorized into 4 different categories listed below:

- Max Story Displacement
- Max Story Drifts
- Story Shear
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

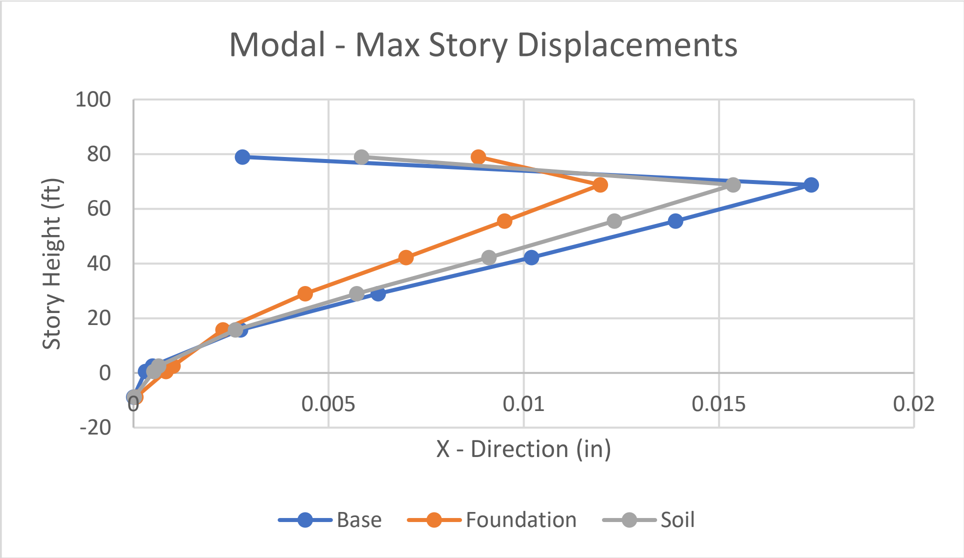

Figure 4.54 Max story displacement. (7/modal/x)

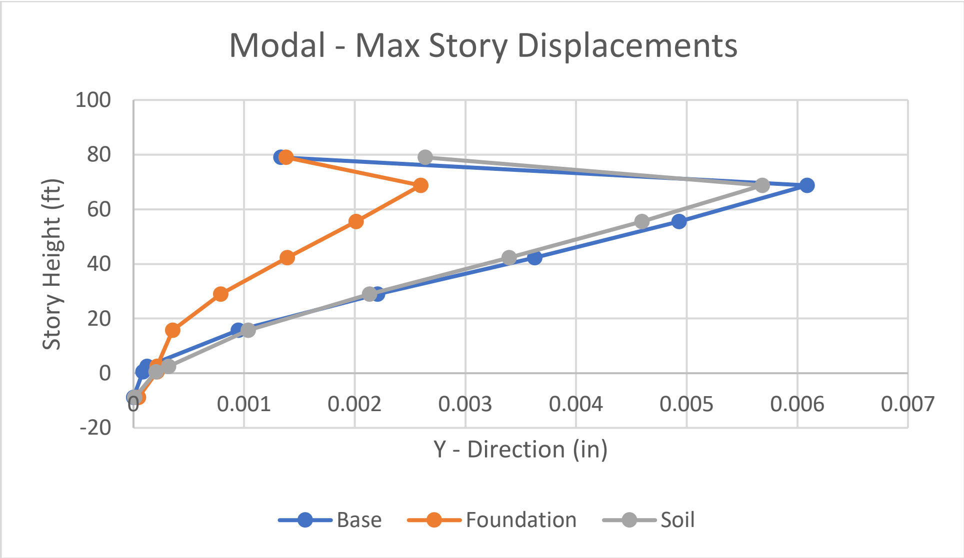

Figure 4.55 Max story displacement. (7/modal/y)

Maximum story displacement for each story under the Modal Response for 7-story building in x- and y-direction consequently is shown above. Significant variations in the responses in each direction can clearly be seen.

b) Max Story Drift

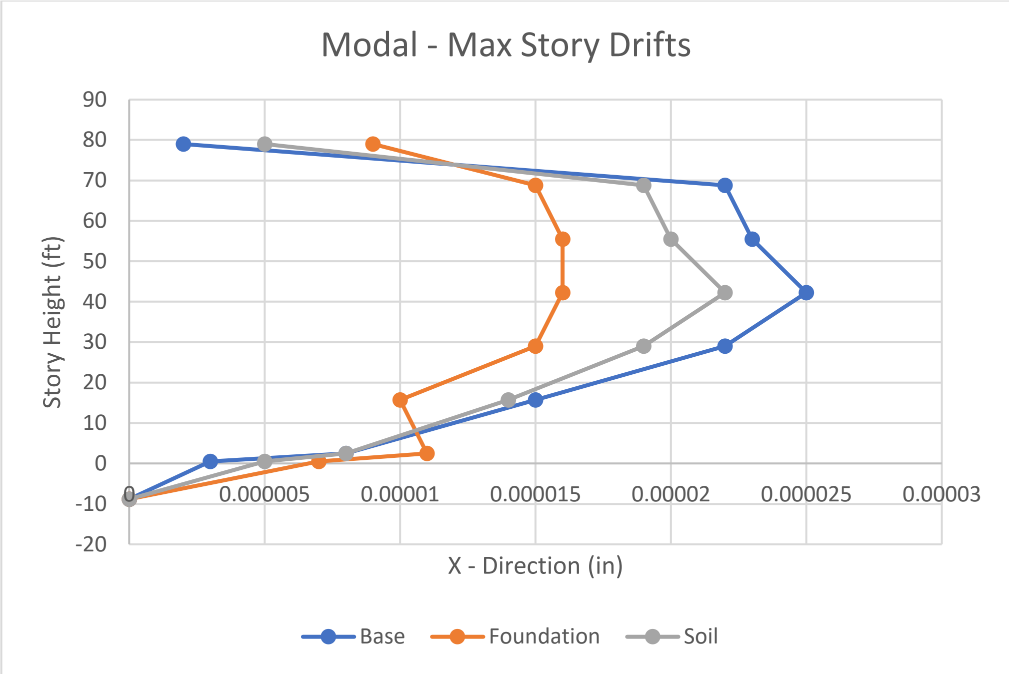

Figure 4.56 Max story drift. (7/modal/x)

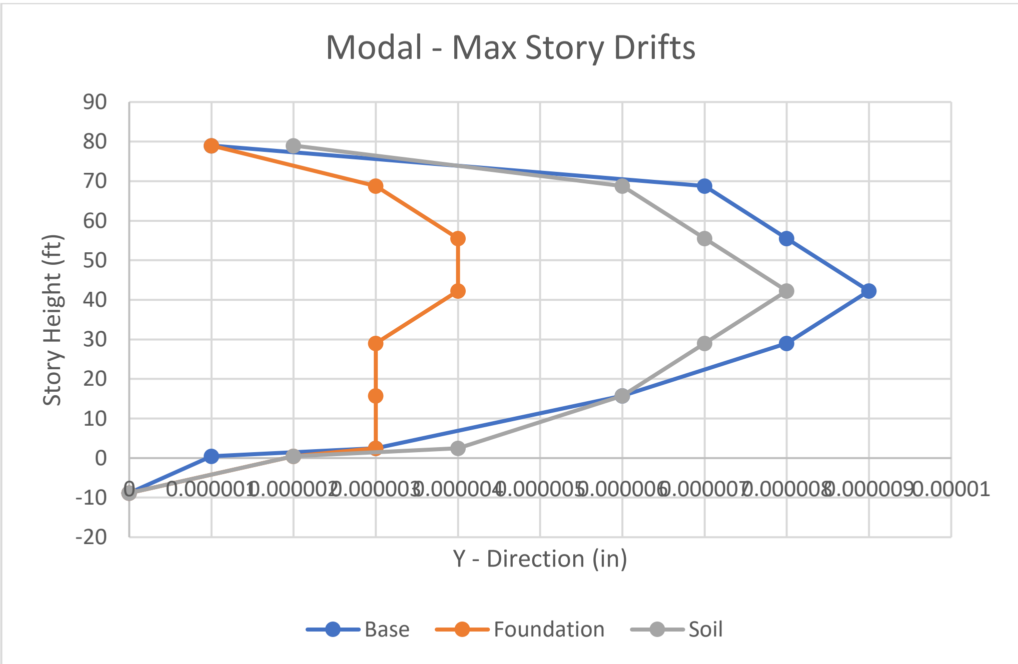

Figure 4.57 Max story drift. (7/modal/y)

Maximum story drift for the modal response is also a function of the building's mass and is similar to the maximum story displacement. Hence, it follows a similar trend.

c) Story Shear

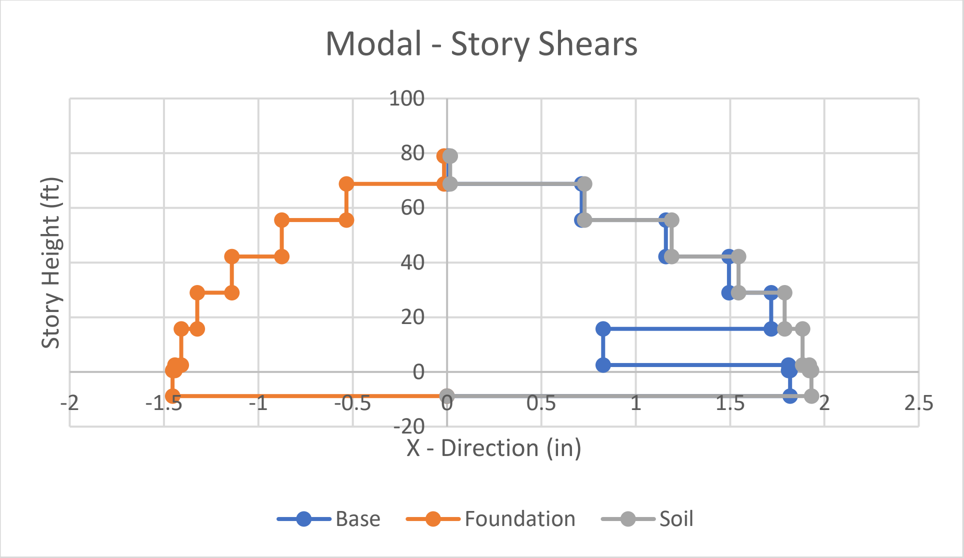

Figure 4.58 Max story shear. (7/modal/x)

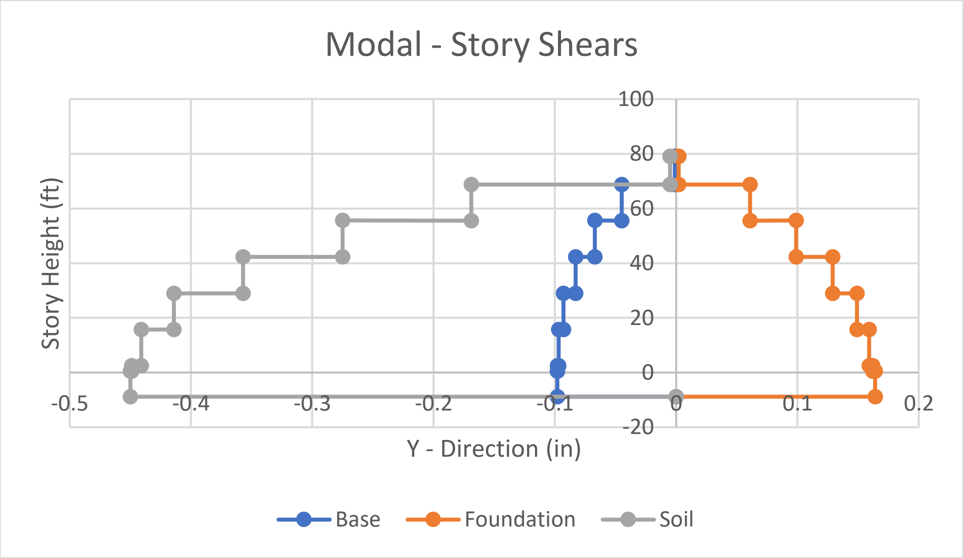

Figure 4.59 Max story shear. (7/modal/y)

Max story shears for modal responses in the x- and y-direction for the 7-story building are shown above. It can be seen that the trends are similar regardless of the difference in values which are although significant.

d) Maximum Overturning Moment

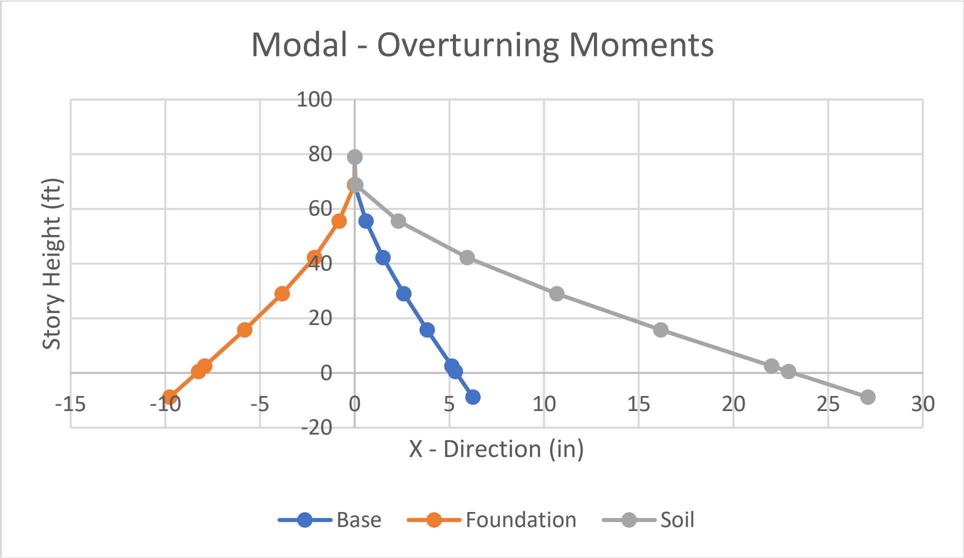

Figure 4.60 Max overturning moment. (7/modal/x)

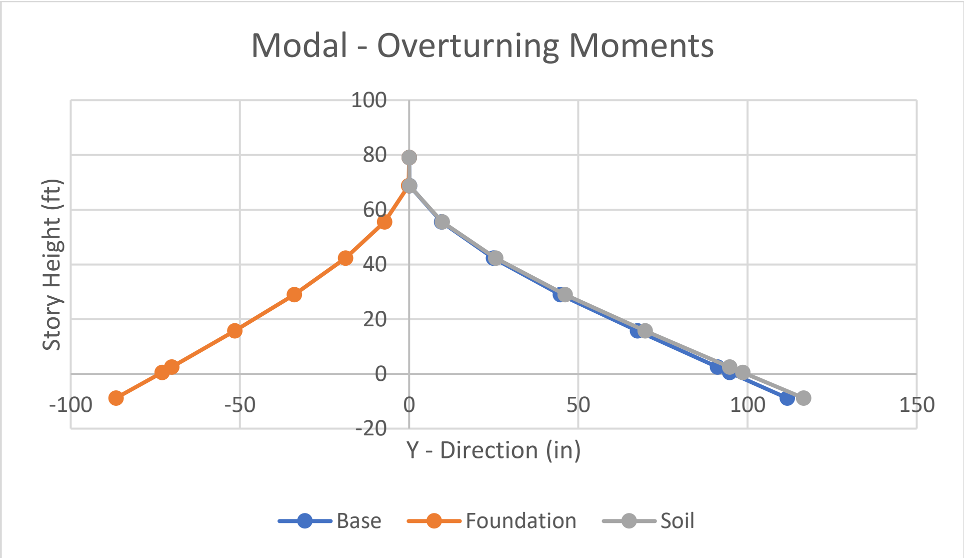

Figure 4.61 Max overturning moment. (7/modal/y)

Max overturning moment for modal responses in the x- and y-direction for the 7-story building are shown above which are in line with the story shears. It can be seen that the plots are similar in shape regardless of the difference in their magnitudes which are although significant.

4.2.1.2 Dead Load Response

Dead Load responses are further categorized into 3 different categories, listed below

- Max Story Displacement
- Max Story Drifts
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) **Max Story Displacement**

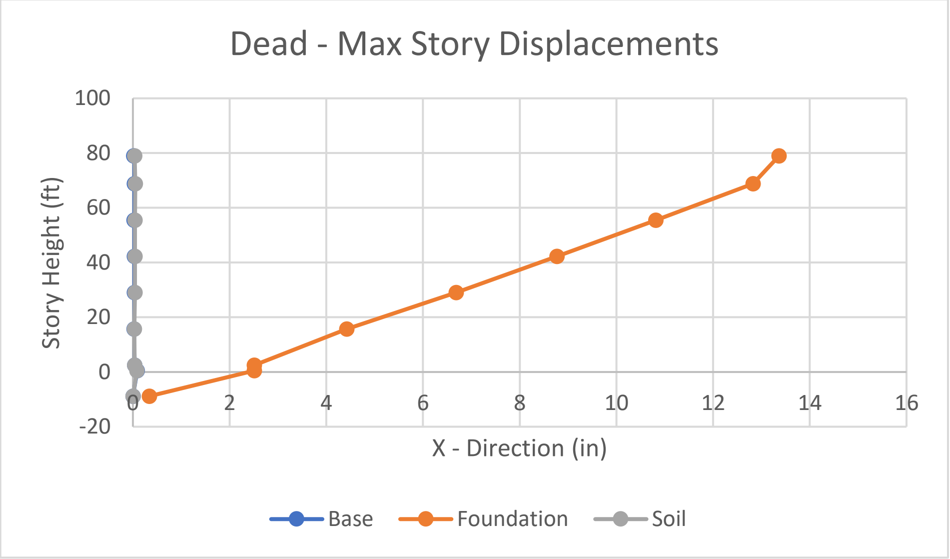

Figure 4.62 Max story displacement. (7/dead/x)

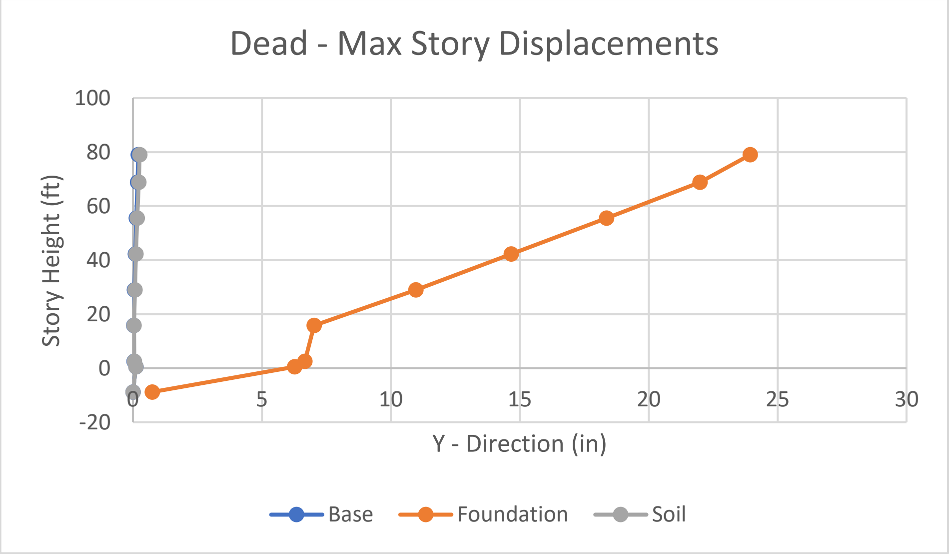

Figure 4.63 Max story displacement. (7/dead/y)

The plots above show the maximum displacements each story within each model undergoes against the dead load in the 7-story building. The abnormality in the foundation model plot stems from the model's joint conditions which are more clearly visible in the model's animation in ETABS.

b) Max Story Drift

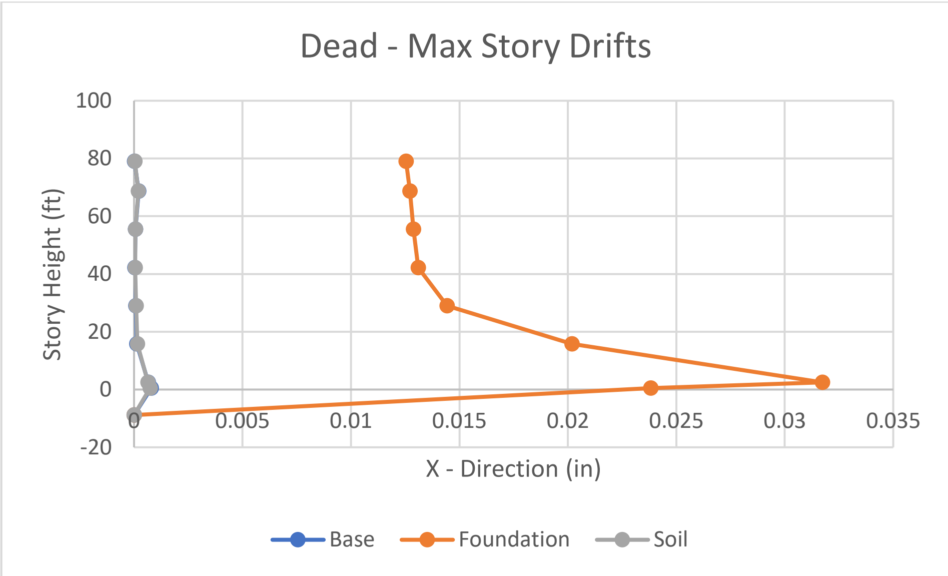

Figure 4.64 Max story drift. (7/dead/x)

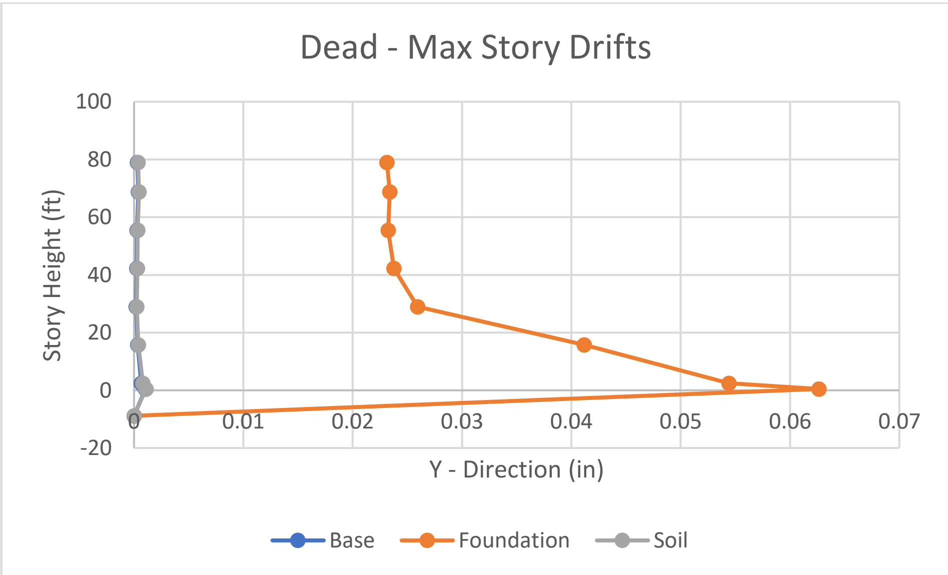

Figure 4.65 Max story drift. (7/dead/y)

The plots above show the maximum drifts each story each model undergoes against the dead load in the 7-story building. The abnormality in the foundation model plot stems from the model's joint conditions which are more clearly visible in the model's animation in ETABS.

c) Max Overturning Moment

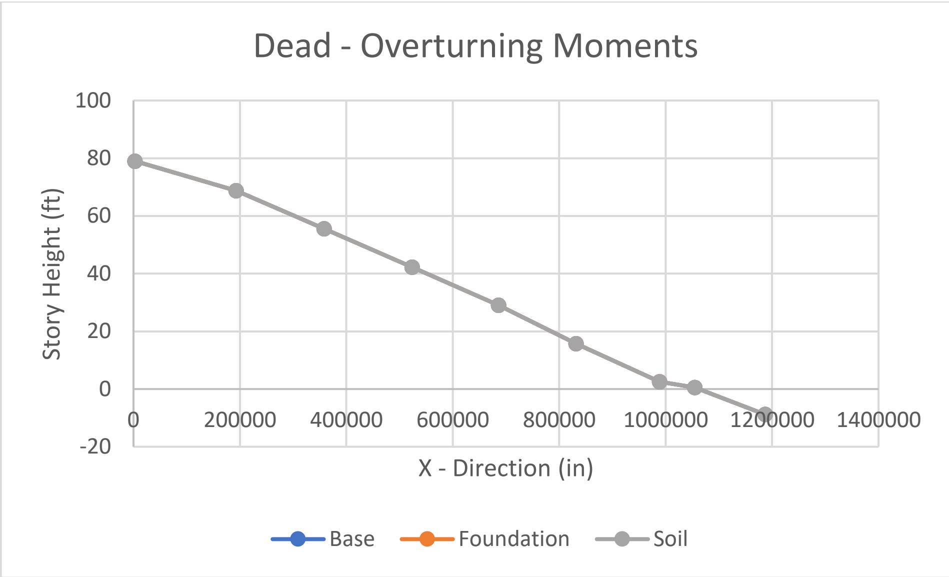

Figure 4.66 Max overturning moment. (7/dead/x)

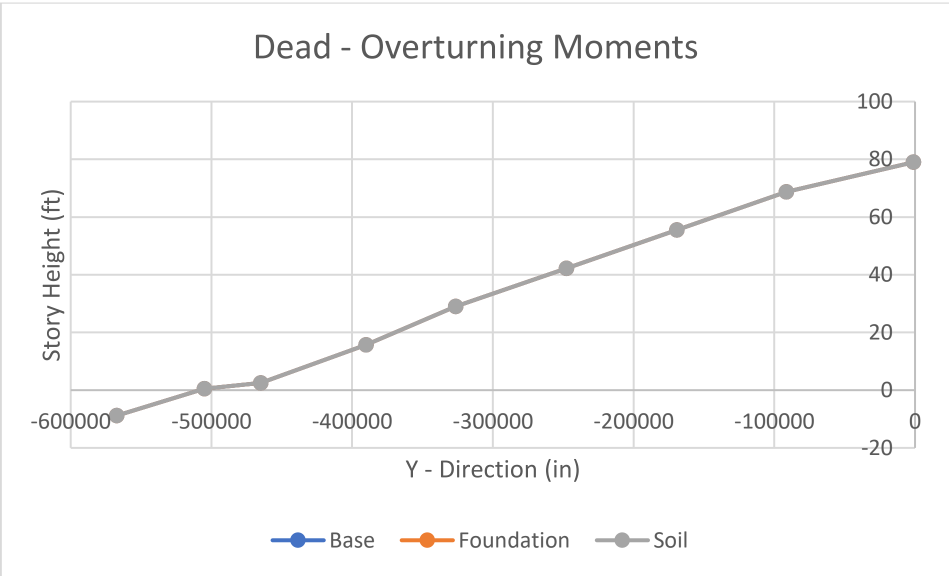

Figure 4.67 Max overturning moment. (7/dead/y)

Maximum overturning moment for each story against the dead load in the 7-story building is shown above in x- and y-direction consequently.

4.2.1.3 Live Load Response

Live Load responses are further categorized into 3 different categories, listed below

- Max Story Displacement
- Max Story Drifts
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

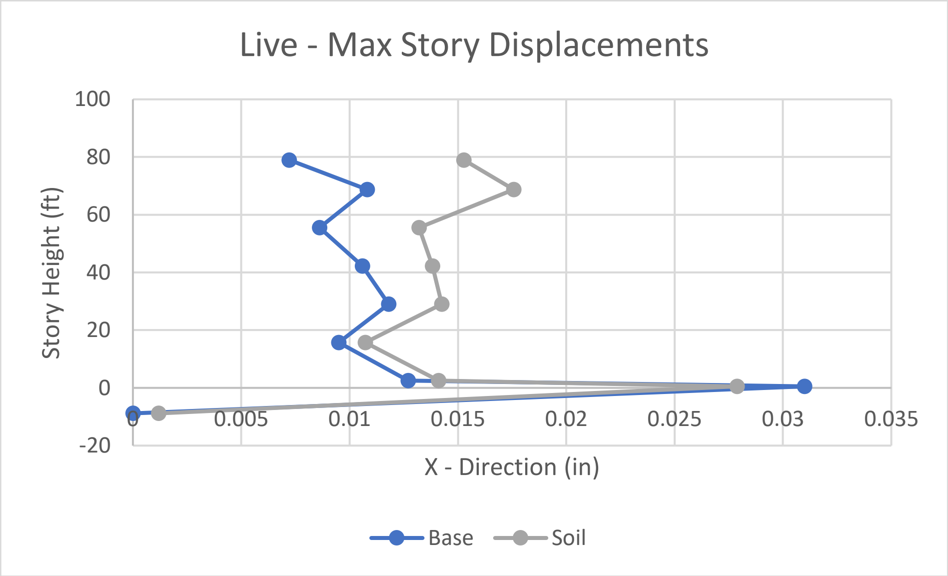

Figure 4.68 Max story displacement. (7/live/x)

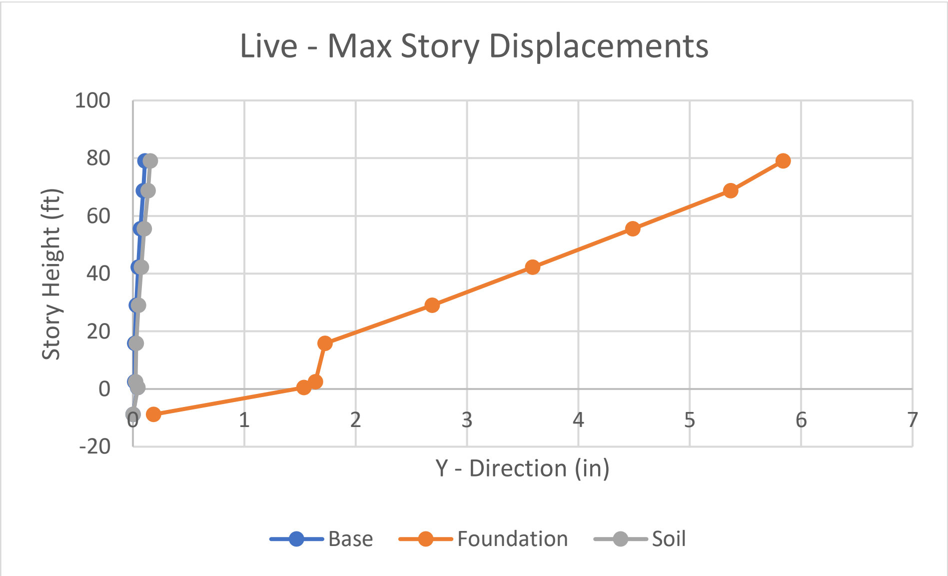

Figure 4.69 Max story displacement. (7/live/y)

Max story displacements for the 7-story building under live loading is shown above. Foundation model response for the x-direction is deleted to highlight its abnormality. It can however be seen that the difference in base model and the soil model is still significant.

b) Max Story Drift

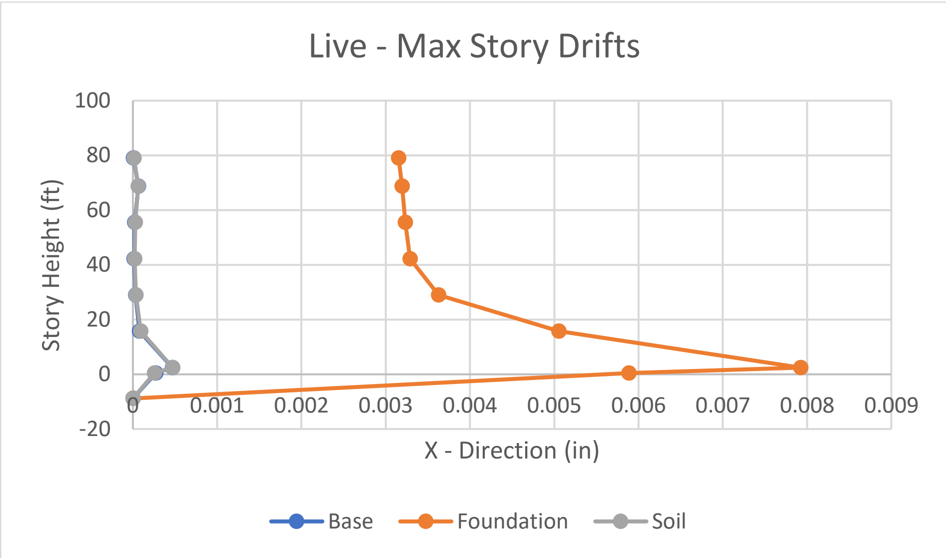

Figure 4.70 Max story drift. (7/live/x)

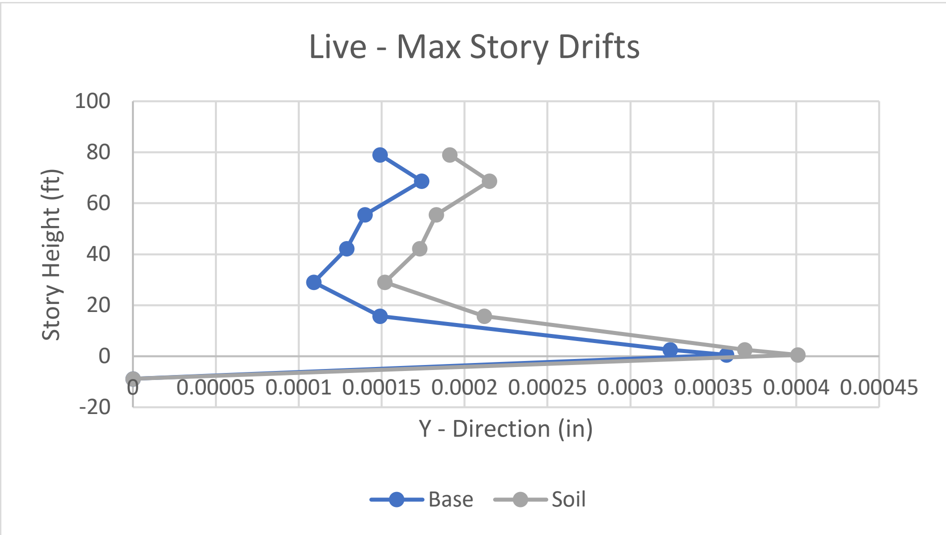

Figure 4.71 Max story drift. (7/live/y)

Max story drifts for the 7-story building under live loading is shown above. Here, foundation model response for the y-direction is deleted for the same reason. It can consequently be seen that the difference in base model and the soil model is significant.

c) Max Overturning Moment

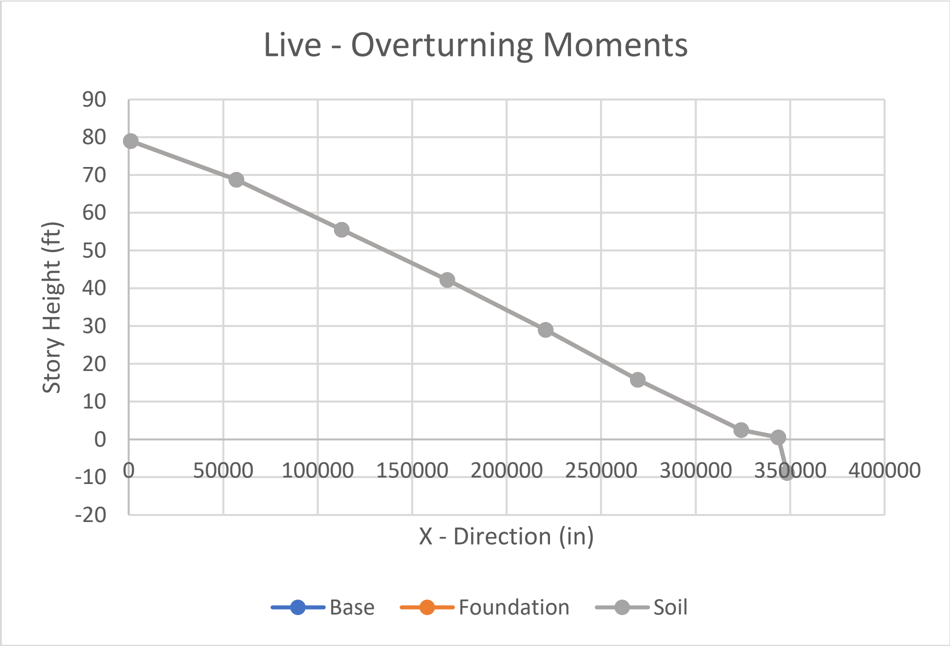

Figure 4.72 Max overturning moment. (7/live/x)

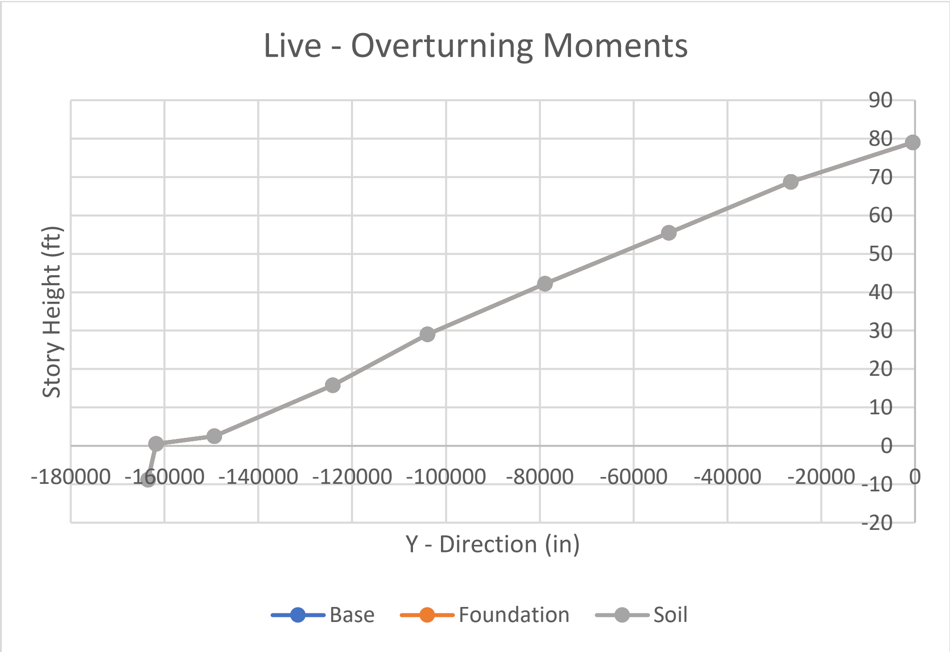

Figure 4.73 Max overturning moment. (7/live/y)

Maximum overturning moment for each story against the live load in the 7-story building is shown above in x- and y-direction consequently.

4.2.1.4 EQx RESPONSE

EQx responses are further categorized into 4 different categories, listed below:

- Max Story Displacement
- Max Story Drifts
- Story Shear
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) **Max Story Displacement**

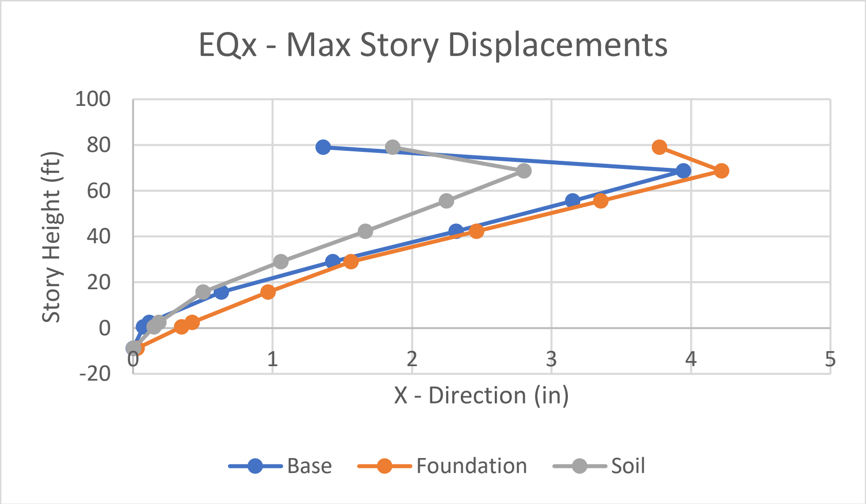

Figure 4.74 Max story displacement. (7/EQx/x)

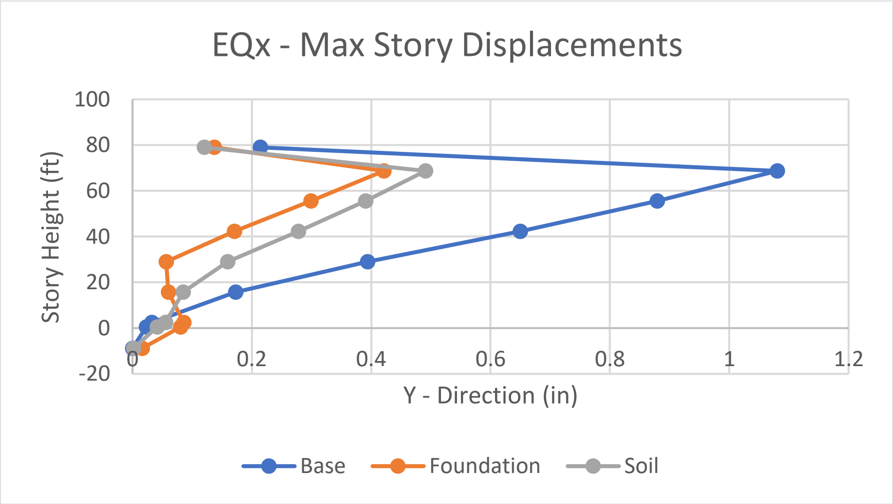

Figure 4.75 Max story displacement. (7/EQx/y)

Maximum story displacements in x- and y-direction under x-directional earthquake loading are shown above. The significant differences in magnitude in the three responses for each plot can clearly be seen.

b) Max Story Drift

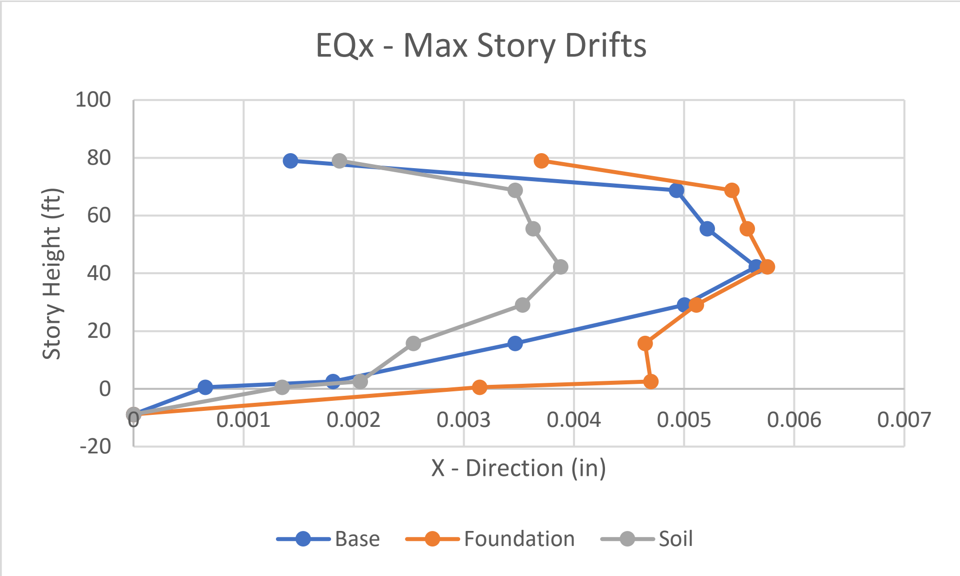

Figure 4.76 Max story drift. (7/EQx/x)

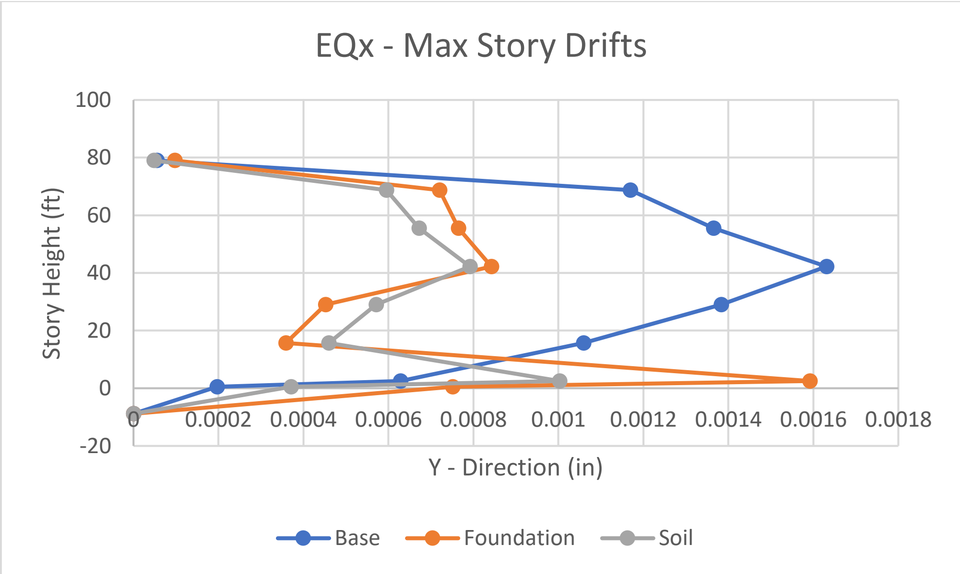

Figure 4.77 Max story drift. (7/EQx/y)

Maximum story drifts for x-directional earthquake loading are shown above. The significant magnitude differences in both the responses can clearly be seen.

c) Story Shear

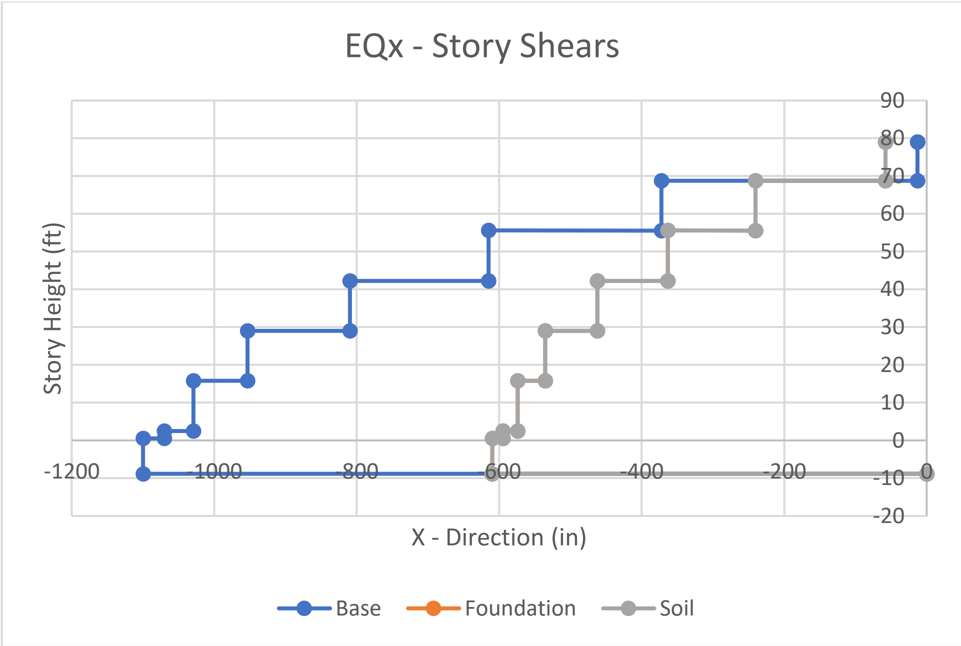

Figure 4.78 Max story shear. (7/EQx/x)

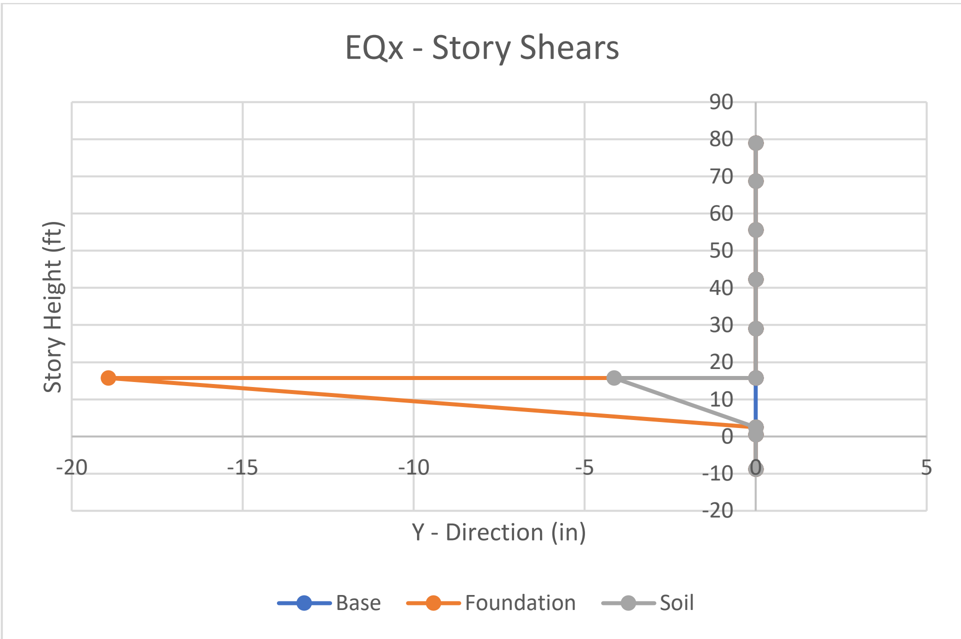

Figure 4.79 Max story shear. (7/EQx/y)

It can be seen from the above responses how the x-directional earthquake generates story shears only in the x-direction and not in the y-direction of the building.

d) Maximum Overturning Moment

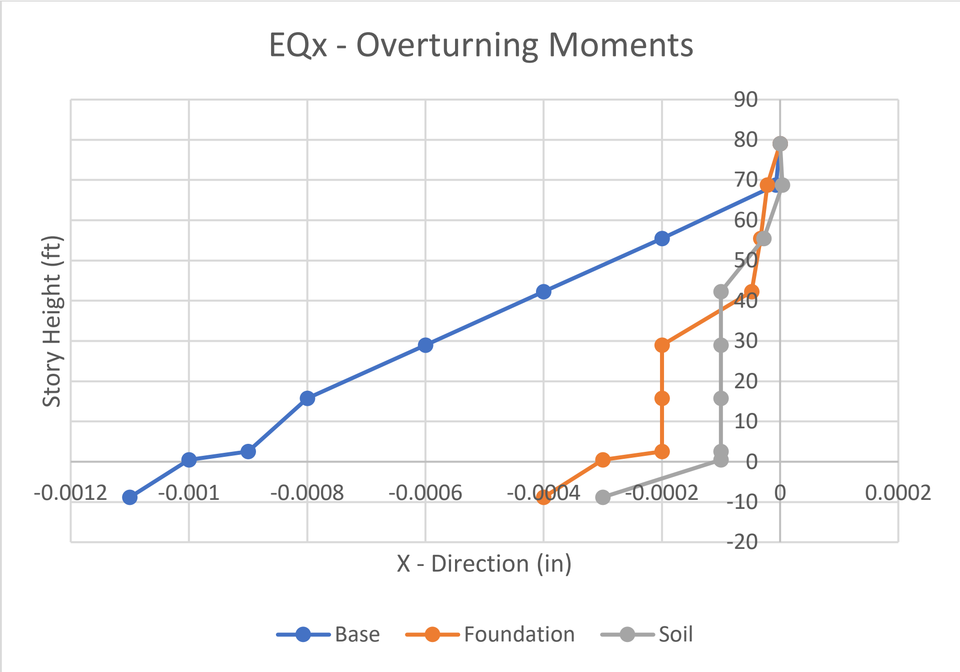

Figure 4.80 Max overturning moment. (7/EQx/x)

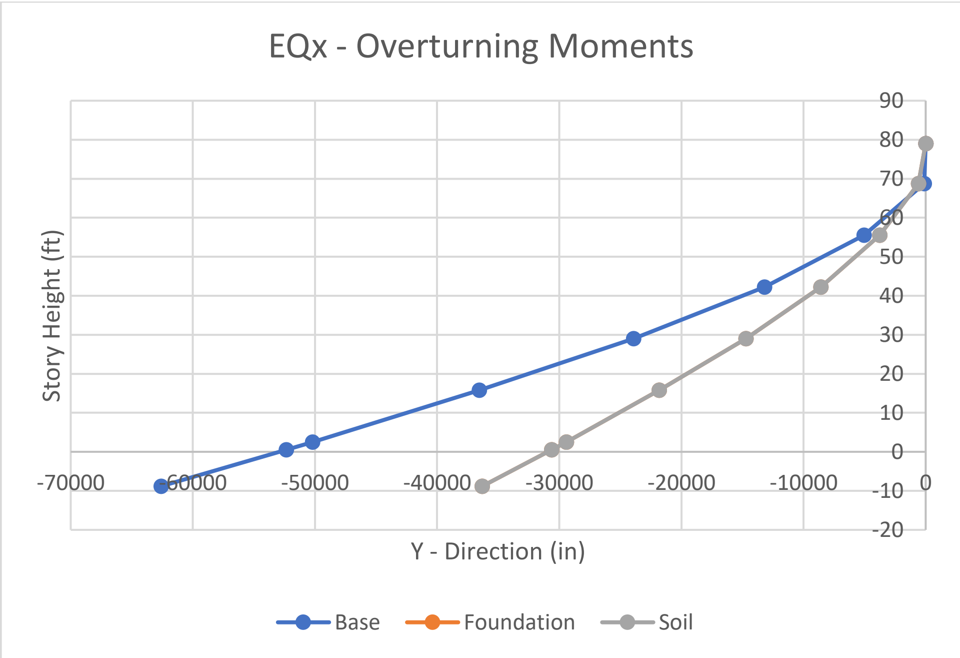

Figure 4.81 Max overturning moment. (7/EQx/y)

Maximum overturning moments under x-directional earthquake show more variation for x-direction responses than the y-directional ones.

4.2.1.5 EQy Response

EQy responses are further categorized into four different categories listed below.

- Max Story Displacement
- Max Story Drifts
- Story Shear
- Story Overturning Moment

The results obtained as a form of comparison between base modal, soil modal and foundation modal for each category are shown below.

a) Max Story Displacement

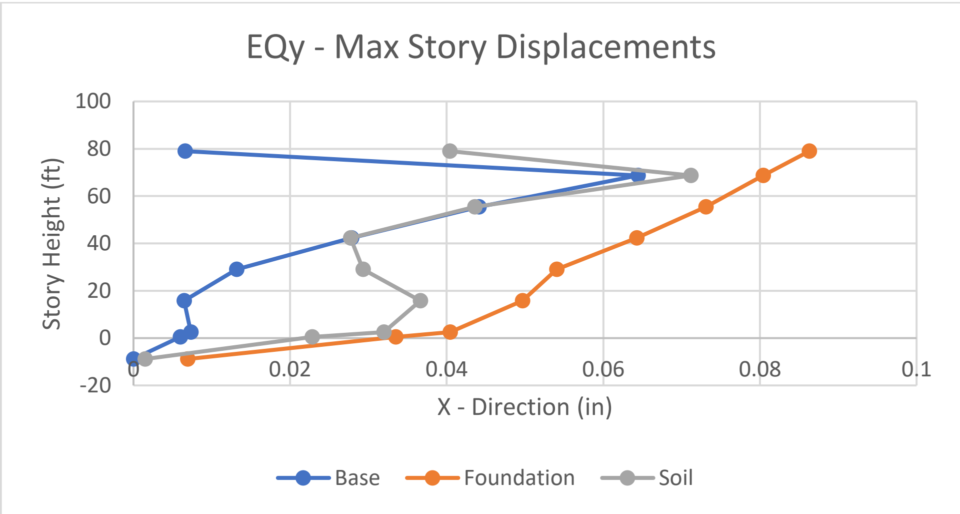

Figure 4.82 Max story displacement. (7/EQy/x)

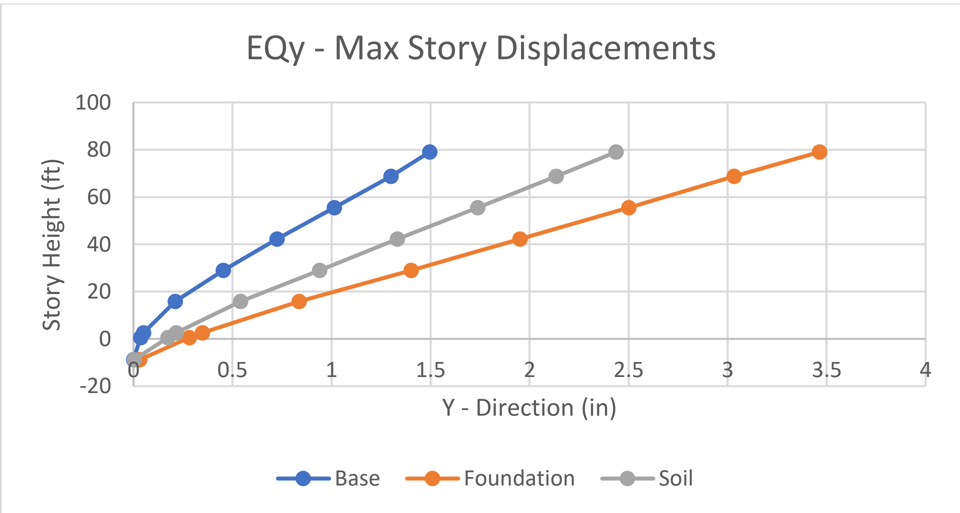

Figure 4.83 Max story displacement. (7/EQy/y).

Maximum story displacements in x- and y-direction under y-directional earthquake loading are shown above. The similar shape of the consequent plots can be seen however, the magnitude difference in the y-directional response is also clearly visible.

b) Max Story Drift

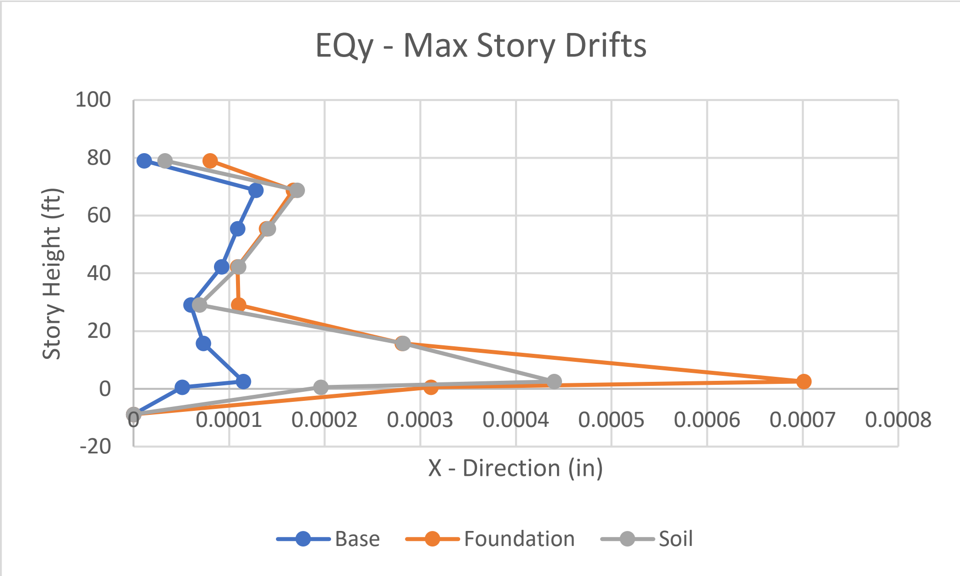

Figure 4.84 Max story drift. (7/EQy/x)

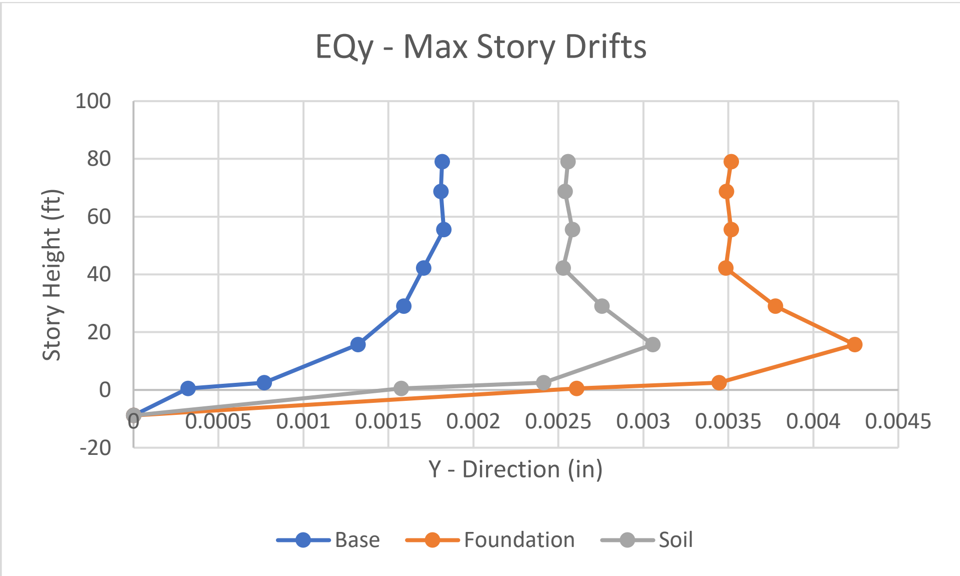

Figure 4.85 Max story drift. (7/EQy/y)

Maximum story drifts in x- and y-direction under y-directional earthquake loading are shown above. It can be seen how the building response in y-direction shows more variation in magnitude than that in x-direction.

c) Story Shear

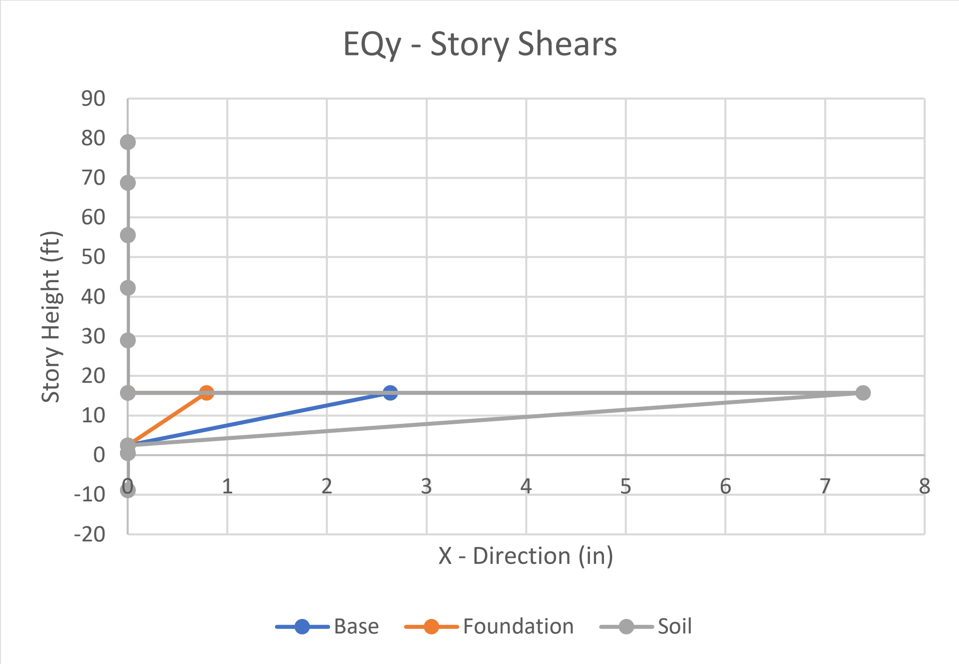

Figure 4.86 Max story shear. (7/EQy/x)

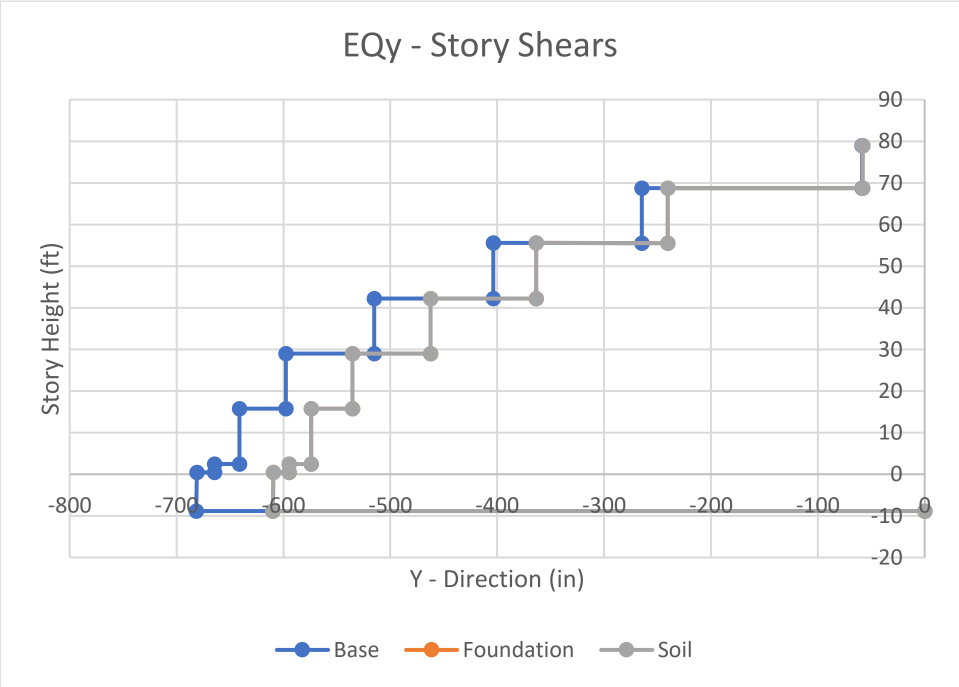

Figure 4.87 Max story shear. (7/EQy/y)

Story shears generating from the y-directional earthquake which give rise to consequent x-direction and y-direction building responses are shown above.

d) Maximum Overturning Moment

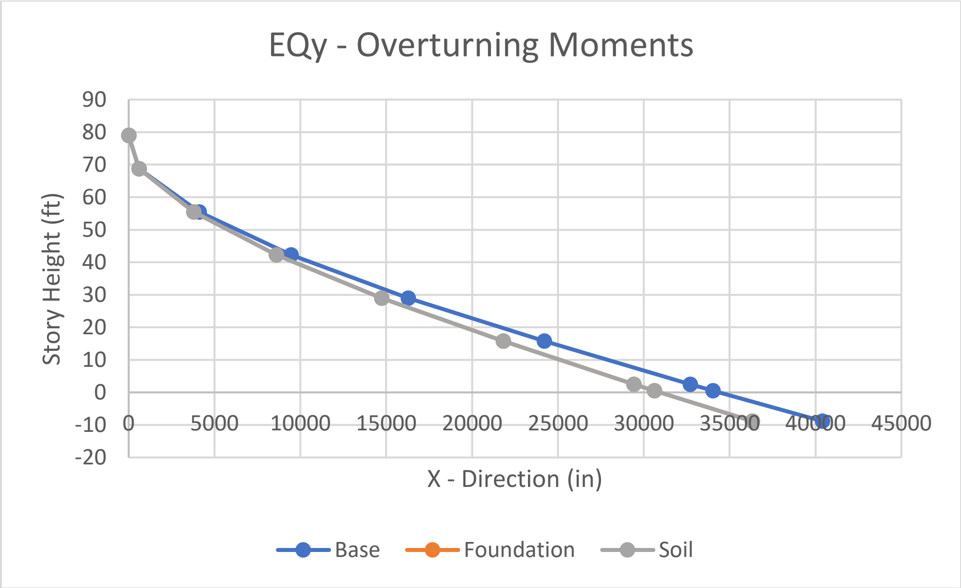

Figure 4.88 Max overturning moment. (7/EQy/x)

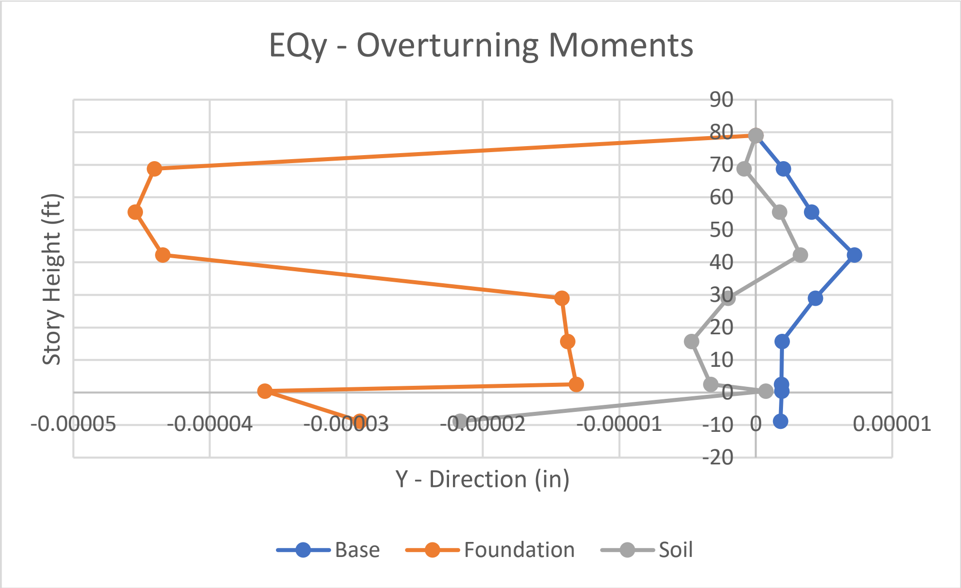

Figure 4.89 Max overturning moment. (7/EQy/y)

Max overturning moments generating from the y-directional earthquake which give rise to consequent x-direction and y-direction building responses are shown above.

4.2.2 Local Responses

In local responses we recorded different responses of Column *C2* and Shear Wall *P5*. Here again three of the modals (Base, Soil, Foundation) were compared with each other using the shear (V2) and moment (M3) diagrams.

4.2.2.1 COLUMN – C2

Responses recorded for column C5 are listed below:

- Dead Load Response
- Live Load Response
- EQx
- EQy

a) Dead Load Response

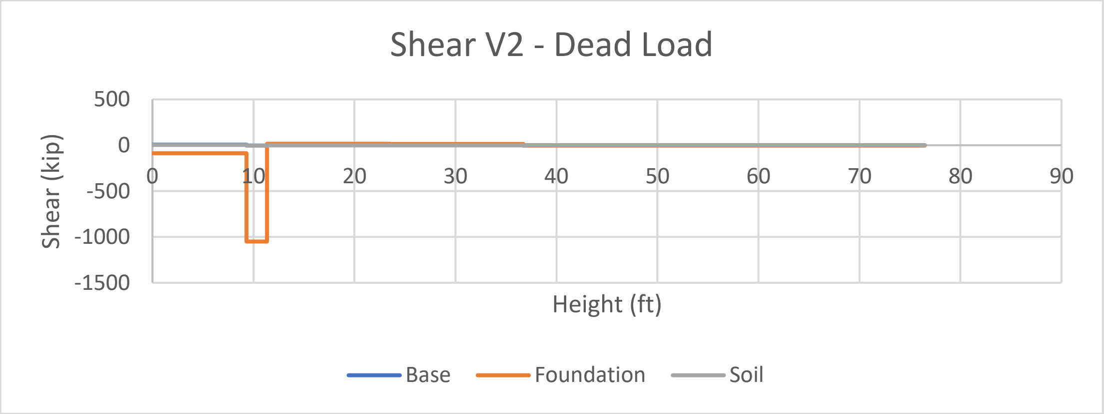

Figure 4.90 DL Shear V2. (7/C2)

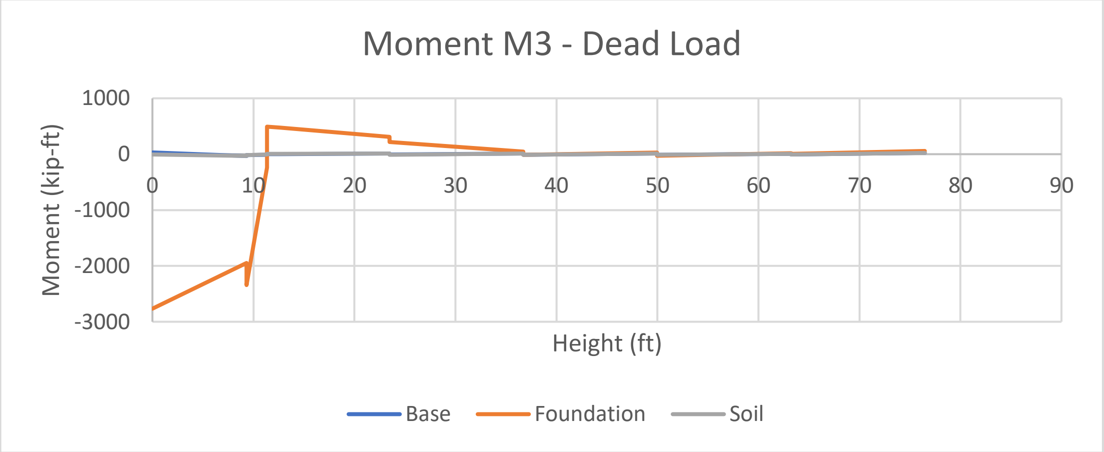

Figure 4.91 DL Moment M3. (7/C2)

Shear V2 and the corresponding moment M3 under Dead Load for the C2 column in the 7-story building is shown above.

b) Live Load Response

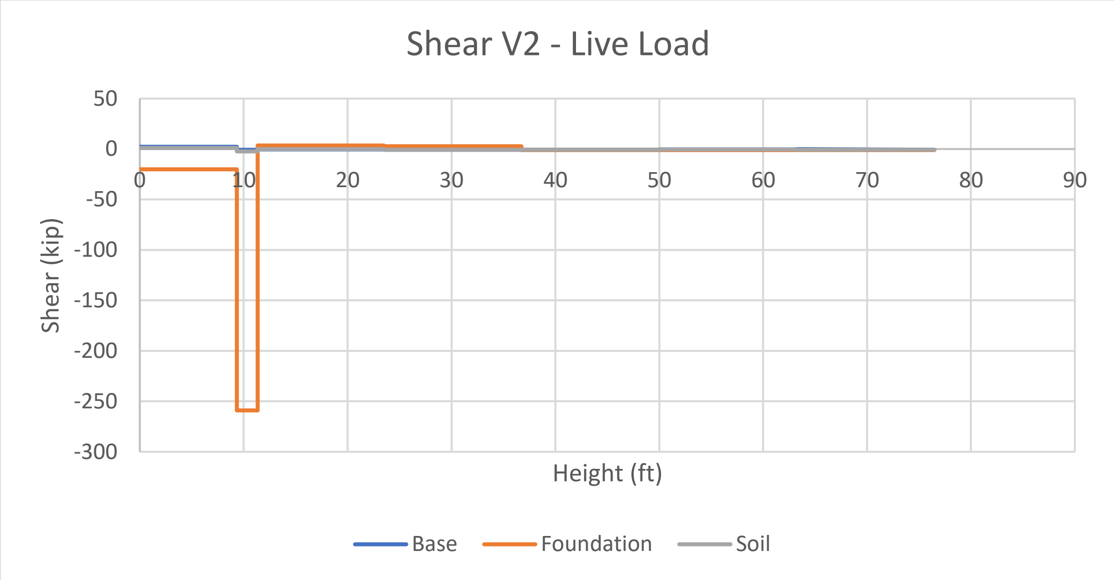

Figure 4.92 LL Shear V2. (7/C2)

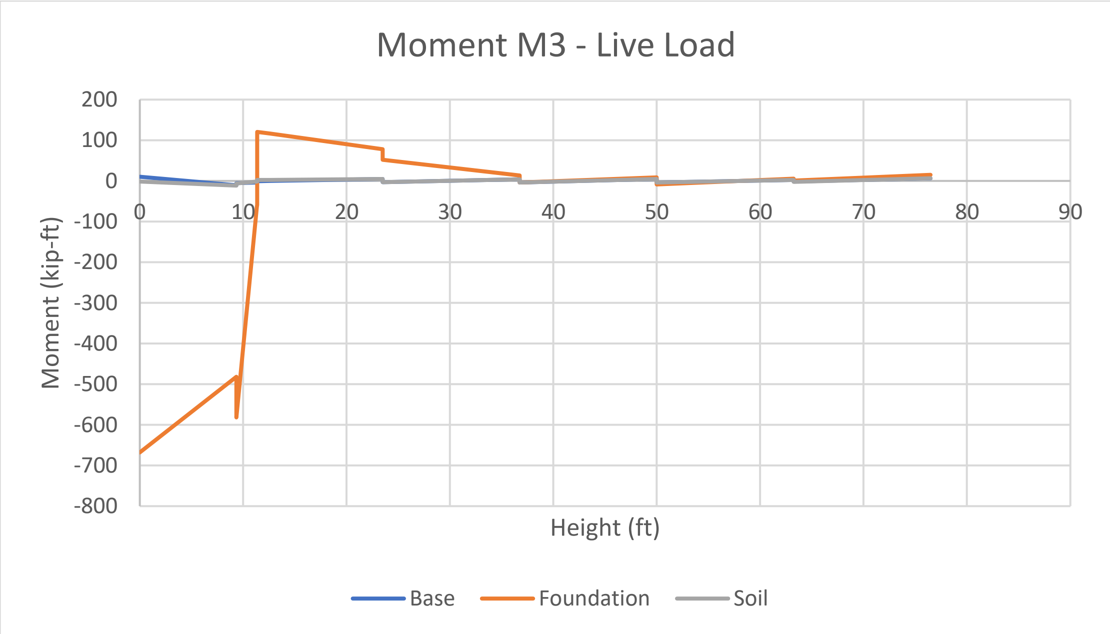

Figure 4.93 LL Moment M3. (7/C2)

Shear V2 and the corresponding moment M3 under Live Load for the C2 column in the 7-story building is shown above. Similar trends with a slight difference in magnitude for these responses can be seen in the above plots. Foundation response looks abnormal for already stated reasons.

c) EQx Response

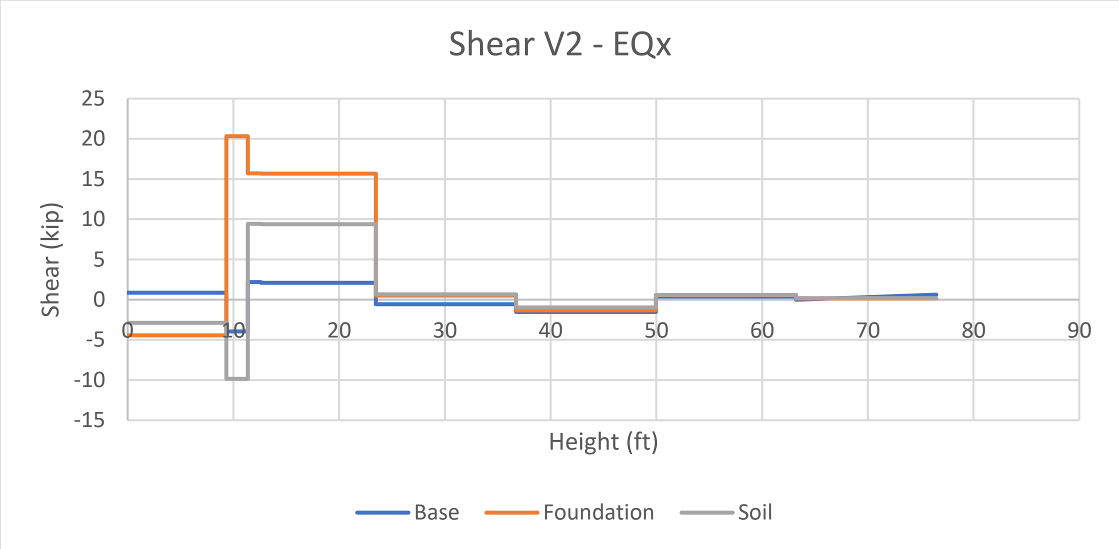

Figure 4.94 EQx Shear V2. (7/C2)

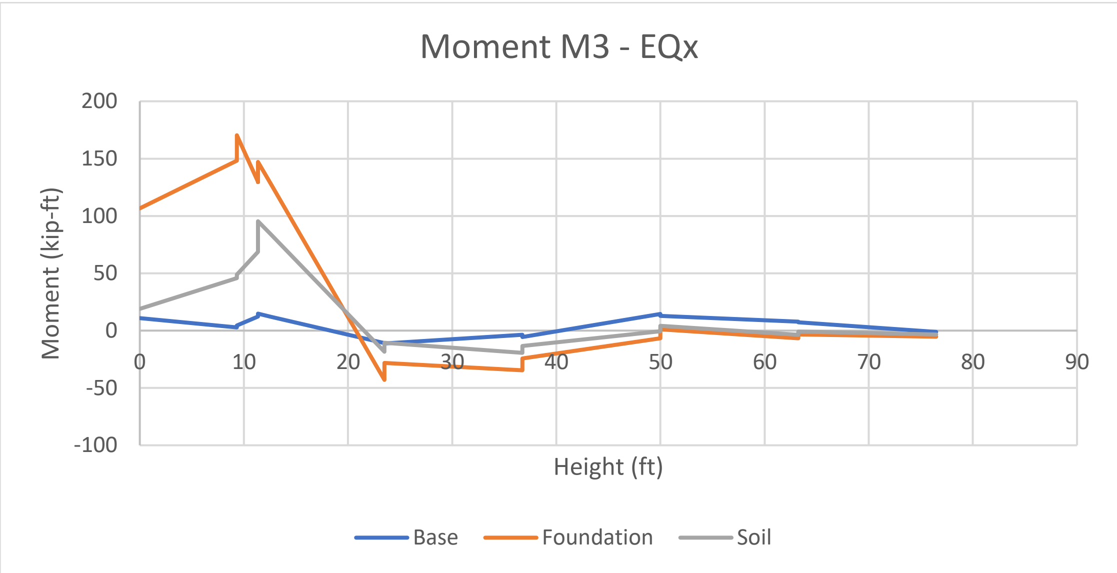

Figure 4.95 EQx Moment M3. (7/C2)

Shear V2 and the corresponding moment M3 under x-directional earthquake loading for the C2 column in the 7-story building is shown above. Similar trends with a significant difference in magnitude for these responses can be seen in the above plots.

d) EQy Response

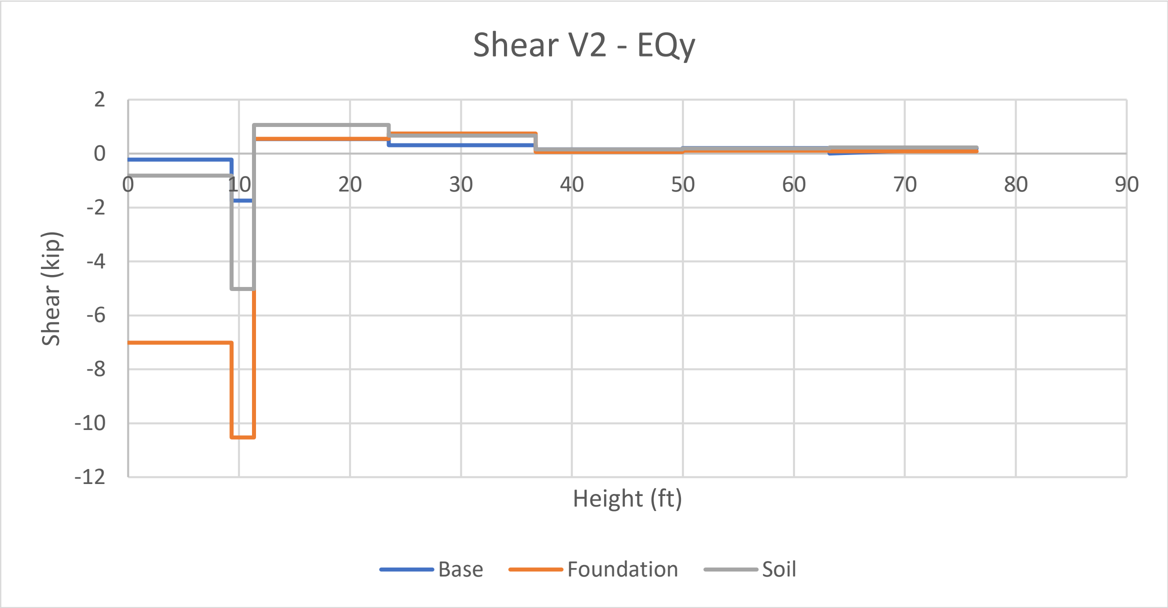

Figure 4.96 EQy Shear V2. (7/C2)

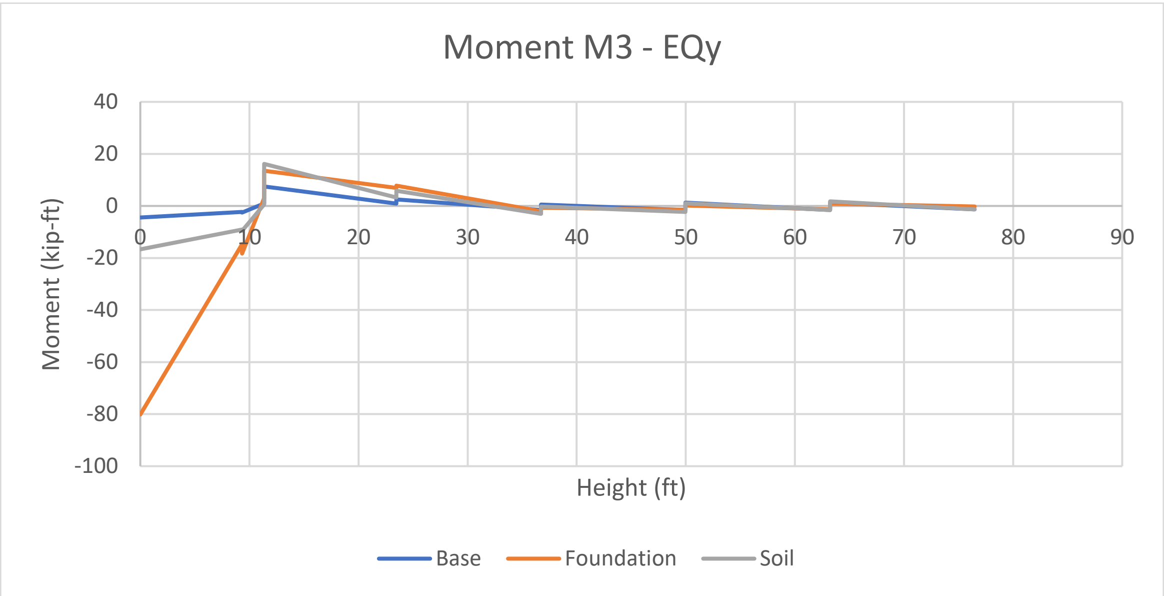

Figure 4.97 EQy Moment M3. (7/C2)

Shear V2 and the corresponding moment M3 under y-directional earthquake loading for the C2 column in the 7-story building is shown above. It can be seen how the difference in magnitude is more for lower stories and decreases as the building height increases.

4.2.2.2 SHEAR WALL – P5

Responses recorded for pier P5 are listed below:

- Dead Load Response
- Live Load Response
- EQx
- EQy

a) Dead Load Response

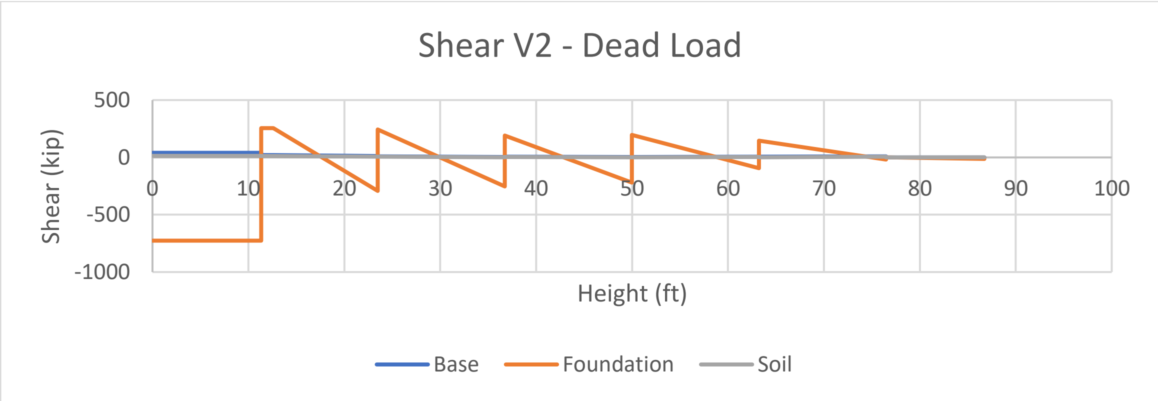

Figure 4.98 DL Shear V2. (7/P5)

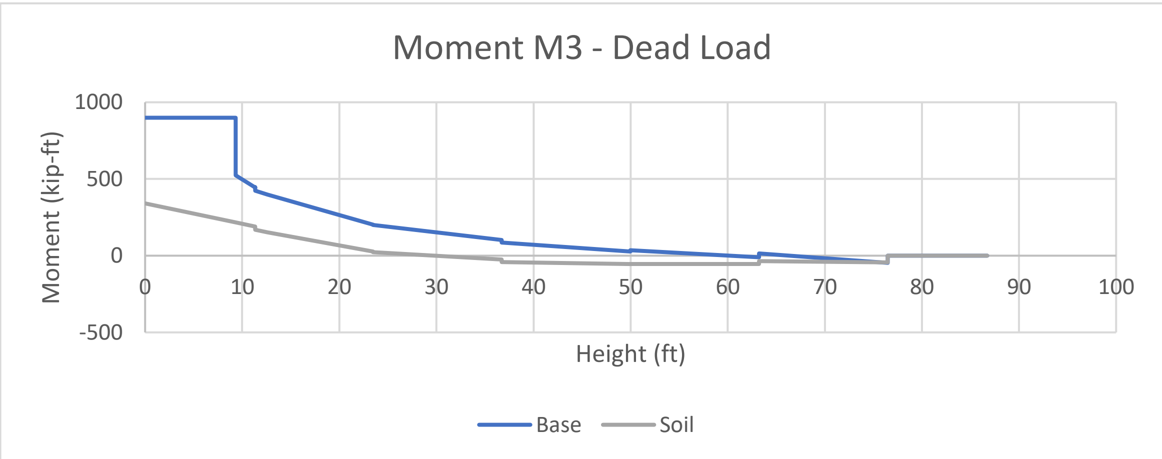

Figure 4.99 DL Moment M3. (7/P5)

Shear V2 and the corresponding moment M3 under Dead Load for the P5 pier in the 7-story building is shown above. Foundation model response from M3 has been removed to ignore the abnormality and look at the prominent magnitude difference between base and soil model.

b) Live Load Response

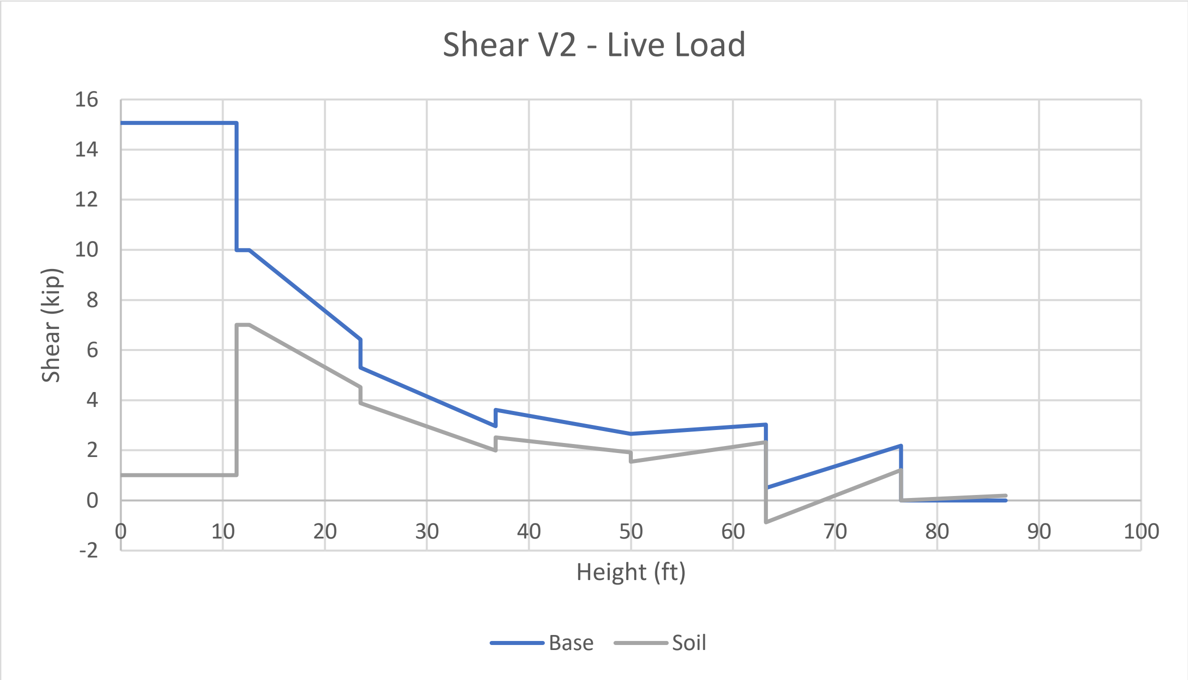

Figure 4.100 LL Shear V2. (7/P5)

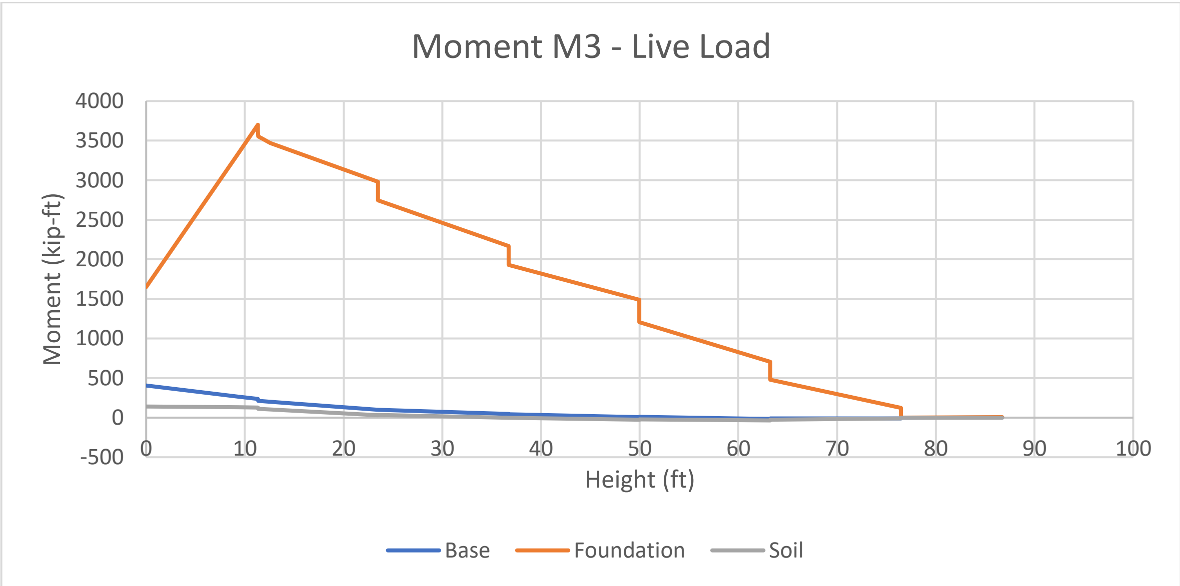

Figure 4.101 LL Moment M3. (7/P5)

Shear V2 and the corresponding moment M3 under Live Load for the P5 pier in the 7-story building is shown above. Similarly here, foundation model response from V2 has been removed to ignore the abnormality and look at the prominent magnitude difference between base and soil model.

c) EQX Response

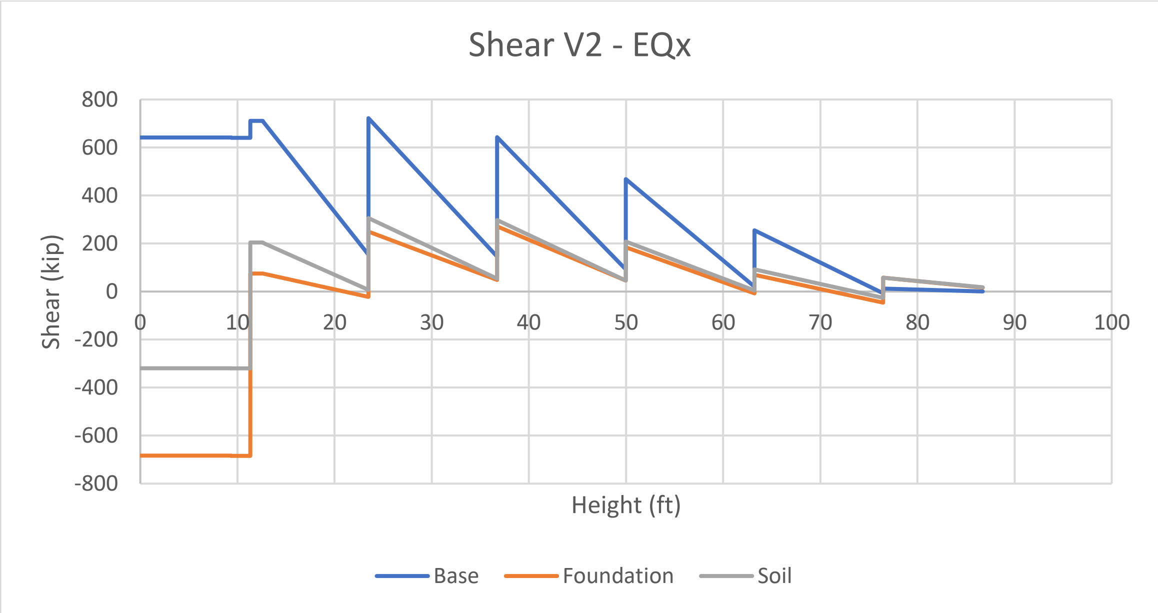

Figure 4.102 EQx Shear V2. (7/P5)

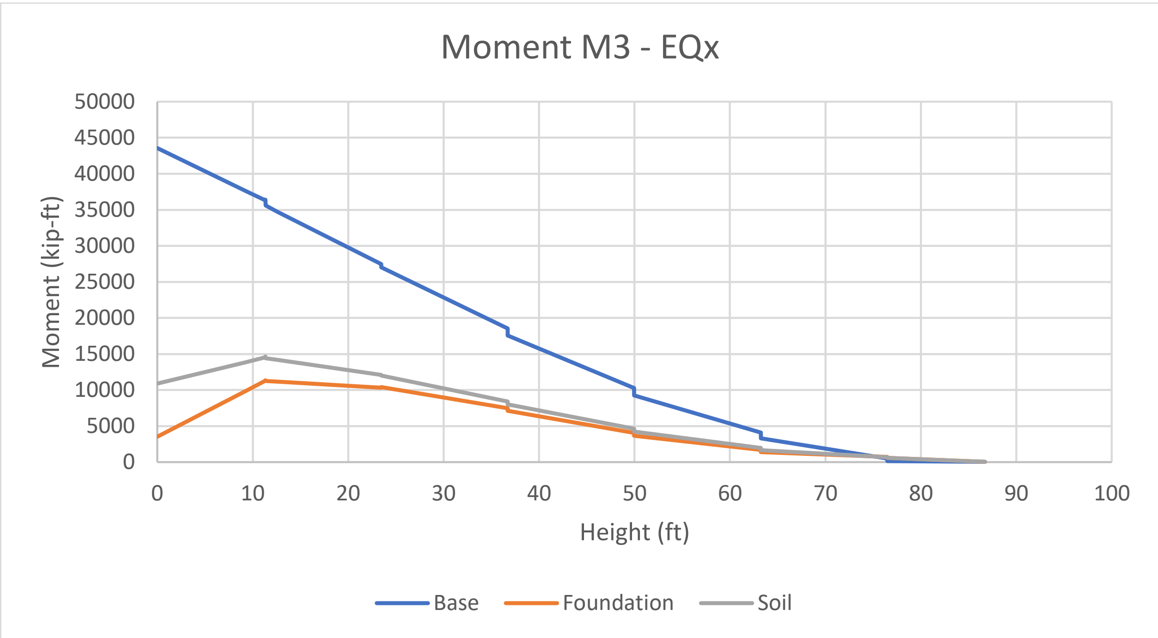

Figure 4.103 EQx Moment M3. (7/P5)

Shear V2 and the corresponding moment M3 under x-directional earthquake loading for the P5 pier in the 7-story building is shown above. It can be seen how the variations are more in the lower stories of the building and dampen down as the story height increases.

d) EQY Response

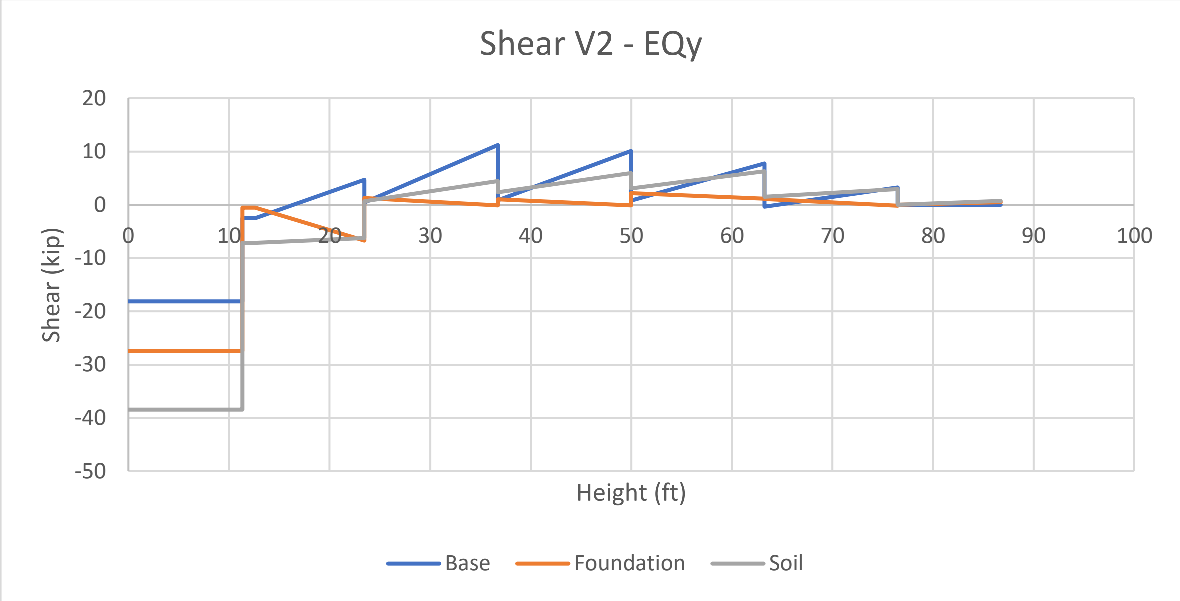

Figure 4.104 EQy Shear V2. (7/P5)

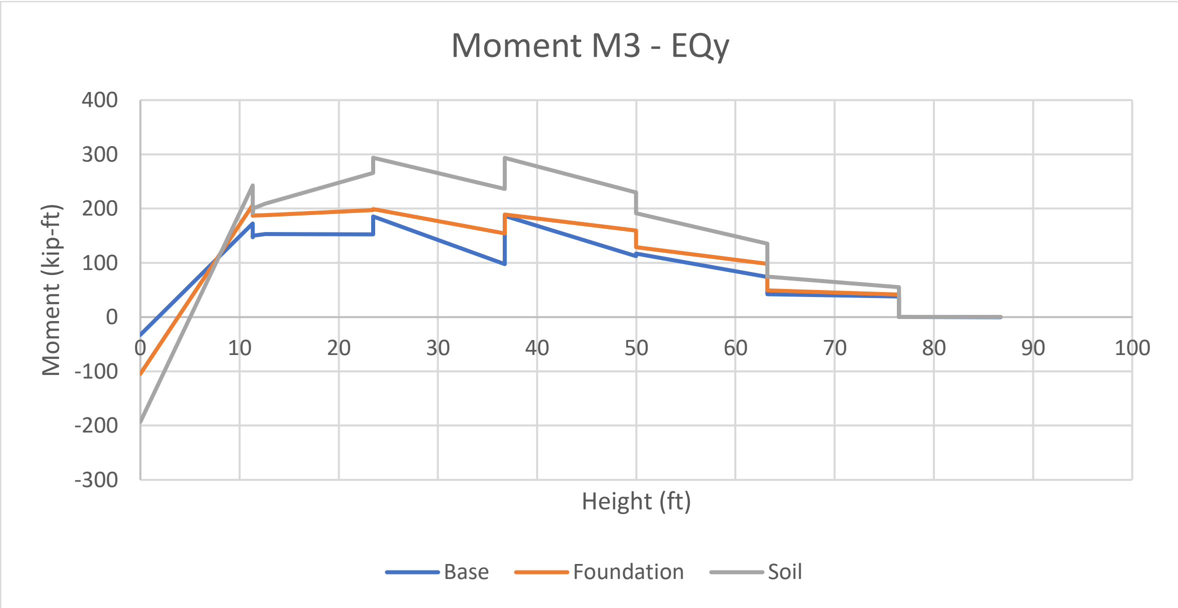

Figure 4.105 EQy Moment M3. (7/P5)

Shear V2 and the corresponding moment M3 under y-directional earthquake loading for the P5 pier in the 7-story building is shown above. Significant differences in magnitude for the three consequent models in both the responses can clearly be seen.

Chapter 5 Conclusion

Looking at and comparing the Global and Local Responses of the 3-Story and 7-Story buildings respectively with their corresponding models under consideration i.e., base model, foundation model and soil model, it can safely be concluded that the effect of soil modelling considerably alters the behavior of our models.

The effect of foundation's joint conditions in the foundation model of our 7-story building cannot be ignored as it can be seen from the plots how it behaves considerably differently from the base and soil model. Fixing only the corners of the 7-story building's raft foundation is found to be a bad practice as the building bounces beyond safe limits in this approach.

Nevertheless, in the global responses, the max story displacement for the top story of the 7-Story building differs by more than 90% between base model and soil model. The overturning moments at the base of the building also differs by more than a 100% for base and soil models. The soil model offers a greater overturning moment and displaces more at the top. In the local responses, for live load, the difference between the moments for the selected column exceeds 500% at the base of the building. The difference between the moments in the shear wall of the 7-Story building also exceeds 150% at the base. Similar trends can also be seen in the 3-Story building.

Thus, the inclusion of soil modelling in the conventional modelling technique for our 7-Story and 3-Story buildings would have contributed significantly to the design of the buildings and would most probably have affected the cost of implementing the new and improved design.

Appendix

A.1 7-Story Building

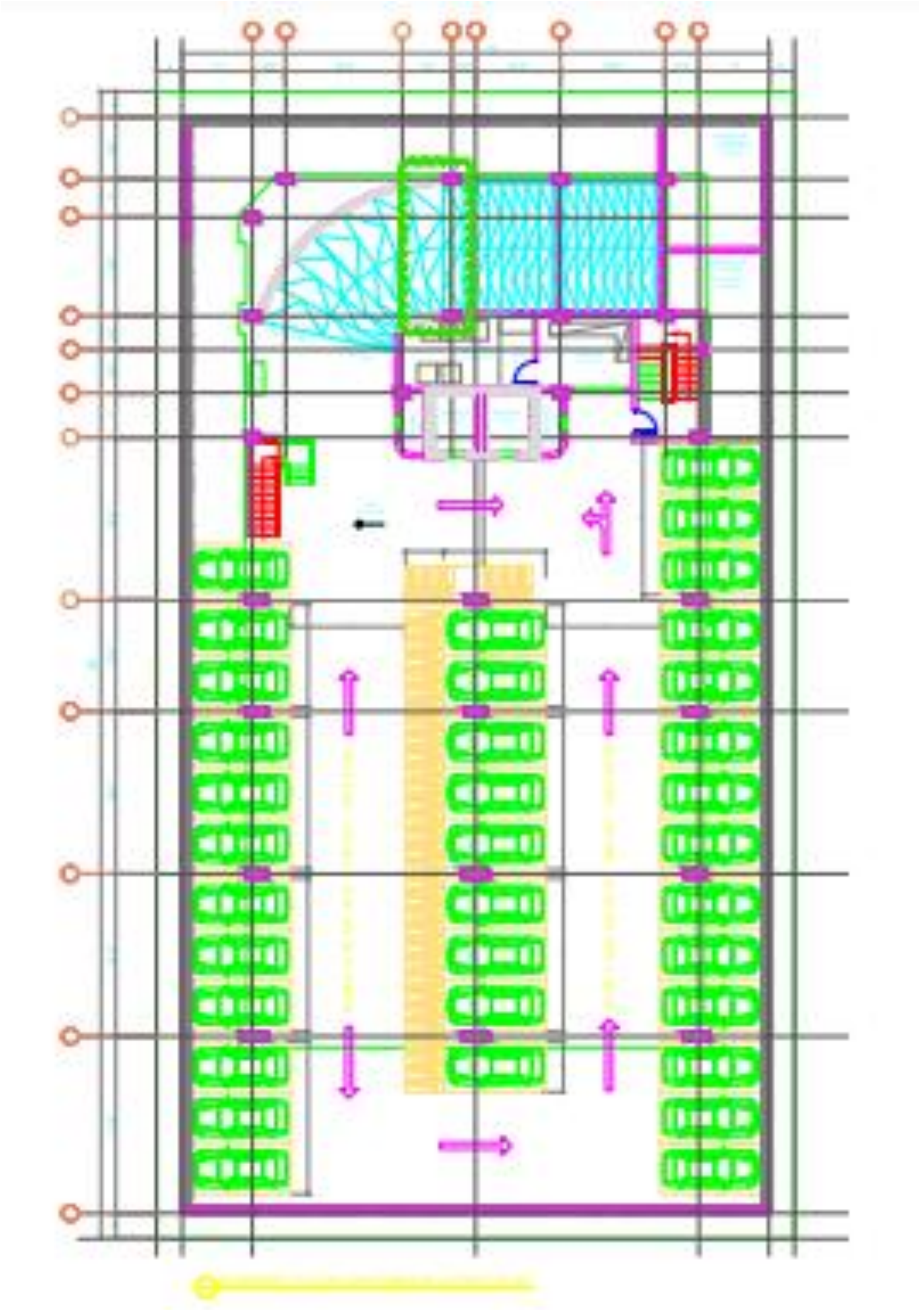

Figure A.0.1 basement floor layout plan.

Figure A.0.2 ground floor plan

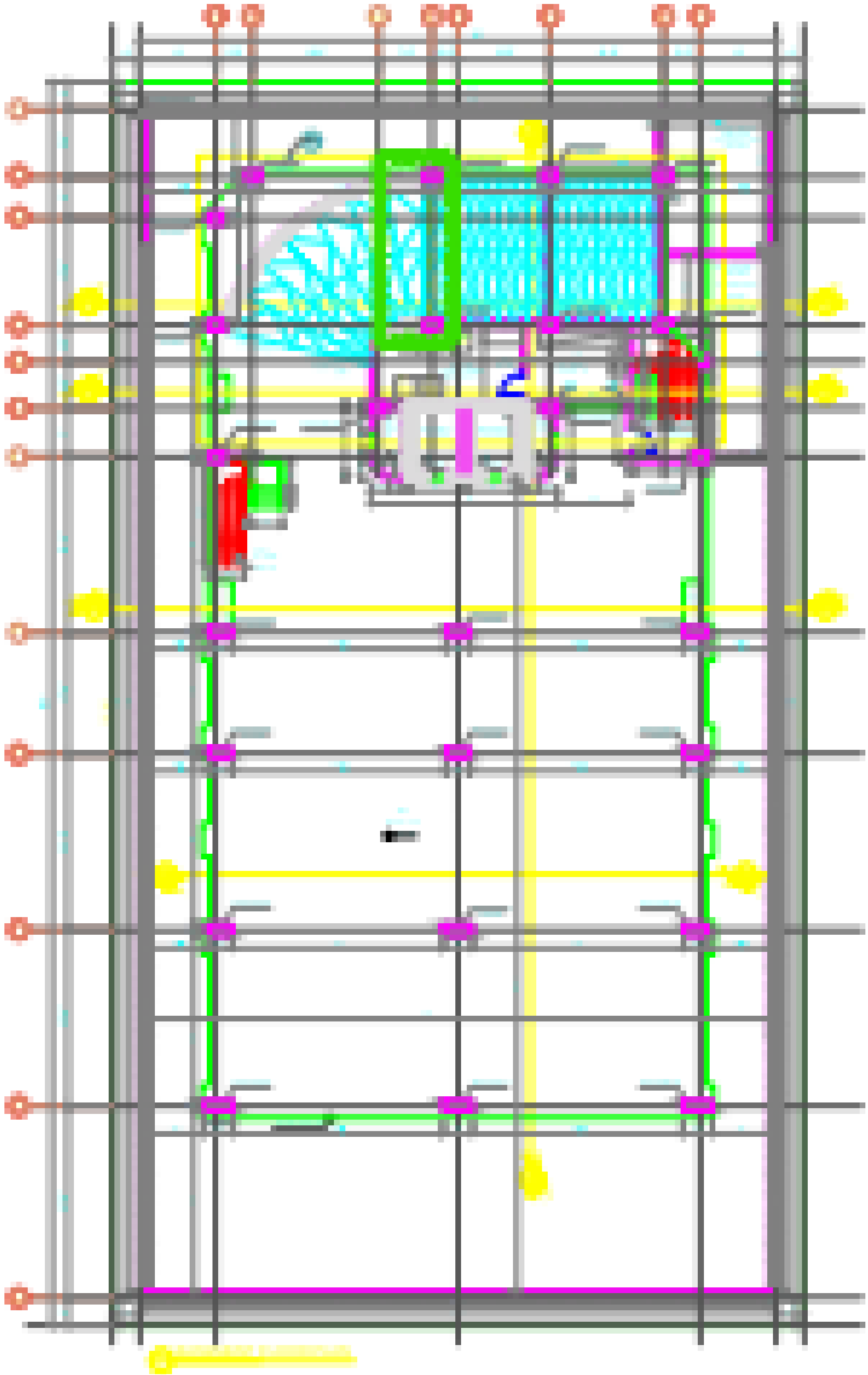

Figure A.0.3 basement floor plan.

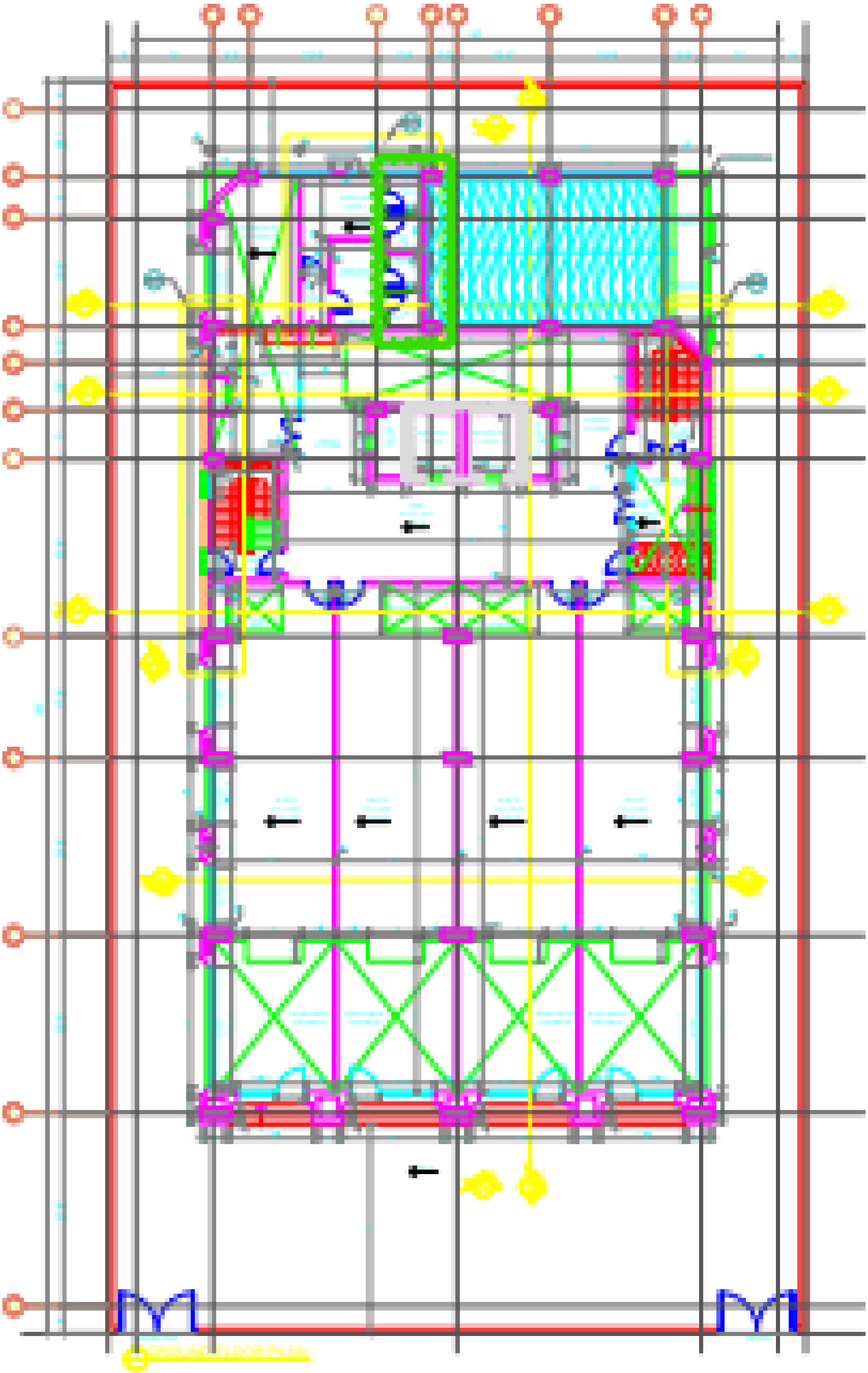

Figure A.0.4 ground floor plan.

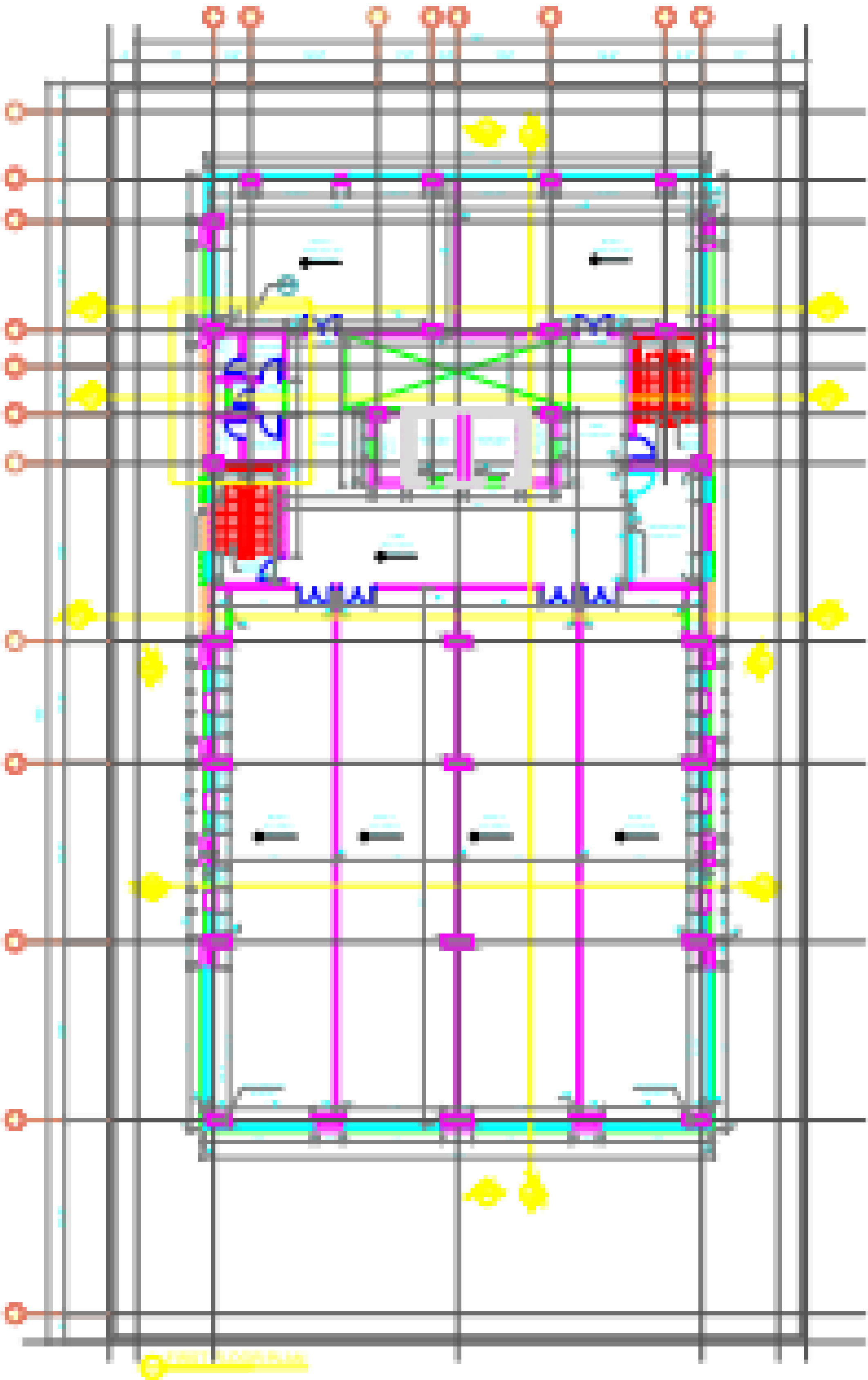

Figure A.5 first floor plan

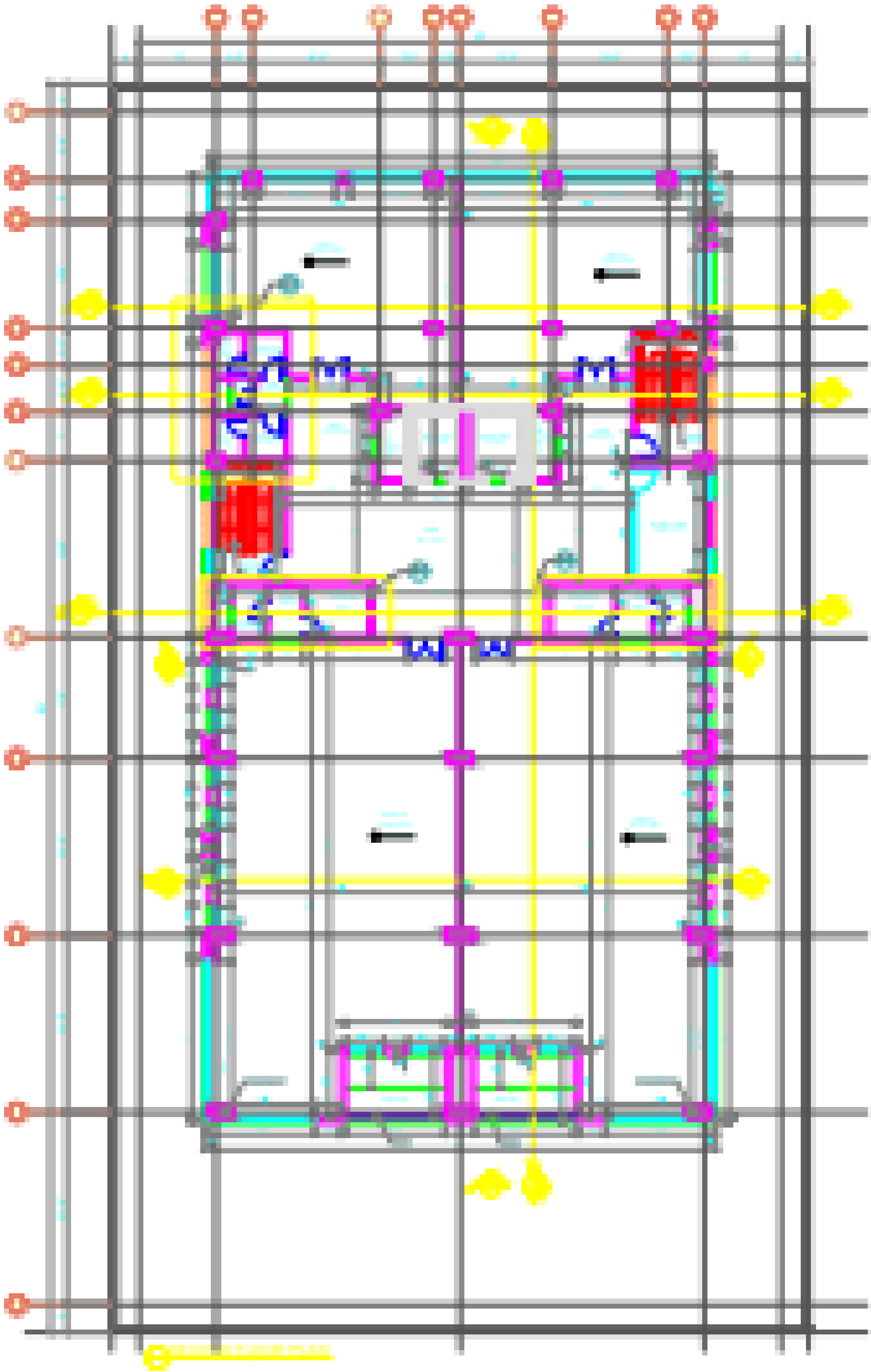

Figure A.6 second floor plan

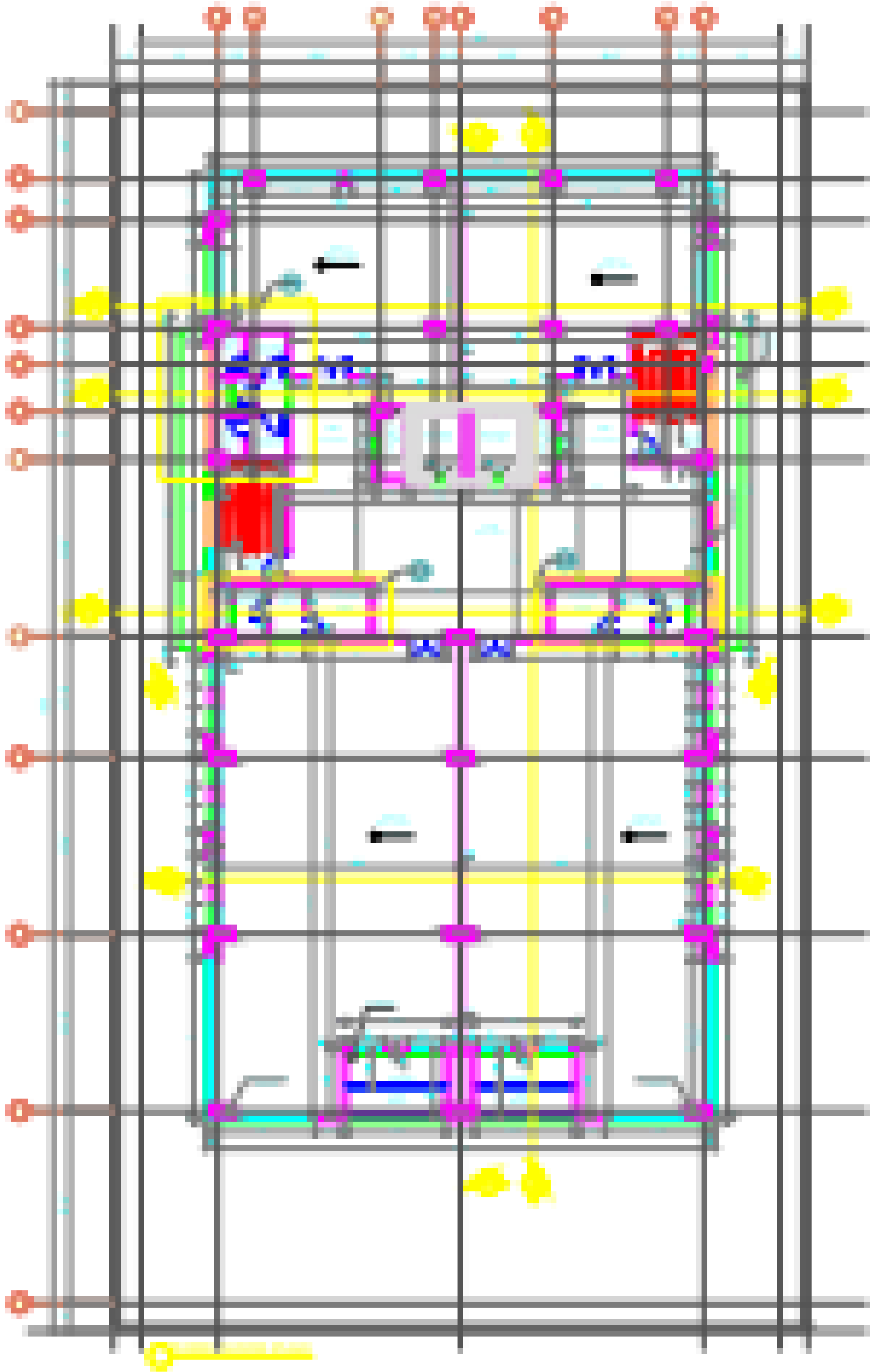

Figure A.7 3rd -floor plan.

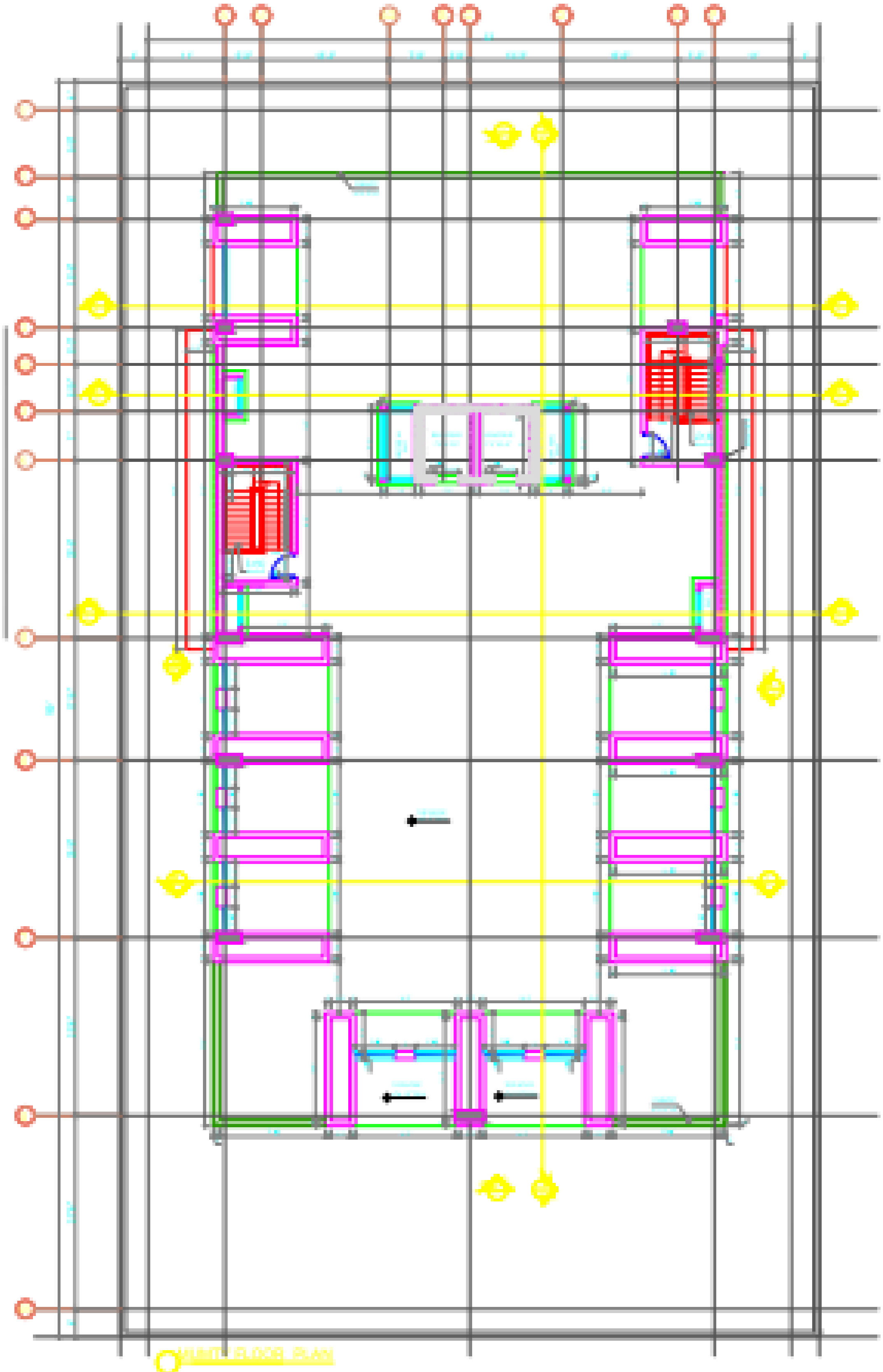

Figure A.8 Mumty floor plan.

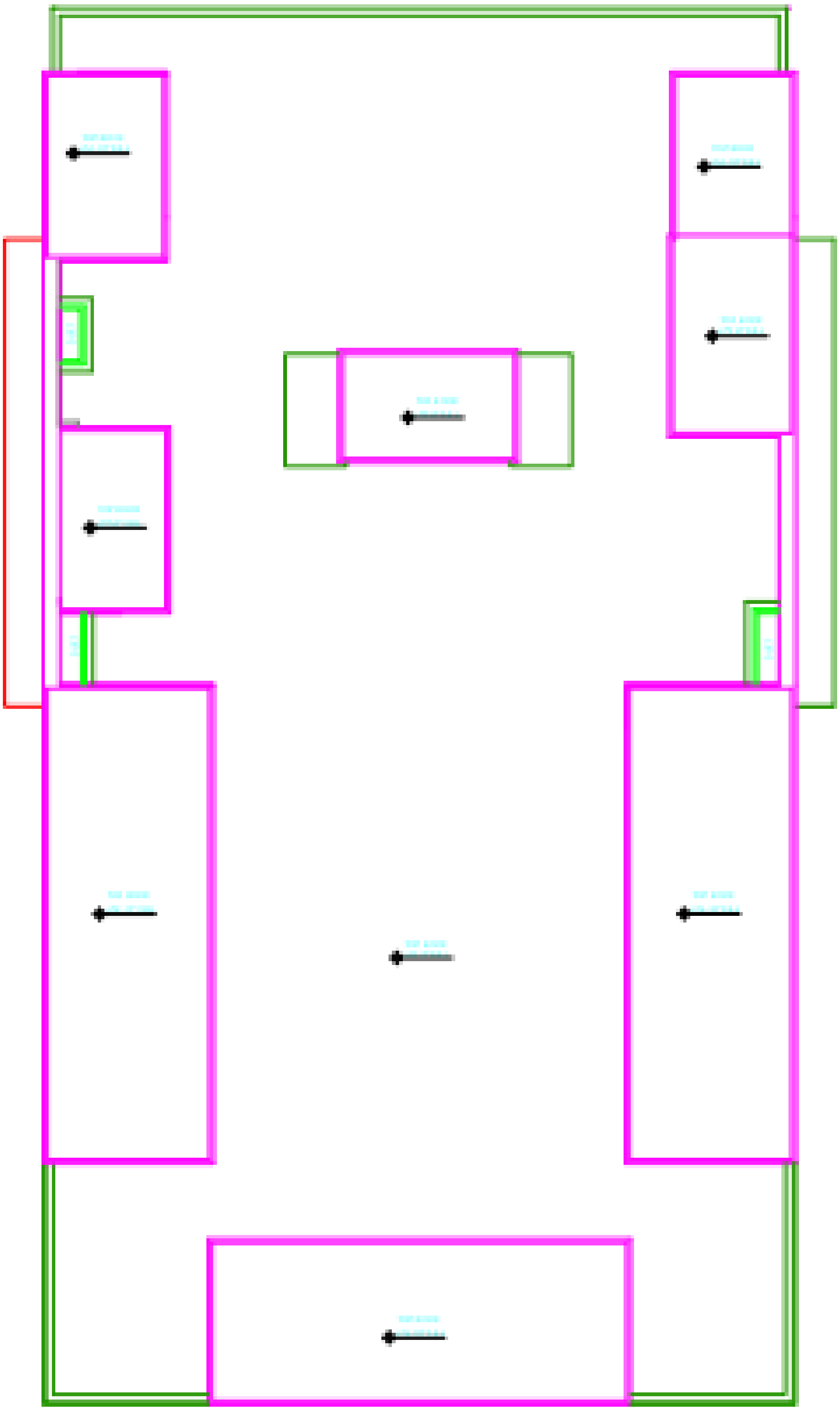

Figure A.9 Top floor plan.

A.2 3-Story Building

Figure A.10 Basement floor plan.

Figure A.11 TOP FLOOR PLAN

References

Lavanya, L., & Vijaya, D. (2018). Soil Structure Interaction Effects on Structure Response with Isolated Footing. *International Journal of Civil and Structural Engineering Research*, *6*(1). Retrieved 2 June 2021, from https://researchpublish.com/upload/book/Soil%20Structure%20Interaction-6003.pdf.

Bosela, P., Brady, P., Delatte, N., & Parfitt, M. (2013). *FAILURE CASE STUDIES IN CIVIL ENGINEERING* (2nd ed.). American Society of Civil Engineers.

Anwar, N., Uthayakumar, A., & Najam, F. (2019). Significance of Soil-Structure Interaction in Seismic Response of Buildings. *NED University Journal of Research*, *1*. https://doi.org/10.35453/NEDJR-STMECH-2019-0004

Beena, K. S., Kavitha, P. E., & Narayanan, K. P. (2011). A review of soil constitutive models for soil structure intereaction analysis.

Vasani, P. C. (2003). Interactive analysis models for soil and structures. *LD College of Engineering Ahmedabad, http://www. fineprint. com*.

Dutta, S. C., & Roy, R. (2002). A critical review on idealization and modelling for interaction among soil–foundation–structure system. *Computers & structures*, *80*(20-21), 1579-1594.

Singh, H., & Jha, J. N. Constitutive models for sustainable design of foundation systems.

Ti, K. S., Huat, B. B., Noorzaei, J., Jaafar, M. S., & Sew, G. S. (2009). A review of basic soil constitutive models for geotechnical application. *Electronic Journal of Geotechnical Engineering*, *14*, 1-18.

ASCE 7-05 Minimum Design Loads for buildings and other structures. (2007). American Society of civil engineers (ASCE).