SEISMIC ANALYSIS OF RC BUILDING CONSIDERING SOIL STRUCTURE INTERACTION

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by

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CANDIDATE'S DECLARATION

I, **Mohd Raquib Ansari**, hereby declare that the work which is being presented in dissertation entitled "**Seismic Analysis of RC Building Considering Soil Structure Interaction**" which is submitted by me to thein partial fulfillment of the requirement for the award of the degree of **Master of Technology**, submitted in the Department of Civil Engineering, Delhi Technological University, Delhi is an authenticate record of my own work carried out during the period from 2023 to 2024 under the supervision of **Gokaran Prasad Awadhiya**.

The matter presented in the dissertation has not been submitted by me for the award of any other degree or any other institute.

Mohd Raaquib Ansari

Candidate's Signature

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CERTIFICATE

Certified that **Mohd Raquib Ansari (2K22/STE/07)** has carried out their research work presented in this dissertation entitled **"Seismic Analysis of RC Building Considering Soil Structure Interaction"** for the award of **Master of Technology** from the Department of Civil Engineering, Delhi Technological University, Delhi; under my supervision. The dissertation embodies results of original work, and studies are carried out by the student himself and the contents of the dissertation do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University.

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ABSTRACT

Soil condition is thus very important during an earthquake. The analysis of the energy transfer mechanism from soil to buildings under seismic waves is censorious for the seismic design of the multi-storey structures and improves with the idea of soil structure for building design. Recent studies and investigations indicate that soil structure interaction (SSI) can be negative for structural seismic response. It is strongly advised to improve the idea of SSI when developing structures in seismic zone IV and V, which are under great danger of seismic waves quite regularly. Equivalent static load; response spectrum technique and non-linear; time history analysis three approaches of analysis are used for seismic demand assessment of the target moment resistant frame buildings.

Under this project, RC building is to investigate SSI in G+10 Storey with a 30 m elevation using a 22.5 m X 22.5 m layout. The work models using SAP2000 for SSI analysis and the finite element tools ETABS.

Evaluated is the influence of SSI on seismic response comprising storey drift, storey displacement, base shear, natural time period, bending moment, twisting moment changes in structural components. SSI acquired results are matched with those related to fixed base support.

Keywords: SSI, Time History Analysis, Static Load, Response Spectrum Techniques etc.

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MOHD RAQUIB ANSARI

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LIST OF ABBREVIATION

SSI	Soil Structure Interaction
NSSI	Non-Soil Structure Interaction
ETABS	Extended Three-Dimensional Analysis of Building System
RS	Response Spectrum
DL	Dead Load
LL	Live Load
TMD	Twisting Moment Diagram
BMD	Bending Moment Diagram

CHAPTER 1

INTRODUCTION

1.1 GENERAL

"Soil Structure Interaction" refers to the response of soil when structures are present. The soil properties during seismic events have a significant influence on the extent of structural damage. The primary seismic design consideration during an earthquake is the movement experienced at the base of a structure. The soil structure interaction problem can be classified into two primary categories: inertial soil structure interaction and kinematic soil structure interaction. The key factors influencing SSI are the relative stiffness of the soil and the structure. Additionally, the dynamic behaviour of the structure can have a considerable impact on SSI. Several techniques have been suggested over the past four decades to address wave equations in infinite domains. This study provides a concise explanation of the current material, focusing specifically on the dynamic interplay between soil and structure. In broad terms, it can be classified using two approaches: global and local methodologies. The magnitude of socio-economic effects can be ascertained by notable ground motion features. The primary factors contributing to earthquake ground motions are the properties of the seismic source, the path of wave propagation, and the local site conditions. The emergence of SSI as a significant part of earthquake engineering is due to the construction of large buildings on various types of soil, such as earth dams, nuclear power plants, embankments, and waste landfills. The year 1991. Specific structures, such as gravity dams, bridges, and underground tunnels, may require particular attention to SSI concerns. The core SSI model is characterized by a rigid foundation that provides support to the structure. These models have an additional six degrees of freedom, which consist of three translations and three rotations. Practically, these models were found to be excessively simplistic. Locating models with flexible foundations is challenging. The presence of vigorous motions in the structure suggests that the earth surrounding the foundation is regularly exhibiting non-linear responses to the intense shaking caused by the damage. The subject of soil-structure interaction has been explored and analysed from several perspectives. The soil response to structure influences its properties, such as its structure and type of excitation. The designer can assess the soil foundation's displacement and inertial forces caused by free field motion by utilizing the Soil Structure Interaction effect.

1.2 SEISMIC SOIL STRUCTURE INTERACTION

In 1983, a scholar utilized a hypothetical model to ascertain the kinematic interaction of embedded foundations through the application of the random vibration theory. The static correlations of ground motion at distinct points exhibit a reduction as the distance between the points increases, particularly when the ground motion includes high-frequency components. In the hypothetical model, earthquake records at a broad scale are considered, such as those related to deep and shallow foundations. The foundation slab has greater rigidity in comparison to the earth. The ground vibrations are noted to impose a limitation, leading to the reduction in the structural integrity of the slab. Therefore, the slab will function as a low pass filter on the ground motion as a result of the kinematic interaction. This method utilizes a linear solution set that does not involve any interaction. It may be applied to both static and dynamic-elastic analysis.

1.3 HISTORY OF SOIL STRUCTURE INTERACTION

An analysis of multiple works has been conducted, resulting in the development of the concept of SSI. In late 1931, Professor Suyehiro conducted visits to several locations and delivered lectures on the subject of Seismology. He analysed the structural response and examined the damage on different types of buildings. He confidently asserted that the main reason is most likely the subsidence of the earth bed caused by the vibration of the foundation. He determined that the cushioning effect of the ground during an earthquake leads to the damaging impact on a building. The professor has produced noteworthy conclusions that have been repeatedly confirmed through the examination of earthquake damage patterns observed since 1932. Hence, the high-speed elements of seismic waves do not impact the subterranean foundations. The majority of structural design is based on the assumption that the structural elements are rigidly connected to the foundation, preventing any movement, settlement, or rotation. Earthquake ground shaking causes structures to experience inertial forces, which result in base shears and bending moments at the interface between the structure and its foundation. If the supporting soil and foundation system lack rigidity, these internal stresses promote displacement and rotation at the structure base.

1.3.1 Inertial Interaction

Inertial interaction pertains to rotations and displacements occurring at the foundation level of a structure, which are induced by forces propelled by inertia, including moment and base shear. In the soil structure system, inertial displacements and rotations can be substantial sources of energy dissipation and flexibility. System behaviour and conditions under which the principal effects of inertial interaction are significant are highlighted. Although the methods are designed for systems with a single degree of freedom, they are applicable to multi-degree-of-freedom systems in which the first mode is predominate. A relatively comprehensive exposition on the process of specifying foundation springs and dashpots to accurately depict the attenuation and flexibility caused by the interaction between the soil and foundation in translational and rotational vibration modes. The focus is on shallow foundations, including footings and mats.

1.3.2 Kinematic Interaction

It accounts for the fact that a rigid structure can not deform the same way that the soil would if the structure was not there. In Kinematic Interaction SSI is associated with the stiffness of the structure. Clough and Penzien derived the tau(ʈ) effects which explains the Kinematic Interaction due to translation excitation.

1.4 METHOD OF SOIL STRUCTURE INTERACTION

1.4.1 Direct Approach

Under this approach, the foundation and the building are treated as one cohesive model and examined together. This approach is often not used since it demands a lot of computing labor.

1.4.2 Substructures Approach

This method uses a lot of steps for numerical analysis, which is based on the idea of superposition. The goal is to separate the two main types of SSI: unsuitability of the foundation to fix the free field deformation on the movement of supporting soil as a result of the dynamic response of the structure foundation system.

1.5 OBJECTIVE

- Our aim is to investigate how soil flexibility affects building frames in SSI.
- To study the effect of SSI on various structural parameters like Base Shear, Natural Time Period, Storey Displacement, Storey Drift, Bending Moment Variations, Twisting Moment Variations.

1.6 STRUCTURE OF THIS DISSERTATION WORK

- Introduction
- Objectives
- Literature review
- Methodology
- Results and Discussion
- Conclusion
- Future scope of the work
- References

CHAPTER 2

LITERATURE REVIEW

A. Massumi and H.R. Tabatabaiefar created models of four different types of structures: 3, 5, 7, and 10 story buildings. These models were representative of the typical buildings found in high-risk earthquake prone areas. The models were selected to include three different types of soil, which were classified as types II, III, and IV according to the Iranian Standard No. 2800-05. The topic is ductile reinforced concrete moment resisting frames, which are fixed-base structures, are modelled and tested under two conditions: one without soil contact and the other considering soil interaction using the direct technique. The constructions are then subjected to various earthquake records. The findings of the two examples, each subjected to various earthquake records, are analyzed and contrasted. This comparison resulted in the identification of a criterion that suggests the need to address soil-structure interaction for seismic design in structures taller than three storeys on soil type IV.

Taha Amil Ansari and Sagar Jamle (2019) conducted a study on the seismic response of a ten-story building. The focus was on the interaction between the structure and the soil, and the research method used was linear static analysis. Non-linear static analysis was also used to conduct performance-based analysis in this study. A 10-storey structure made of reinforced concrete was simulated in SAP 2000 V14. The simulation included both a normal fixed base building and a flexible base The study concluded that an increase in the flexibility of the building's base leads to an increase in the creation of hinges around the point of failure. The SSI analysis of the building revealed a rise in the time period, roof displacement and storey drift.

Dhiraj Raj and Bharathi M (2022) Studied a four-story RC structure with square plan geometry is examined for analysis. This building is studied for three distinct foundation soils: Type-I (Hard soil), Type-II (Medium soil), and Type-III (Soft soil), as well as two seismic zones: IV and V. FEMA 356 and FEMA 440 evaluations took into account fifty possible combinations of seismic zones, soil types, bracing location and orientation, and foundation with and without SSI. It has been discovered that for a sufficiently stiff structure (with bracing), the increase in the fundamental time period for the construction considering the SSI effect is about double that of the fundamental time period with a fixed base for Type-III soil and 1.5 times for Type-II soil. Considering the SSI effect, a relatively flexible structure (regular building without bracing) established on Type-II soil exhibits the least variance in storey drift, while a relatively stiff structure (with bracing) built on Type-III soil displays the most variation in storey drift.

Nirav M. Katarmal and Hemal J. Shah (2016) analyzed a 15-story model that incorporated a fixed base support, both with and without SSI. The modeling of buildings occurs in SAP2000. For SSI research, three varieties of soil are utilized. The soil is represented by a spring model or FEM and the George Gazetas equation is utilized to calculate its stiffness. Several structural parameters, including natural time period, base shear, and roof displacement were analyzed and discussed in relation to the impact of SSI.

S. Hamid Reza Tabatabaiefar et at (2012) studied the impacts of dynamic soil-structure interaction on seismic behavior and lateral structural response of midrise moment-resisting building frames using the Finite Difference Method. Three kinds of mid-rise structures, including 5, 10, and 15-story buildings, were chosen in combination with three soil types having shear wave velocities of less than 600m/s. The above-mentioned frames were evaluated using two distinct boundary conditions: (i) fixed-base (no soil-structure interaction) and (ii) flexible-base. The lateral deflections and related inter-storey drifts of the flexible base models sitting on type I soil increased by 1%, 3%, and 7% in comparison to fixed-base models for models S5, 10, and S15, respectively.

G. Saad et al (2012), F. Saddik, and S. Najjar conducted a study on the seismic performance of reinforced concrete buildings that have numerous subsurface levels. The study begins with a baseline scenario in which the structures are simulated with a predetermined condition at ground level. Subsequently, the number of basements is systematically increased to examine the resulting variations in performance. The research utilizes the local site circumstances in Beirut. The evaluation of the base shear, inter-story shears, and moments is conducted to quantify the impact of soil structure interaction on the design process

Shehata E. Abdel Raheem et al (2014) conducted an analysis on the effects of SSI (Soil-Structure Interaction) on a standard multi-story building supported by a raft foundation. Three techniques were employed to assess the seismic demands of the target moment resistant frame buildings: equivalent static load (ESL), reaction spectrum (RS) approaches, and nonlinear time history (TH) analysis using a set of nine-time history records. A three-dimensional finite element model was created to examine how various soil conditions and the number of stories impact the vibration characteristics and seismic response requirements of building structures. The numerical findings produced from the soil structure interaction model are compared to those obtained from the fixed-base support conditions. Analysed were the maximum values of story shear, story moment, story displacement, story drift, moments at beam ends, and force of inner columns. The study results of various methodologies were utilized to assess the benefits, constraints, and feasibility of implementing each strategy for seismic.

Ahmed Abdelraheem Farghaly (2017) -An analysis is conducted on a 2D model of two neighbouring structures with varying heights (6 and 12 storeys) and foundation levels, without any separation distance, under the influence of seismic load. The analysis takes into account the effects of soil-structure interaction (SSI). The design of the low height structure includes a specific configuration of contact elements (gap elements) at intervals of 1 meter in the contact zone. This arrangement is intended to accommodate all potential deformation contact modes that may occur during seismic activity (earthquakes). The soil is represented using 2D shell components that are in contact with the foundations of the two neighbouring structures. This research examines the phenomenon of double pounding that occurs between two neighbouring structures at higher places in the superstructure contact zone and at the foundation level. The phenomenon of double pounding, resulting from the increased stresses exerted on nearby buildings due to soil softening, provides a valuable assessment of the strain experienced by the buildings. Additionally, it alters the behavior of the soil beneath the foundations and surrounding the basement floor.

Jinu Mary Mathew et al (2021) conducted a study to examine the impact of seismic movements on the behavior of a nine-story reinforced concrete building. The study considered both the presence and absence of soil-structure interaction. The user modeled a 9-storey reinforced concrete (RC) structure with an asymmetric plan and a height below 45 meters. The building is located in seismic zone III and was planned according to the IS 456:2000 and IS 1893:2002 codes. The detailing of the building was done in accordance with the IS 13920:1993 code. The parameters of nonlinear hinge properties are calculated according to the criteria provided by FEMA-356 and ATC 40. The pushover analysis is conducted in both the X and Y axes, utilizing user-defined nonlinear hinge properties. The analysis has been conducted for three distinct scenarios: (1) A fixed foundation without taking into account soil structure interaction (SSI), (2) A flexible base considering SSI in hard soil conditions, and (3) A flexible base considering

SSI in soft soil conditions. Research has determined that SSI (soil-structure interaction) can impact the seismic performance of buildings, specifically in terms of seismic force requirements and deformations. By analysing the capacity curve, it can be determined that the impacts of Soil-Structure Interaction (SSI) are substantial in soil condition but insignificant in stiff soil circumstances.

Bhuvana Rekha et al (2021) conducted a study on the impact of soil structure interaction on reinforced concrete frame buildings subjected to seismic excitations. By considering several scenarios, such as buildings with 5, 10, 15, and 20 storeys, and different soil types categorized as type I, type II, and type III, numerous types of foundations are examined, including isolated, mixed, mat, and pile foundations. The complete foundation-soil-structure system is simulated and evaluated using the SAP2000 Software, which is based on finite element analysis. This analysis aims to examine the stress experienced by the soil and framed structure when subjected to SSI. Comparative research has been conducted to analyse the impact of SSI on reinforced concrete framed structures. The study demonstrates that incorporating SSI impacts into the analysis and design of structures yields higher levels of safety compared to the standard approach.

G.S. Nicoletta and C.C. Spyrakos - Their paper introduces a system that can be integrated into either Eurocode 8 or the New Greek Seismic Code (NEAK) for designing building structures, taking into account the impacts of SSI. The eleven-step process can be utilized for both regular and irregular buildings, employing either a pseudo-dynamic equivalent static method or reaction spectrum analysis. To illustrate the suggested approach, we evaluate typical multi-story buildings made of reinforced concrete, which are supported by spread footings. A comprehensive analysis is carried out to investigate the impact of soil factors on the reaction of buildings, design forces, and steel reinforcement. The analysis of the buildings involves comparing the design forces and steel reinforcements using current codes that do not take into account the impacts of soil-structure interaction (SSI). Additionally, the proposed upgrading of the codes includes the consideration of SSI effect.

CHAPTER 3

METHODOLOGY

3.1 PROBLEM

G + 10 Storey building is to be modelled and analysed. Following is the data to model the building.

Table 3.1: Building Dimension

S.No	Parameters	Values
1	Column size at all typical floors	500 mm x 500 mm
2	Column size at ground level	600 mm x 600 mm
3	Main beams at all floors	300 mm x 600 mm
4	Secondary beams	200 mm x 600 mm
5	Slab thickness	100 mm
6	Brick wall thickness	230 mm
7	Floor wall height	2.4 m
8	Terrace parapet height	1 m
9	Story height	3 m
10	Total height of building	30 m
11	Floors	G + 10

Table 3.2: Loading Parameter

S.No	Parameters	Values
1	Live load	4.0 kN/m^2 at typical floor 1.5 KN/m^2 on terrace
2	Floor finish	1.0 KN/m^2
3	Water proofing	2.0 KN/m^2
4	Terrace finish	1.0 KN/m^2
5	Earthquake load	As per IS – 1893 (Part 1)-2002
6	Type of soil	Type i, Type ii, Type iii for fixed base & clayey soil for flexible base
7	Concrete Grade	M30 for central column, Ground, M25 for rest
8	Steel Grade	Fe415 is used throughout
9	Seismic zone	iii
10	Zone factor	0.16
11	Importance factor, I	1.5
12	Time period, Ta	$0.075h^{0.75}= 0.961$
13	Response reduction factor	5

3.2 MODELLING OF RC BUILDING WITHOUT CONSIDERING SSI (i.e. FIXED BASE)

- A building with plan dimension 7.50 m X 7.50 m is modelled using ETABS.
- Following are the visual representation of the modelled building.

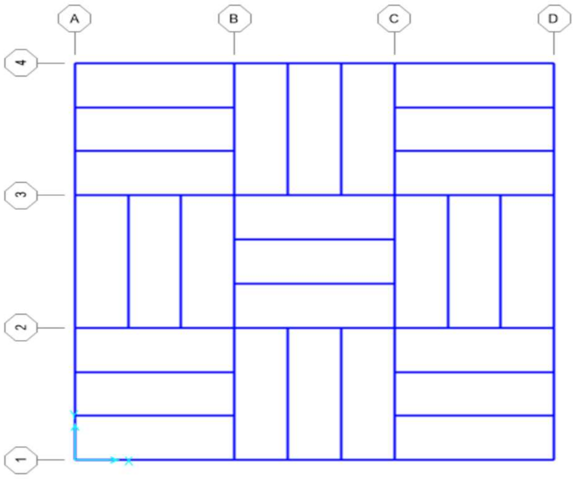


Fig 3.1 Plan view of the building

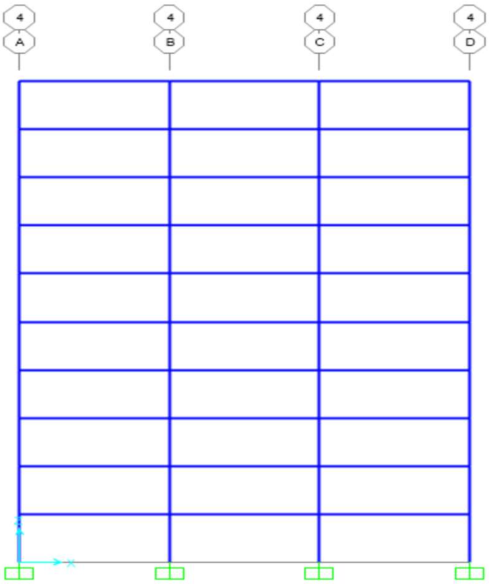


Fig 3.2 Elevation view of building

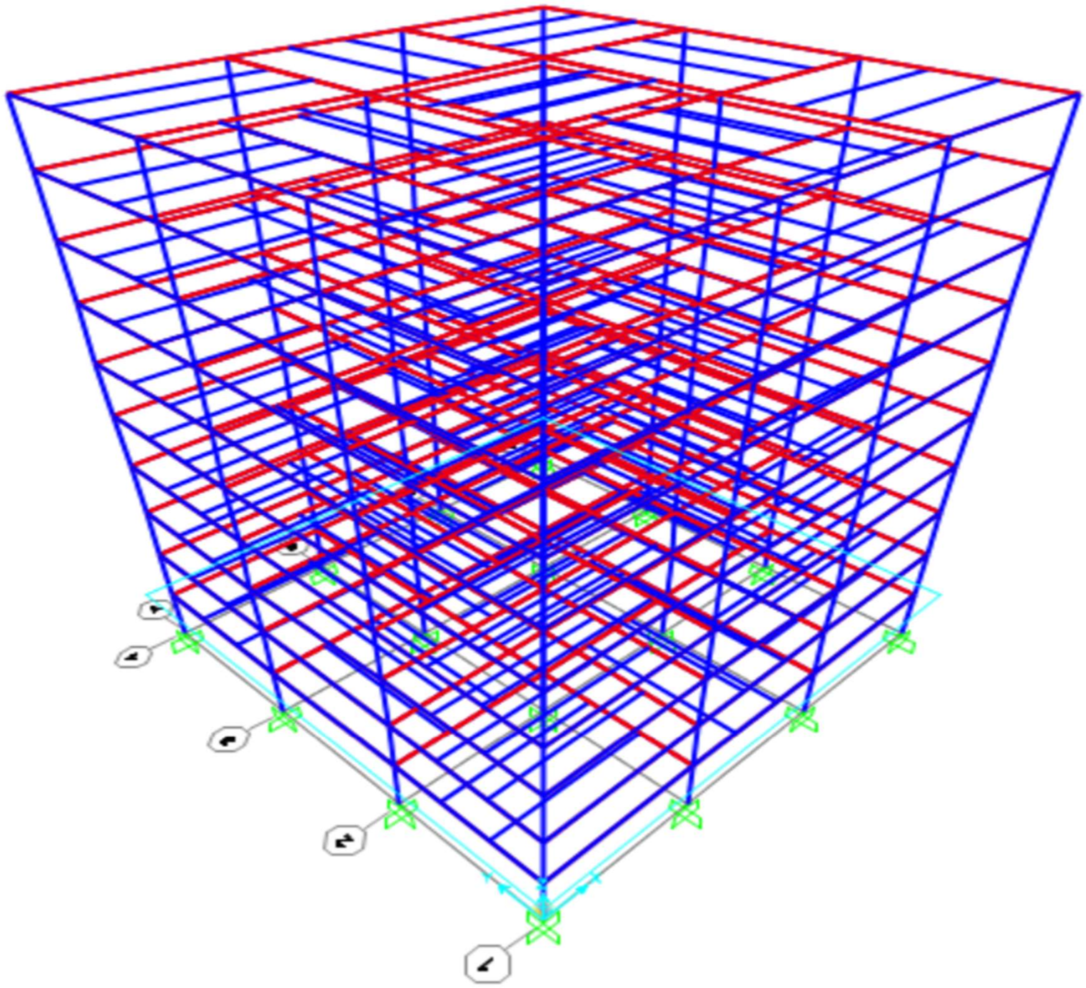


Fig 3.3: 3-D view of building

3.2.1 Load Calculations

Following table shows load due to self-weight of each structural member of the building.

Table 3.3: Load Calculation

S.No	Member	Self-weight
1	Column(500 x 500)	0.5 x 0.5 x 25 = 6.3 KN/m
2	Column(600 x 600)	0.6 x 0.6 x 25 = 9.0 KN/m
3	Main Beam(300 x 600)	0.3 x 0.6 x 25 = 4.5 KN/m
4	Sec Beam(200 x 500)	0.2 x 0.5 x 25 = 2.5 KN/m
5	Slab(100 mm thick)	0.1 x 25 = 2.5 KN/m
6	Brick Wall(230 mm)	(0.23 x 19) + (2 x 0.012 x 20) = 4.9 KN/m^2
7	Floor Wall(2.4 m)	2.4 x 4.9 = 11.76 KN/m
8	Terrace Parapet(1m)	1.0 x 4.9 = 4.9 KN/m

3.2.2 Slab Load Calculations

Load on Terrace and Typical floor of the building due to self-weight of slab, water proofing, floor finish and live load is shown in the table given below.

Table 3.4: Slab Load Calculation

Component	Terrace (DL + LL)	Typical (DL + LL)
Self (100 mm thick)	2.5 + 0.0	2.5 + 0.0
Water Proofing	2.0 + 0.0	0.0 + 0.0
Floor Finish	1.0 + 0.0	1.0 + 0.0
Live Load	0.0 + 1.5	0.0 + 4.0
Total	5.5 + 1.5 KN/m^2	3.5 + 4.0 KN/m^2

3.3.3 Load Combinations

The various load combinations used in the analysis and investigation must be considered in accordance with IS 1893, and the parameters used in the seismic analysis of the tall structure in the current research in accordance with IS 1893-2016 (Part 1) are listed in the table below.

Table 3.5: Load Combination

S.NO	Load Combinations	DL	LL	EQ	WL	RS
1	DConS1	1.5	-	-	-	-
2	DConS2	1.5	1.5	-	-	-
3	DConS3	1.2	1.2	-	1.2	-
4	DConS4	1.2	1.2	-	-1.2	-
5	DConS5	1.5	-	-	1.5	-
6	DConS6	1.5	-	-	-1.5	-
7	DConS7	0.9	-	-	1.5	-
8	DConS8	0.9	-	-	-1.5	-
9	DConS9	1.2	1.2	1.2 (EX)	-	-
10	DConS10	1.2	1.2	-1.2 (EX)	-	-
11	DConS11	1.2	1.2	1.2 (EY)	-	-
12	DConS12	1.2	1.2	-1.2 (EY)	-	-
13	DConS13	1.5	-	1.5 (EX)	-	-
14	DConS14	1.5	-	-1.5 (EX)	-	-
15	DConS15	1.5	-	1.5 (EY)	-	-
16	DConS16	1.5	-	-1.5 (EY)	-	-

17	DConS17	0.9	-	1.5 (EX)	-	-
18	DConS18	0.9	-	-1.5 (EX)	-	-
19	DConS19	0.9	-	1.5 (EY)	-	-
20	DConS20	0.9	-	-1.5 (EY)	-	-
21	DConS21	1.2	1.2	-	-	1.2
22	DConS22	1.5	-	-	-	1.5
23	DConS23	0.9	-	-	-	1.5

3.3.4 Applying loads on the building

All the loads that were previously calculated are applied now. Following fig is the visual representation of the load on the building.

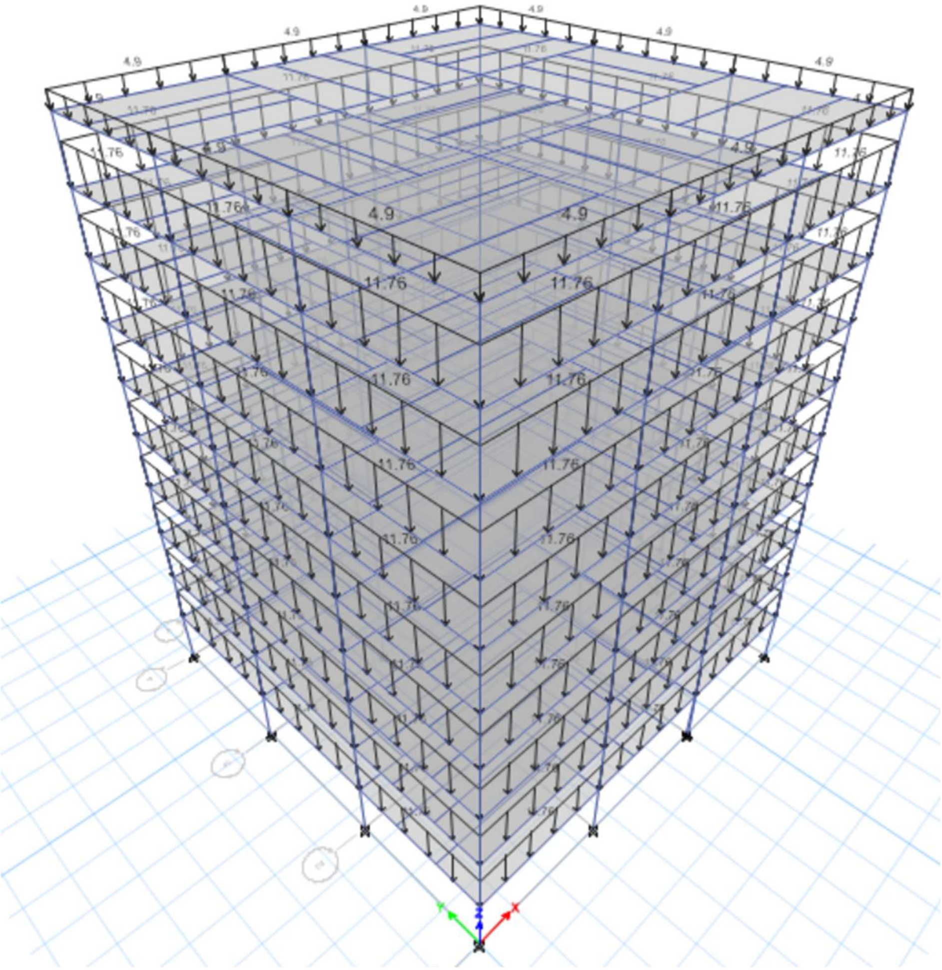


Fig 3.4: Applying load on building

3.3 ANALYSIS OF BUILDING WITH FIXED BASE

3.3.1 Soil Type I

IS 1893 -2016 (Part 1) has taken ROCKY SOIL as Soil Type I. We will analyse that how the building modelled with fixed base on soil type I will behave by calculating following parameters.

3.3.1.1 Base Shear

For soil type I, the base shear on the building is **416.75 KN.**

3.3.1.2 Natural Time Period

Here is a table showing natural time period for 12 different modes.

Table 3.6: Natural Time Period for different modes

Mode No.	Natural Time Period (sec)
1	2.33
2	2.31
3	1.92
4	0.75
5	0.74
6	0.62
7	0.42
8	0.41
9	0.35
10	0.27
11	0.26
12	0.23

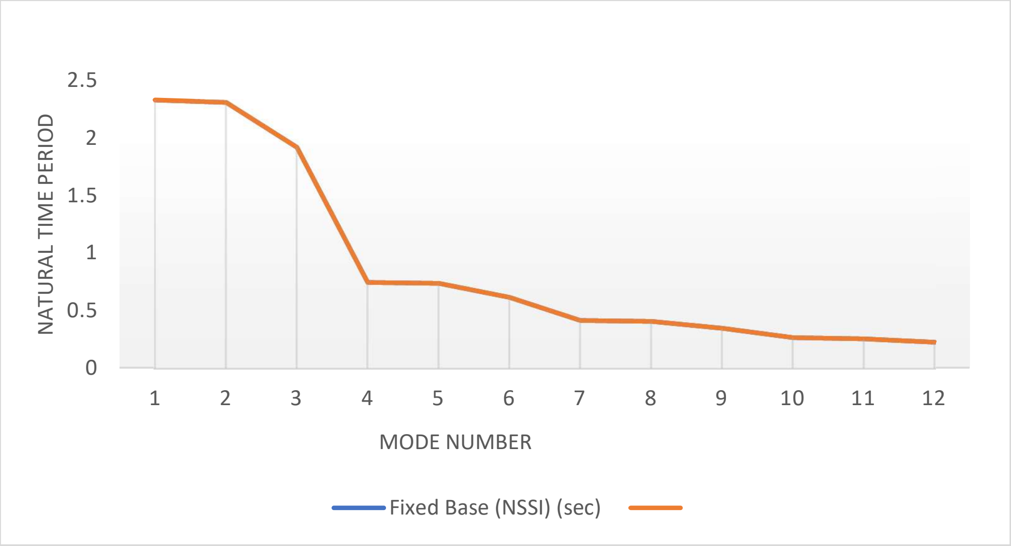


Fig 3.5: Natural Time Period

3.3.1.3 Storey Displacement

Following table shows storey displacement at different storey numbers for soil type I.

Table 3.7: Storey Displacement at fixed base (soil type I)

Storey No.	Storey Disp. at fixed base (soil type I) in mm
1	1.177
2	4.015
3	7.415
4	10.899
5	14.296

6	17.489
7	20.357
8	22.763
9	24.569
10	25.702

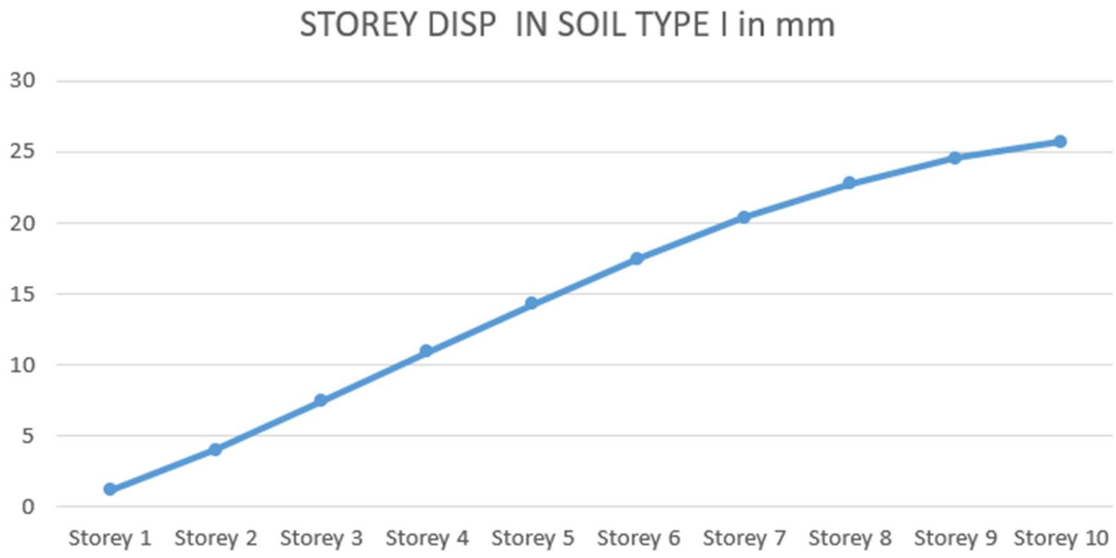


Fig 3.6: Storey Displacement in Soil type I

3.3.1.4 Storey Drift Ratio

Following table shows storey drift ratio at different storey numbers.

Table 3.8: Storey drift ratio at fixed base (soil type I)

Storey No	Storey Drift Ratio in soil type i (fixed base)
1	0.000392
2	0.000946
3	0.001134
4	0.001162
5	0.001133
6	0.001065
7	0.000956
8	0.000803
9	0.000603
10	0.000379

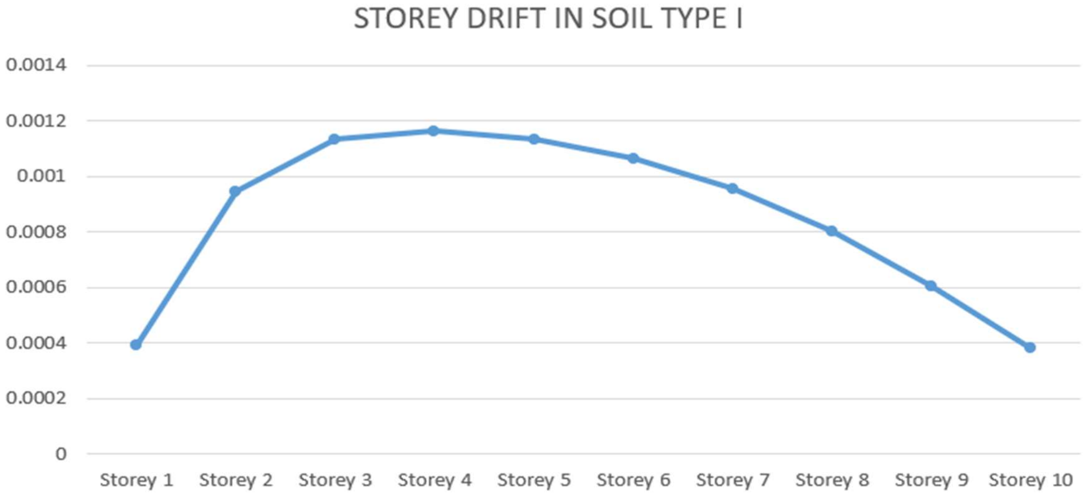


Fig 3.7 Storey Drift Ratio in Soil type I

3.3.1.5 Bending Moment

Bending moment diagram for seismic and gravity loads will be different. Following are the BMD for different type of loads.

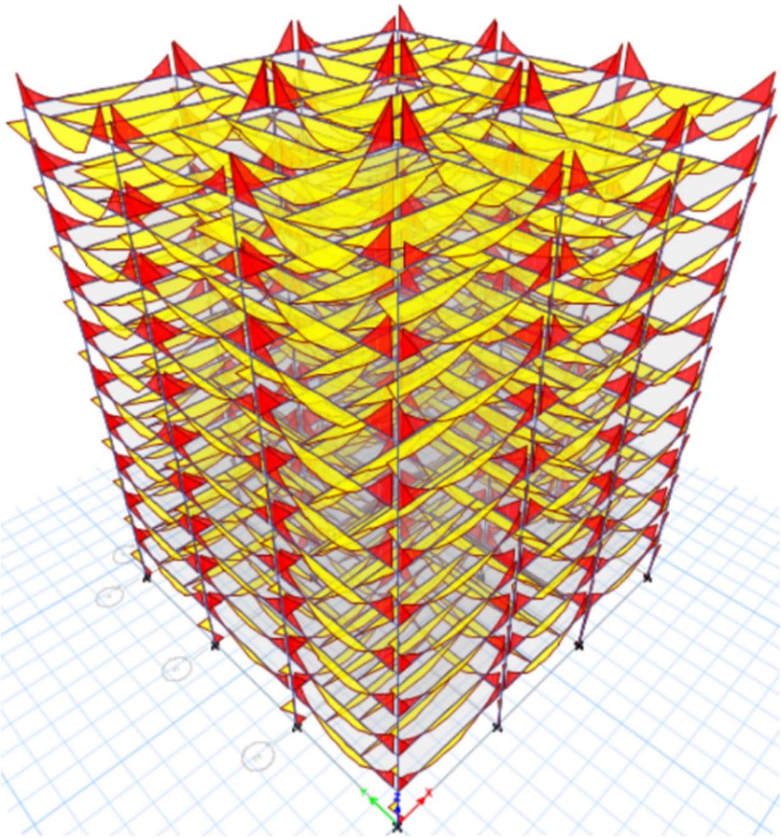


Fig 3.8: BMD (Dead Load)

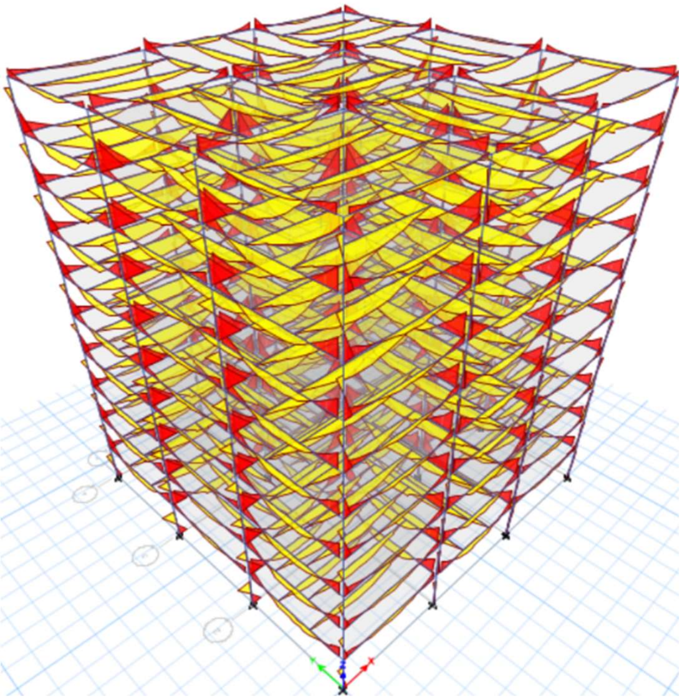


Fig 3.9: BMD (Live Load)

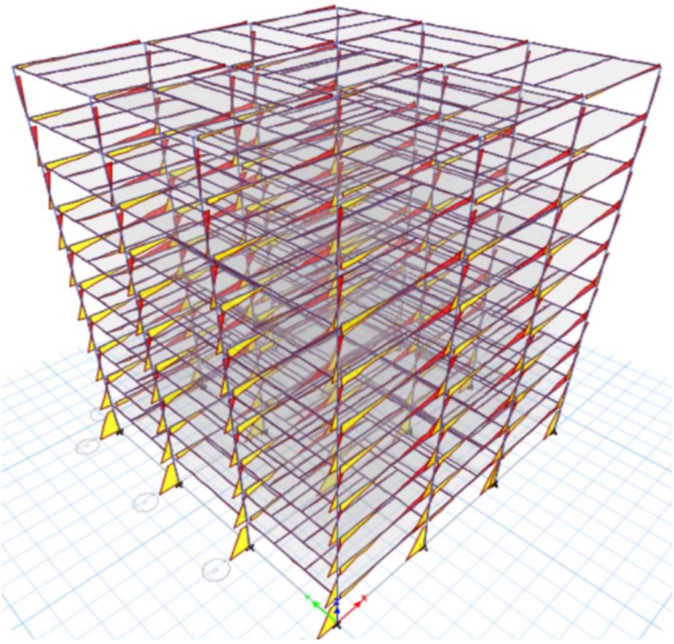


Fig 3.10: BMD (EQX)

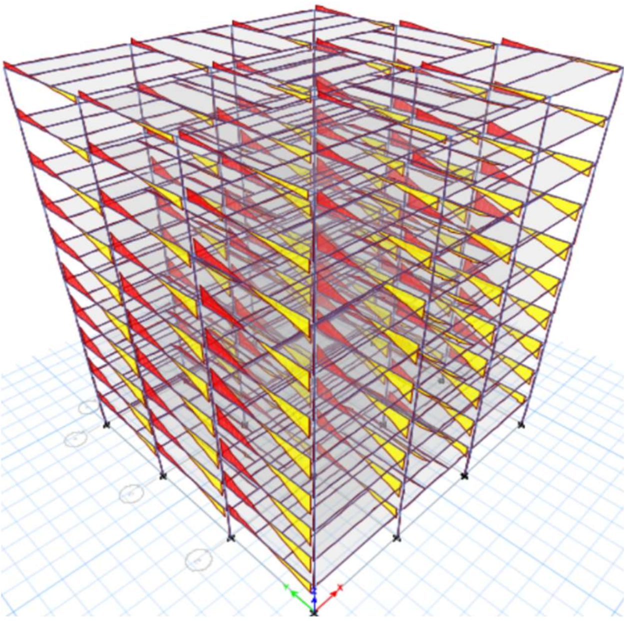


Fig 3.11: BMD (EQY)

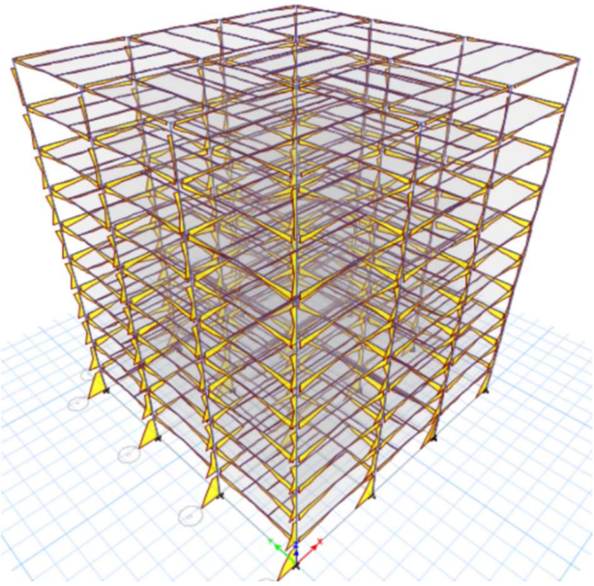


Fig 3.12: BMD (RS)

Bending Moment Variations (Beam 10 at storey 10 has been taken)

Table 3.9: Bending Moment Variations in Soil type I

S. No	Load Conditions	Moment at fixed base (KN-m)
1	EQY	8.3787
2	EQX	-0.2444
3	LIVE	-19.3759
4	DEAD	-132.1703
5	RS	1.0942

3.3.1.6 Twisting Moment

Twisting moment diagram for seismic and gravity loads will be different. Following are the TMD for different type of loads.

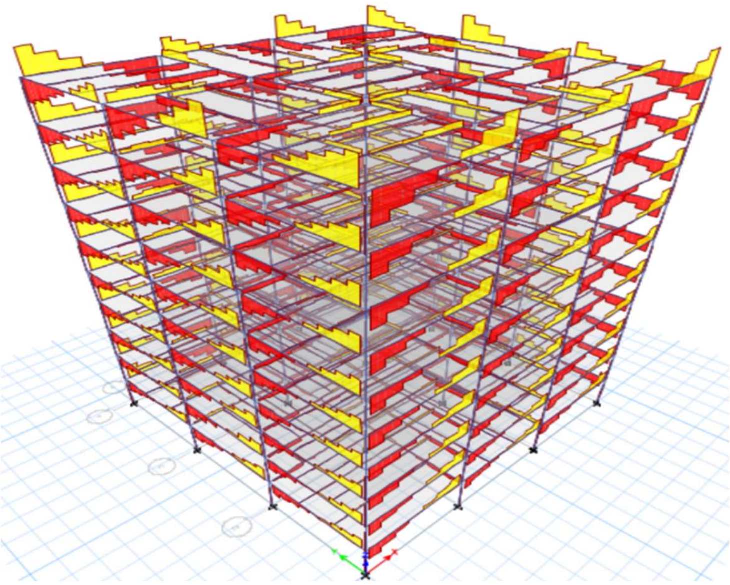


Fig 3.13: TMD (Dead Load)

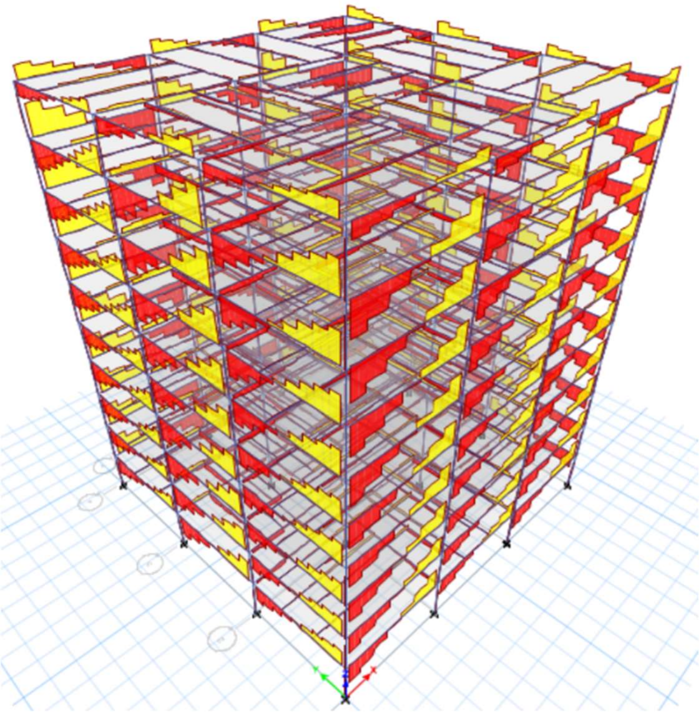


Fig 3.14: TMD (Live Load)

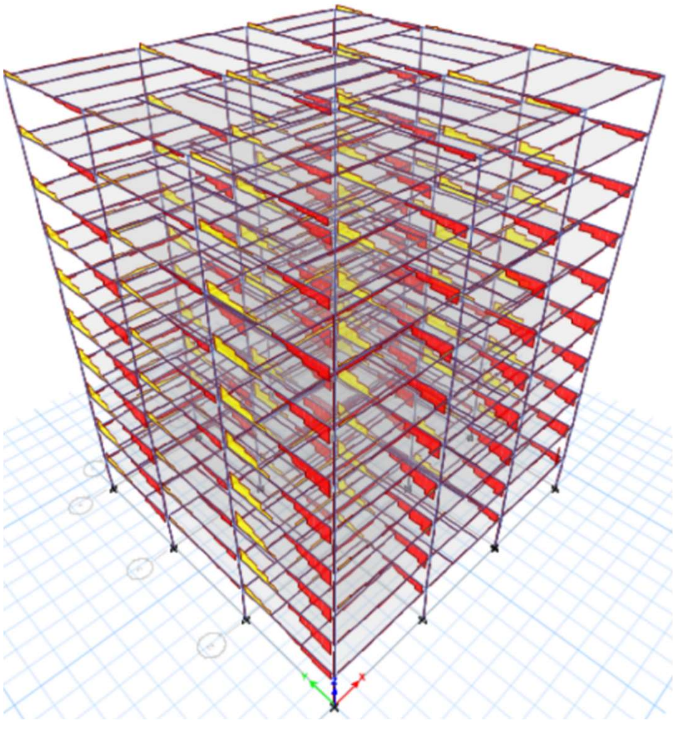


Fig 3.15: TMD (EQX)

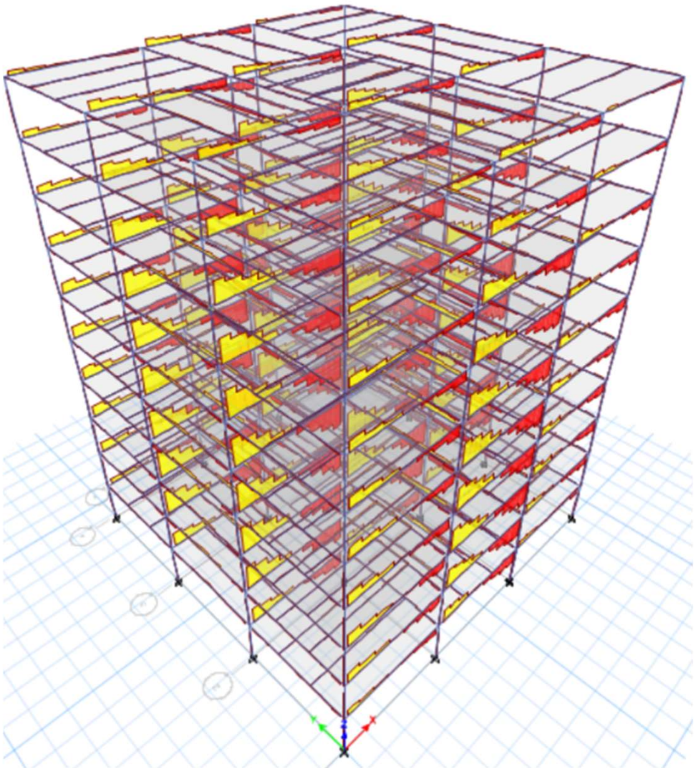


Fig 3.16: TMD (EQY)

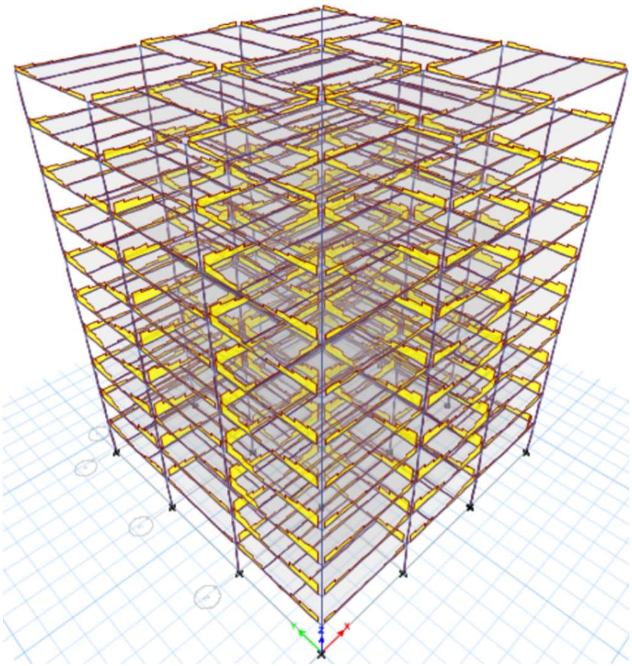


Fig 3.17: TMD (RS)

Twisting Moment Variations (Beam 10 at storey 10 has been taken)

Table 3.10: Twisting Moment Variations in Soil type I

S. No	Load Combinations	Torsion at fixed base (KN-m)
1	EQY	-0.1555
2	EQX	-1.7048
3	LIVE	5.2033
4	DEAD	22.9563
5	RS	0.2292

3.3.2 Soil Type II

IS 1893 -2016 (Part 1) has taken MEDIUM SOIL as Soil Type II. here we will analyse that how the building modelled with fixed base on soil type II will behave, by calculating following parameters.

3.3.2.1 Base Shear

For soil type II, the base shear on the building is **529.47 KN.**

3.3.2.2 Natural Time Period

Natural Time Period will remain same in all 3 types of soils.

3.3.2.3 Storey Displacement

Following table shows storey displacement at different storey for soil type II.

Table 3.11: Storey Displacement at fixed base (soil type II)

Storey No	Storey Disp. at fixed base (soil type II) in mm
1	1.505
2	5.137
3	9.487
4	13.945
5	18.290
6	22.375
7	26.044
8	29.122
9	31.433
10	32.882

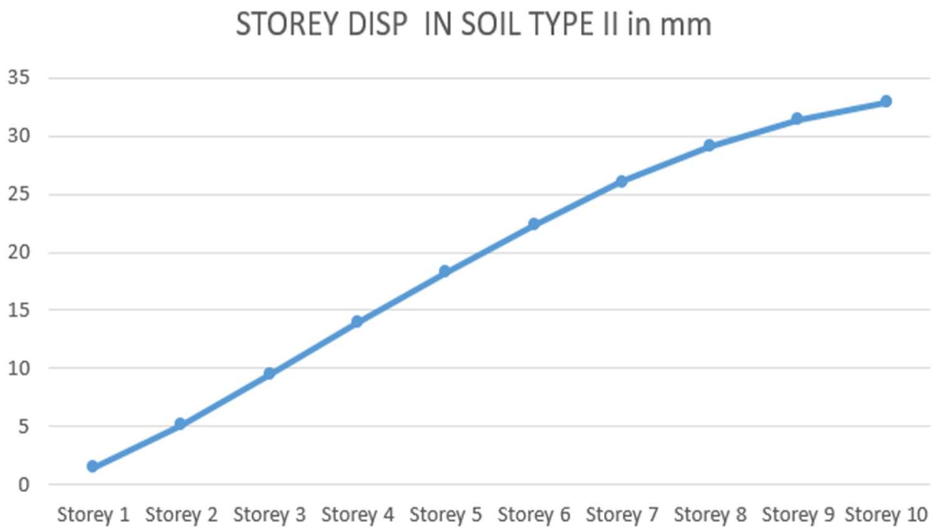


Fig 3.18: Storey Displacement in soil type II

3.3.2.4. Storey Drift Ratio

Following table shows storey drift at different storey numbers for soil type II.

Table 3.12: Storey Drift Ratio at fixed base (Soil type II)

Storey No	Storey Drift Ratio at fixed base (Soil type II)
1	0.000502
2	0.001211
3	0.001451

4	0.001487
5	0.001450
6	0.001363
7	0.001224
8	0.001027
9	0.000771
10	0.000485

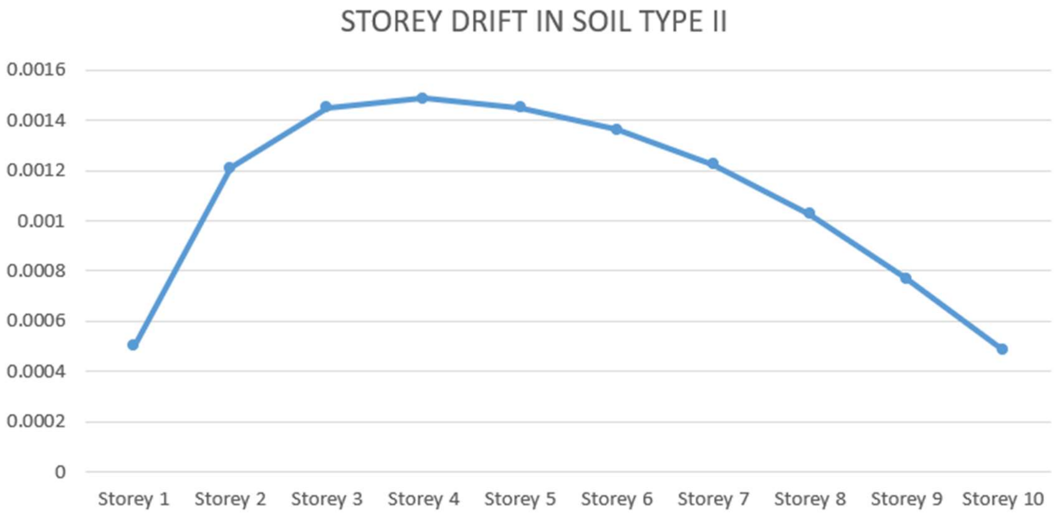


Fig 3.19: Storey Drift Ratio in Soil type II

3.3.2.5. Bending Moment

Bending moment for dead and live loads will be same for all three types of soils. Bending moment diagram for seismic and gravity loads will be different. Following are the BMD for different type of loads.

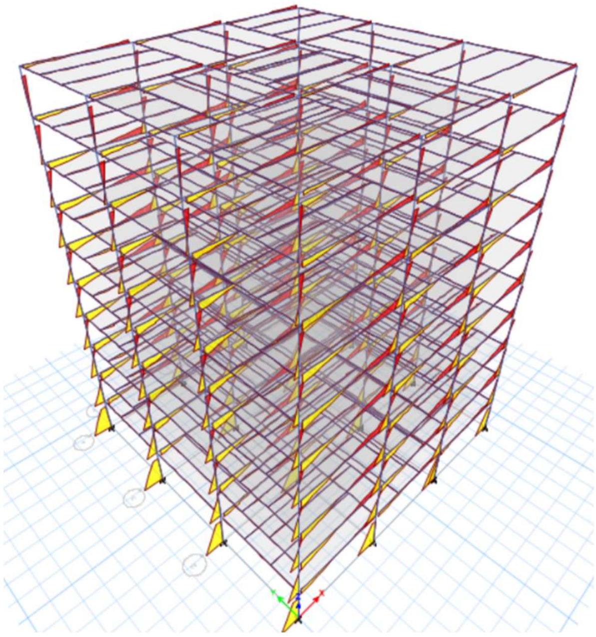


Fig 3.20: BMD (EQX)

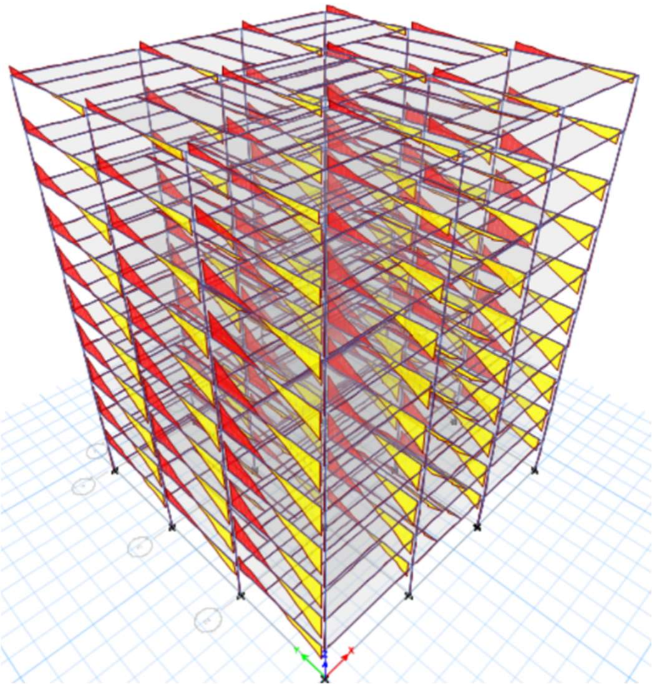


Fig 3.21: BMD (EQY)

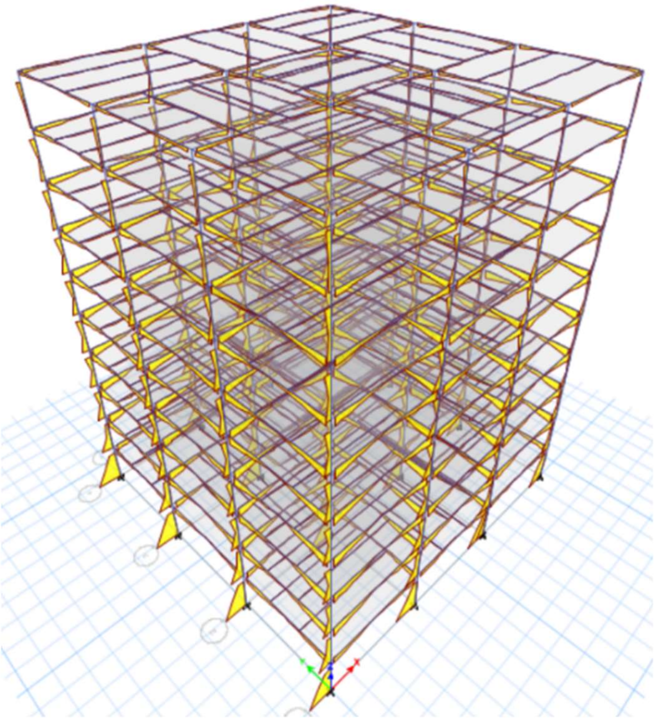


Fig 3.22: BMD (RS)

Bending Moment Variations (Beam 10 at storey 10 has been taken)

Table 3.13: Bending Moment Variations in Soil type II

S. No	Load Conditions	Moment at fixed base (KN-m)
1	EQY	10.6452
2	EQX	-0.3127
3	LIVE	-19.3759
4	DEAD	-132.1703
5	RS	1.3687

3.3.2.6. Twisting Moment

Twisting moment for dead and live loads will be same for all three types of soils. Twisting moment diagram for seismic and gravity loads will be different. Following are the TMD for different type of loads.

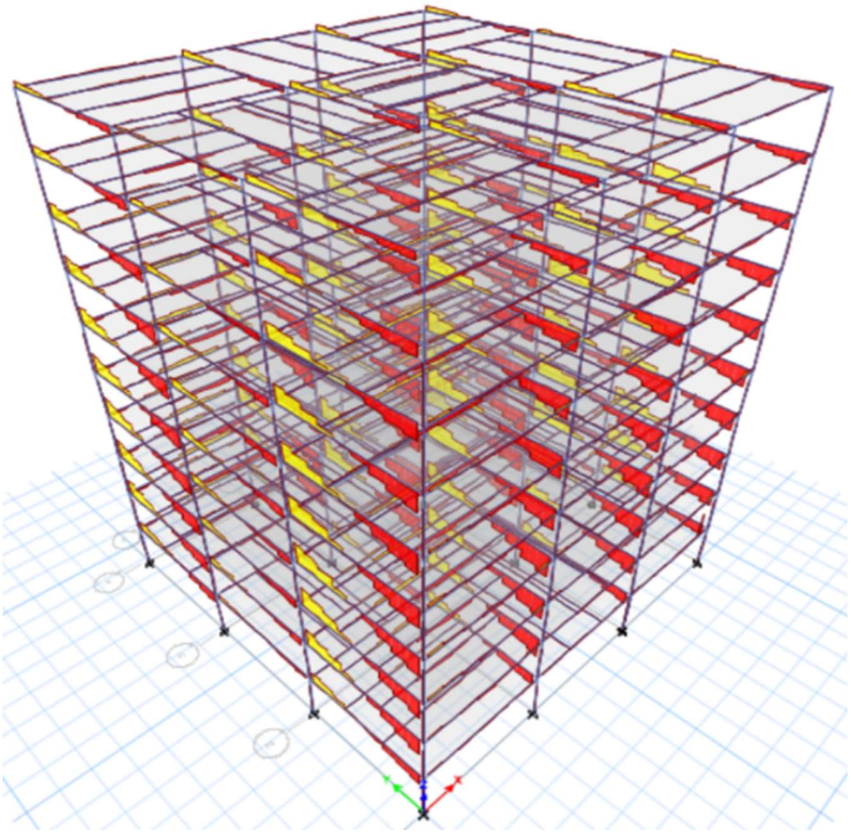


Fig 3.23: TMD (EQX)

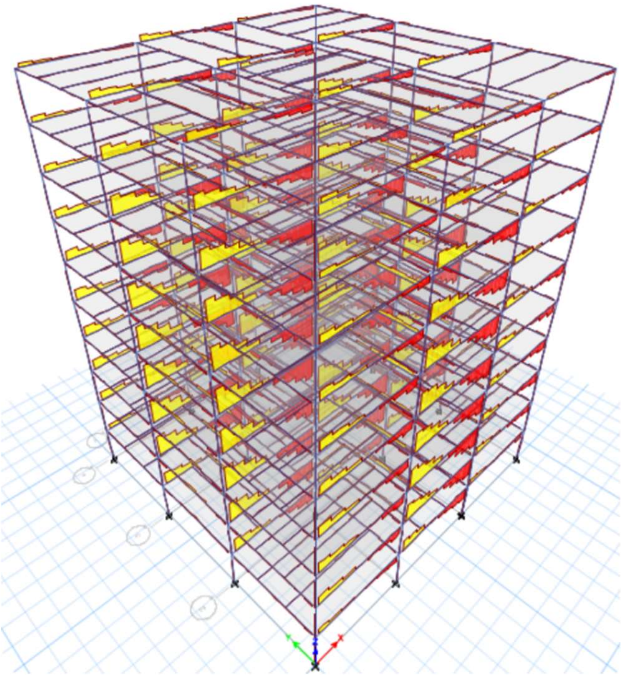


Fig 3.24: TMD (EQY)

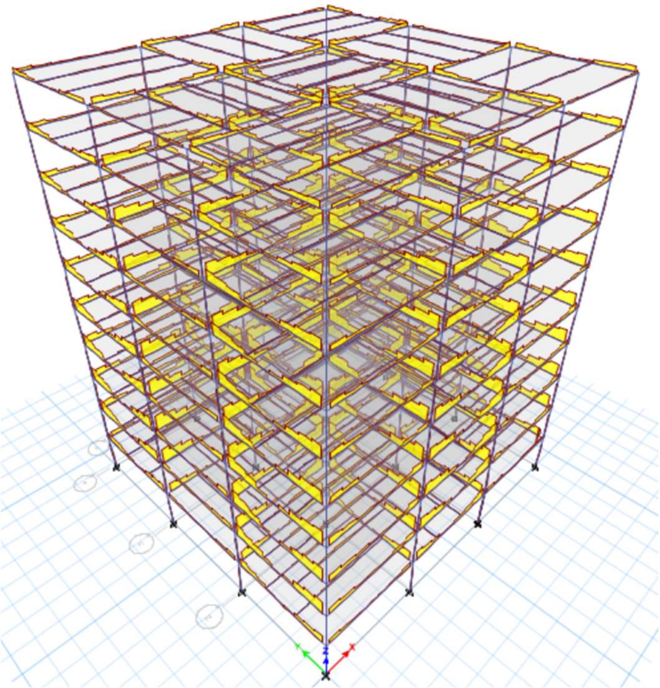


Fig 3.25: TMD (RS)

Twisting Moment Variations (Beam 10 at storey 10 has been taken)

Table 3.14: Twisting Moment Variations in Soil type II

S. No	Load Conditions	Torsion at fixed base (KN-m)
1	EQY	-0.1976
2	EQX	-2.1811
3	LIVE	5.2033
4	DEAD	22.9563
5	RS	0.2865

3.3.3 Soil Type III

IS 1893 -2016 (Part 1) has taken SOFT SOIL as Soil Type III. here we will analyse that how the building modelled with fixed base on soil type III will behave, by calculating following parameters.

3.3.3.1 Base Shear

For Soil Type iii, the base shear on building is **650.16 KN.**

3.3.3.2 Natural Time Period

Natural time period will be same for all three types of soils.

3.3.3.3 Storey Displacement

Following table shows storey displacement at different storey for soil type III.

Table 3.15: Storey Displacement at fixed base (Soil Type III)

Storey No.	Storey Disp. at fixed base (soil type III) in mm
1	1.849
2	6.308
3	11.649
4	17.123
5	22.459
6	27.475
7	31.980
8	35.760
9	38.598
10	40.378

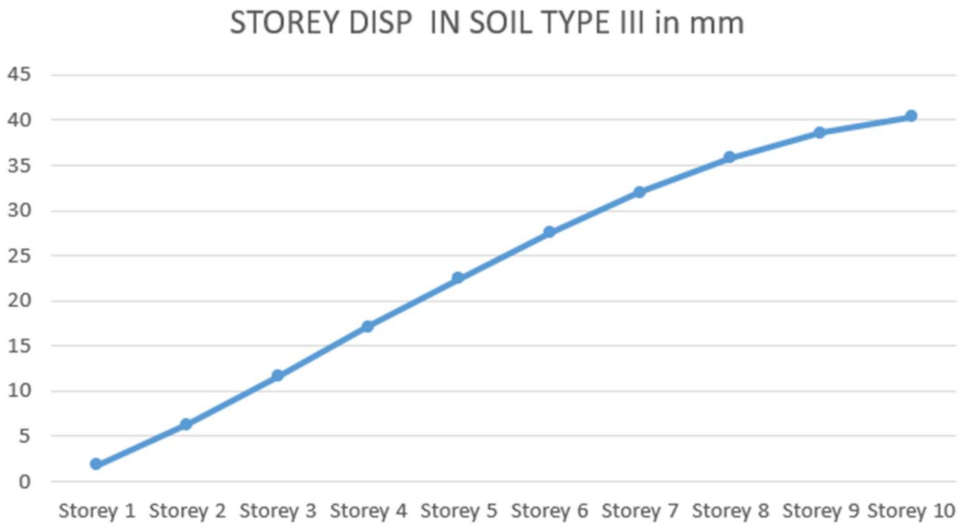


Fig 3.26: Storey Displacement in Soil Type III

3.3.3.4 Storey Drift Ratio

Following table shows storey drift ratio at different storey numbers for soil type III.

Table 3.16: Storey Drift Ratio at fixed base (soil type III)

Storey No.	Storey Drift Ratio in soil type iii (fixed base)
1	0.000616
2	0.001486
3	0.001782
4	0.001826

5	0.001780
6	0.001673
7	0.001503
8	0.001261
9	0.000947
10	0.000595

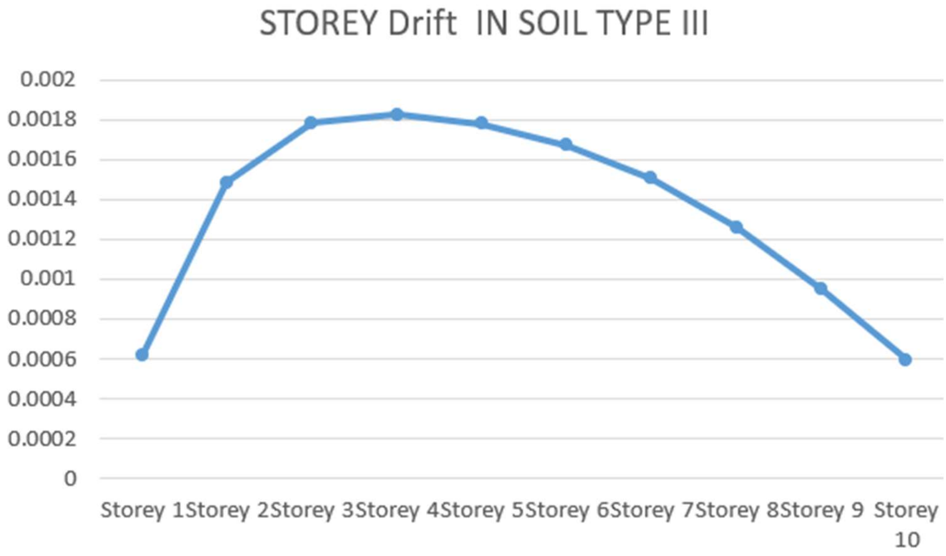


Fig 3.27: Storey Drift ratio in soil type III

3.3.3.5 Bending Moment

Bending moment for dead and live loads will be same for all three types of soils. Bending moment diagram for seismic and gravity loads will be different. Following are the BMD for different type of loads.

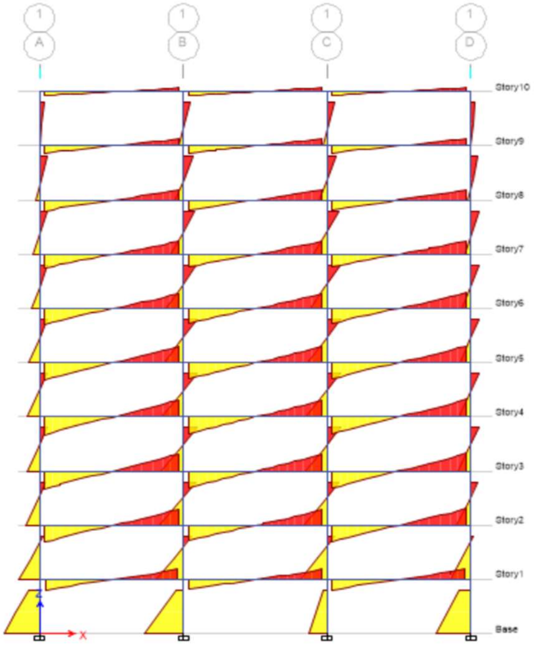


Fig 3.28: BMD (EQX)

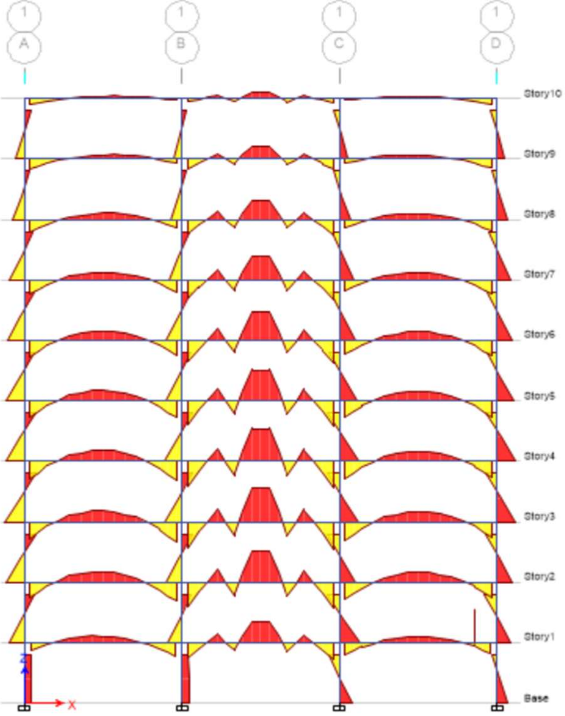


Fig 3.29: BMD (EQY)

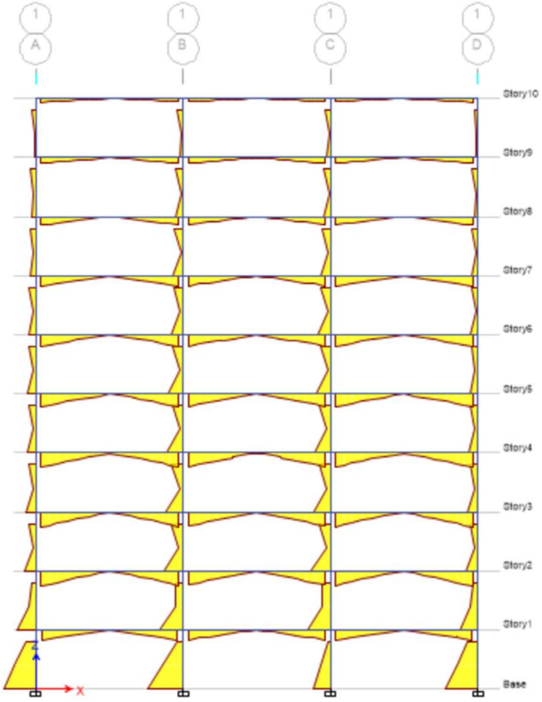


Fig 3.30: BMD (RS)

<u>Bending Moment Variations (Beam 10 at storey 10 has been taken)</u>

Table 3.17: Bending Moment Variations in soil type III

S. No	Load Conditions	Moment at fixed base (KN-m)
1	EQY	13.0717
2	EQX	-0.3840
3	LIVE	-19.3759
4	DEAD	-132.1703
5	RS	1.5973

3.3.3.6 Twisting Moment

Twisting moment for dead and live loads will be same for all three types of soils. Twisting moment diagram for seismic and gravity loads will be different. Following are the TMD for different type of loads.

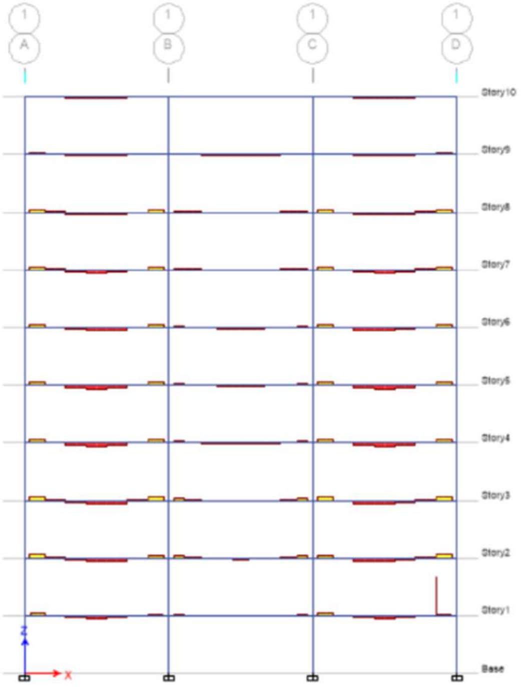


Fig 3.31: TMD (EQX)

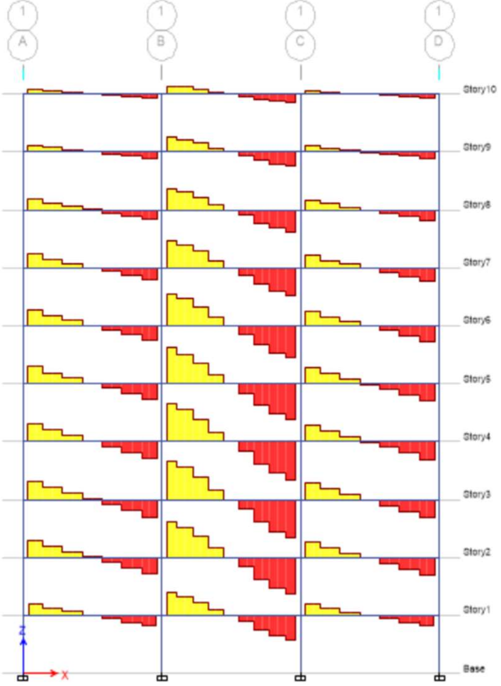


Fig 3.32: TMD (EQY)

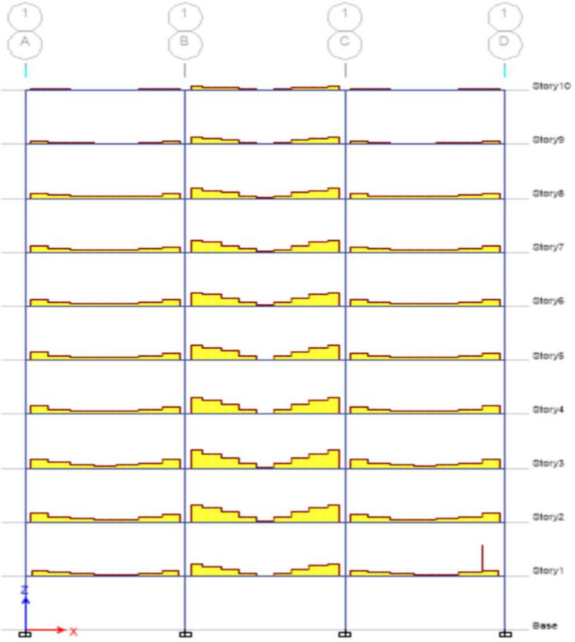


Fig 3.33: TMD (RS)

Twisting Moment Variations (Beam 10 at storey 10 has been taken)

Table 3.18: Twisting Moment Variations in soil type III

S. No	Load Conditions	Torsion at fixed base (KN-m)
1	EQY	-0.2427
2	EQX	-2.6782
3	LIVE	5.2033
4	DEAD	22.9563
5	RS	0.3340

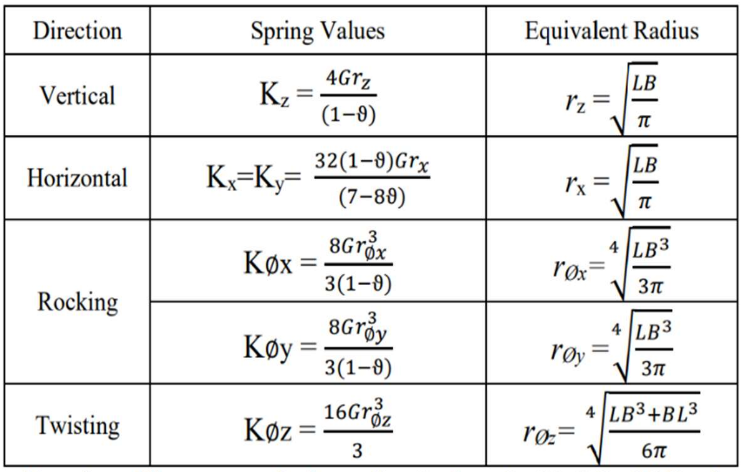
CHAPTER 4

FLEXIBLE BASE

4.1 MODELLING OF RC BUILDING CONSIDERING SSI

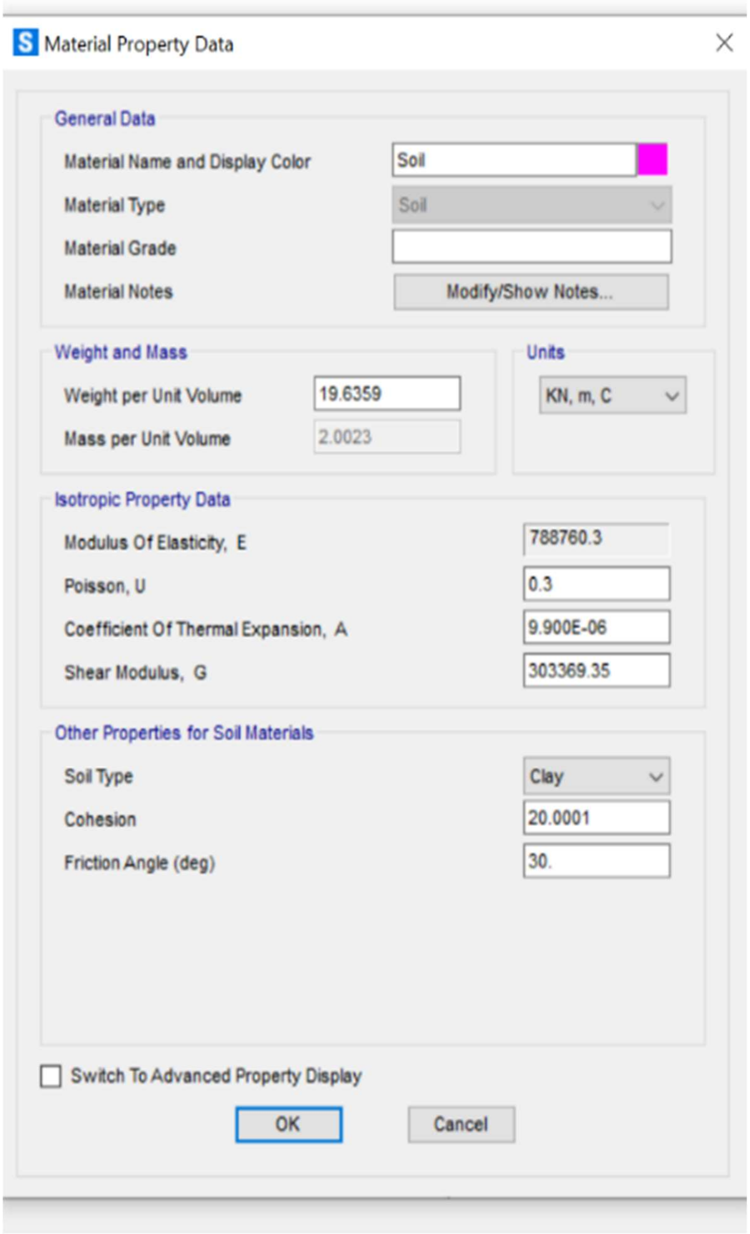
- Using thick R.C. Shell elements, a 24.5 x 24.5 x 1 m raft foundation has been designed to enable the simulation of the impacts of SSI for the clayey soil.
- The model of the structure with raft foundation is as depicted. Obtained and computed, the characteristics of clayey soil are displayed.
- In accordance with the Richart and Lysmer model, the spring stiffness values for vertical, horizontal, swaying, and twisting motions are computed. Quad shell elements are utilized to interconnect the entire area, and soil springs are implemented.
- The current investigation focuses primarily on clayey soil. The most crucial characteristics of the clayey soil are enumerated and illustrated below.

Soil spring as per Richart and Lysmer



Direction	Spring Values	Equivalent Radius
Vertical	$K_z = \frac{4Gr_z}{(1-\vartheta)}$	$r_z = \sqrt{\frac{LB}{\pi}}$
Horizontal	$K_x = K_y = \frac{32(1-\vartheta)Gr_x}{(7-8\vartheta)}$	$r_x = \sqrt{\frac{LB}{\pi}}$
Rocking	$K\emptyset x = \frac{8Gr_{\emptyset x}^3}{3(1-\vartheta)}$	$r_{\emptyset x} = \sqrt[4]{\frac{LB^3}{3\pi}}$
	$K\emptyset y = \frac{8Gr_{\emptyset y}^3}{3(1-\vartheta)}$	$r_{\emptyset y} = \sqrt[4]{\frac{LB^3}{3\pi}}$
Twisting	$K\emptyset z = \frac{16Gr_{\emptyset z}^3}{3}$	$r_{\emptyset z} = \sqrt[4]{\frac{LB^3+BL^3}{6\pi}}$

K=spring stiffness, r = equivalent radius, L= Length of Raft B= Width of Raft



Material Property Data

General Data

Material Name and Display Color: Soil

Material Type: Soil

Material Grade:

Material Notes

Weight and Mass

Weight per Unit Volume: 19.6359

Mass per Unit Volume: 2.0023

Units: KN, m, C

Isotropic Property Data

Modulus Of Elasticity, E: 788760.3

Poisson, U: 0.3

Coefficient Of Thermal Expansion, A: 9.900E-06

Shear Modulus, G: 303369.35

Other Properties for Soil Materials

Soil Type: Clay

Cohesion: 20.0001

Friction Angle (deg): 30.

☐ Switch To Advanced Property Display

Fig 4.1: Material Properties

Table 4.1: Spring stiffness values

Direction	Notation	Spring Values (KN/m)
Vertical	K_z	33673997.4
Horizontal	Kx = Ky	2184898.3
Rocking	KØx = KØy	460490537
Twisting	KØz	4420709157

4.2 MAT FOUNDATION

MAT foundation of the G+10 building has been made with SAP2000. Following is the visual representation of the MAT foundation, Plan view, elevation view, of building with MAT foundation.

Fig 4.2: Plan view of MAT Foundation

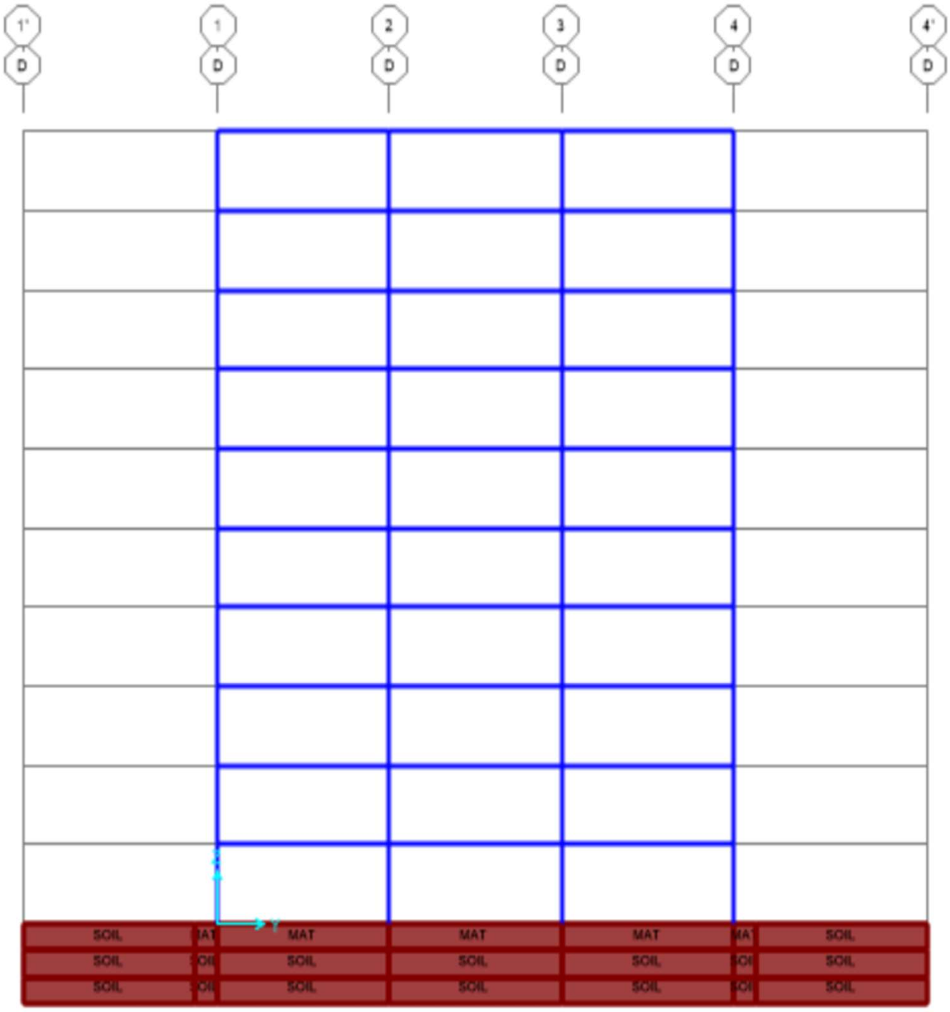


Fig 4.3: Elevation view of MAT Foundation

4.3 APPLYING JOINT RESTRAINTS

As we are modelling the building with flexible base for Soil structure interaction. so, now we are providing flexible supports on MAT foundation.

Following figure shows that the flexible supports has been provided.

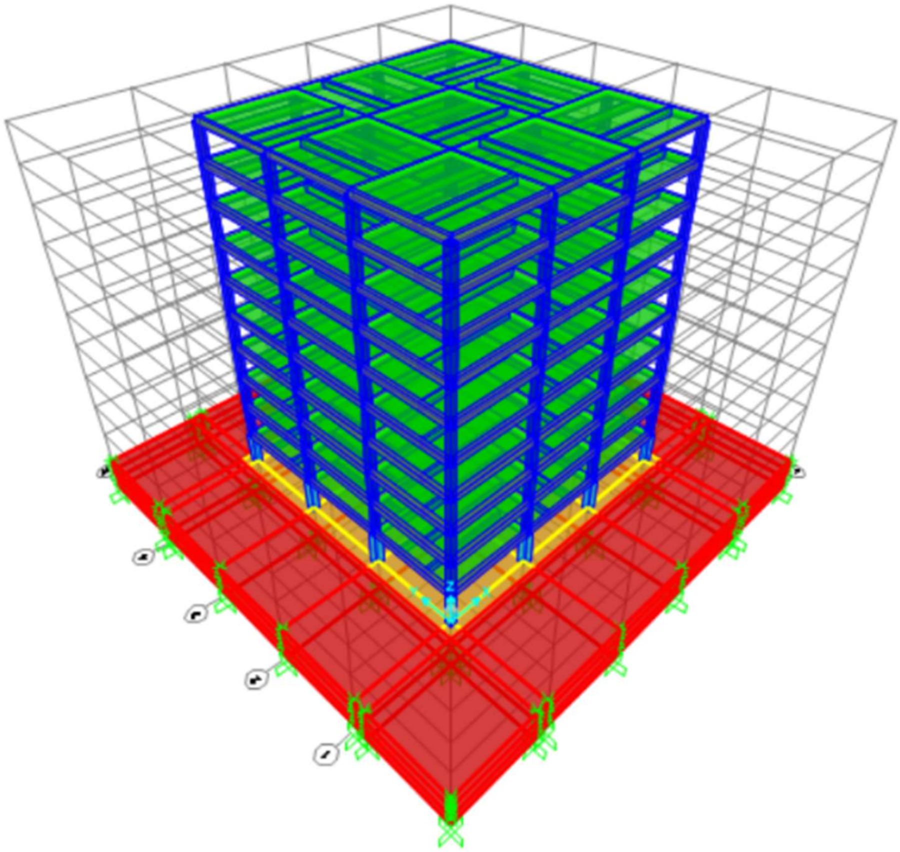


Fig 4.4: Building with Flexible Supports

4.4 PROVIDING SOIL SPRINGS

In accordance with the Richart and Lysmer model, spring stiffness values for vertical, horizontal, swaying, and twisting motions are computed. Quad shell elements are utilized to interconnect the entire area, and soil springs are implemented.

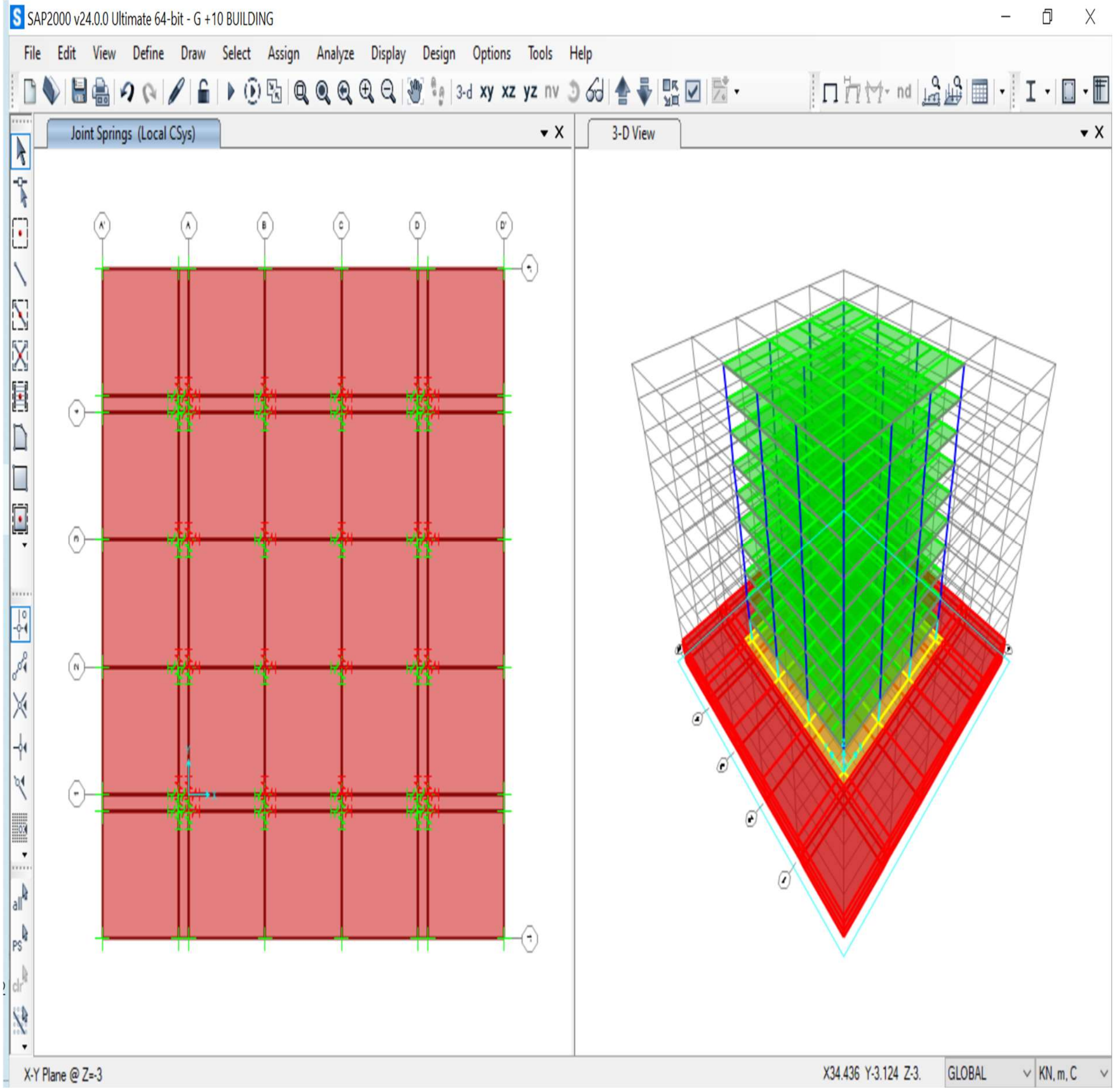


Fig 4.5: Applying Soil Springs

4.5 ANALYSIS OF BUILDING WITH FLEXIBLE BASE

4.5.1 Base Shear

For Clayey Soil, the base shear of building is **1829.9 KN**.

4.5.2 Natural Time Period

Following table shows different time period at different modes for building with flexible base (SSI).

Table 4.2: Natural Time Period for different modes

MODE NO.	Natural Time Period (SSI) (sec)
1	2.64
2	2.62
3	2.28
4	0.83
5	0.83
6	0.73
7	0.46
8	0.46
9	0.40
10	0.31
11	0.29
12	0.26

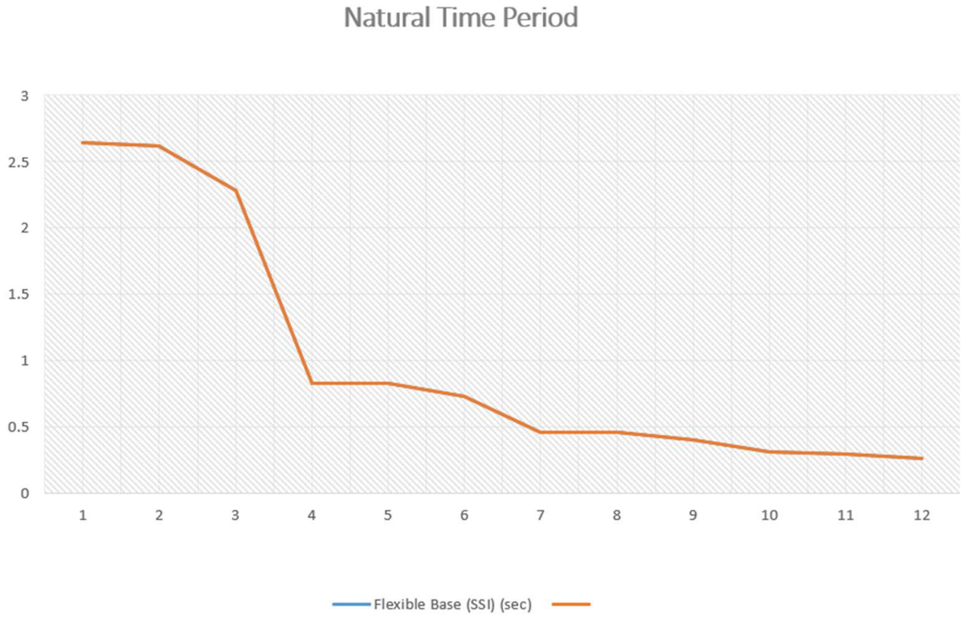


Fig 4.6: Natural Time Period for Flexible Base

4.5.3 Storey Displacement

Following table shows storey displacement at different storey number for the building with flexible base (SSI).

Table 4.3: Storey Displacement at flexible base

Storey No	Storey Disp. at Flexible Base (clayey soil) in mm
1	25.841
2	47.086
3	65.404

4	82.489
5	98.499
6	113.161
7	126.013
8	136.629
9	144.447
10	149.314

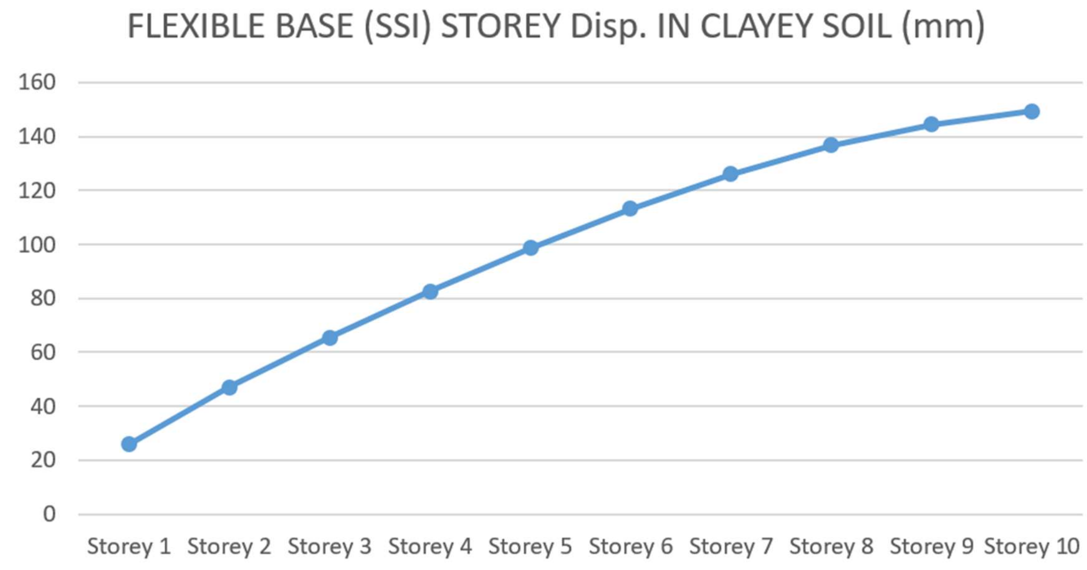


Fig 4.7: Storey Displacement in Clayey soil (SSI)

4.5.4 Storey Drift Ratio

Following table shows storey drift ratio at different storey number for the building with flexible base (SSI).

Table 4.4: Storey Drift Ratio at Flexible Base

Storey No	Storey Drift Ratio at Flexible Base
1	0.007081
2	0.006106
3	0.005695
4	0.005336
5	0.004887
6	0.004284
7	0.003538
8	0.002606
9	0.001622
10	0.001345

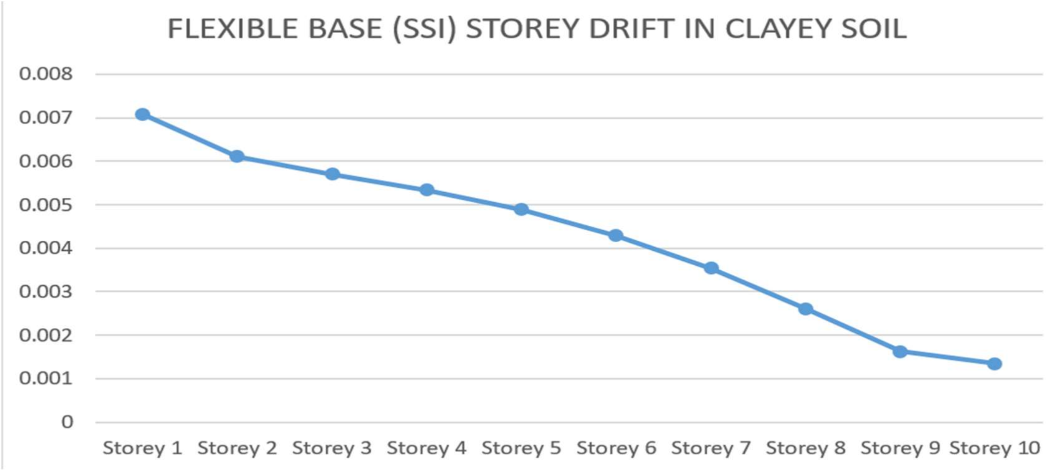


Fig 4.8: Storey Drift Ratio at Flexible Base

4.5.5 Bending Moment

Bending moment diagram for seismic and gravity loads will be different. Following are the BMD for different type of loads.

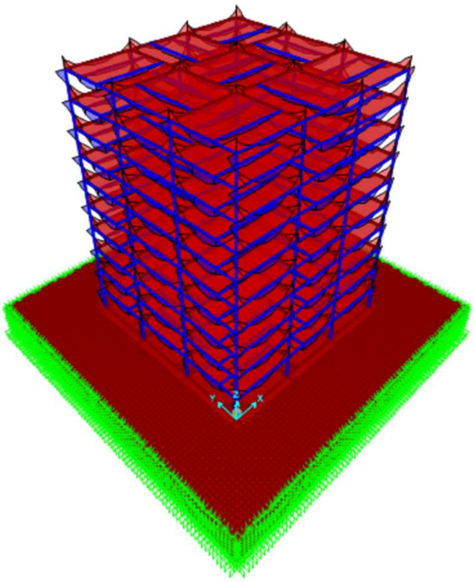


Fig 4.9: BMD (Dead Load)

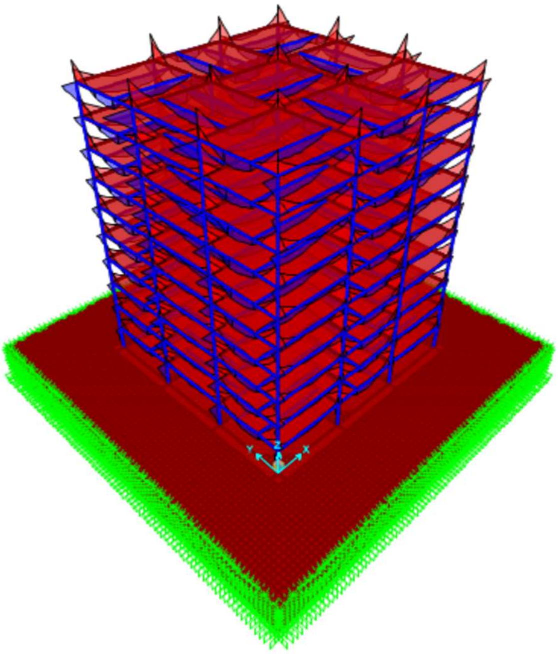


Fig 4.10: BMD (Live Load)

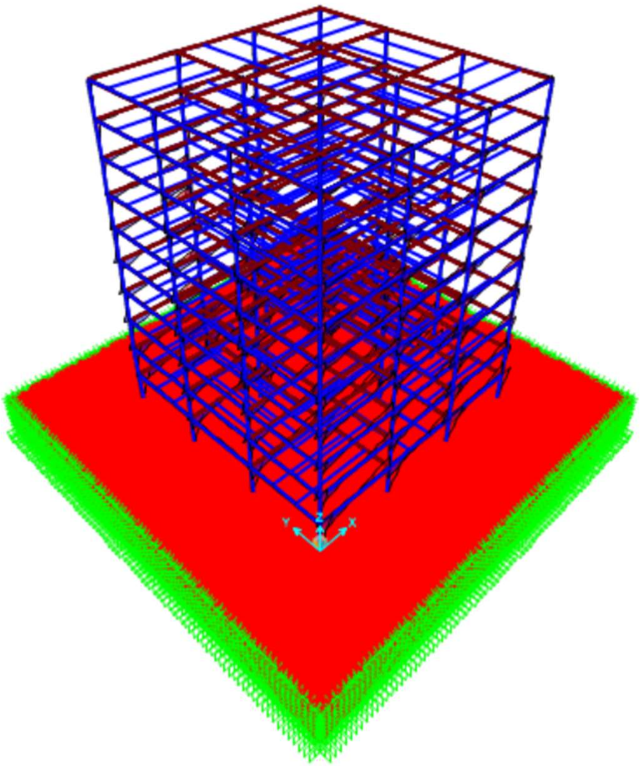


Fig 4.11: BMD (EQX)

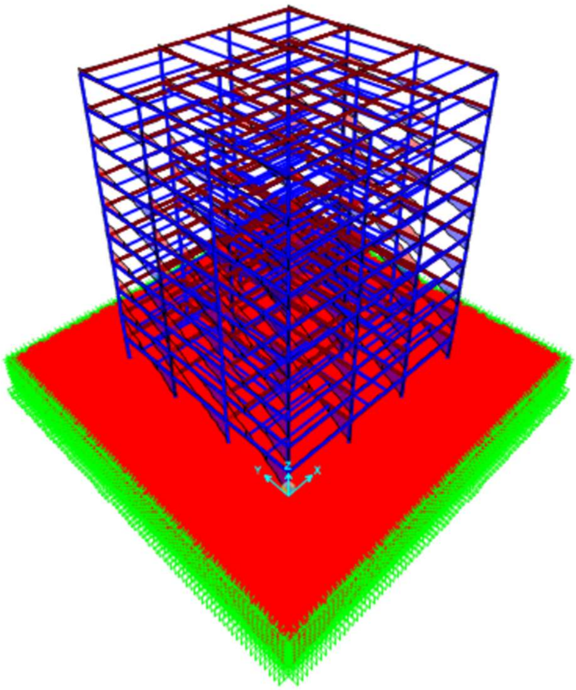


Fig 4.12: BMD (EQY)

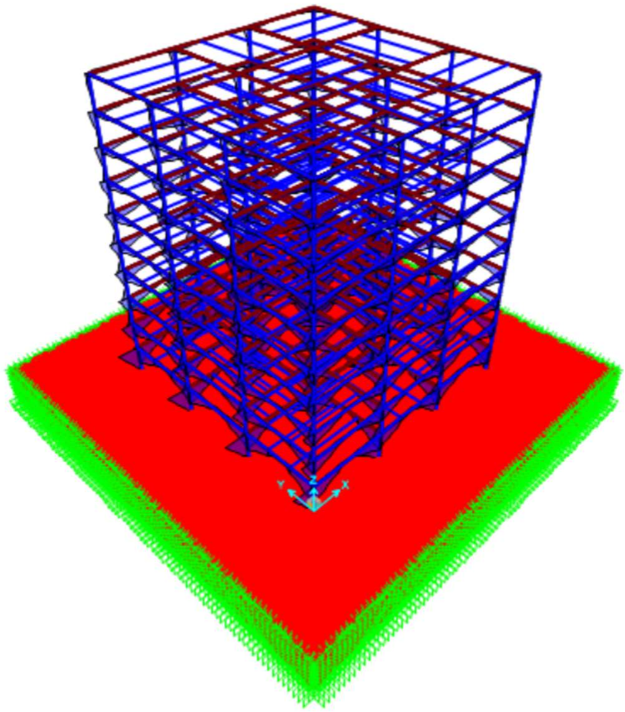


Fig 4.13: BMD (RS)

Bending Moment Variations (Beam 10 at storey 10 has been taken)

Table 4.5: Bending Moment Variation at Flexible Base

S. No	Load Conditions	Moment at Flexible Base (KN-m)
1	EQY	35.8634
2	EQX	-0.2935
3	LIVE	-47.4727
4	DEAD	-65.1691
5	RS	1265.973

4.5.6 Twisting Moment

Twisting moment diagram for seismic and gravity loads will be different. Following are the TMD for different type of loads

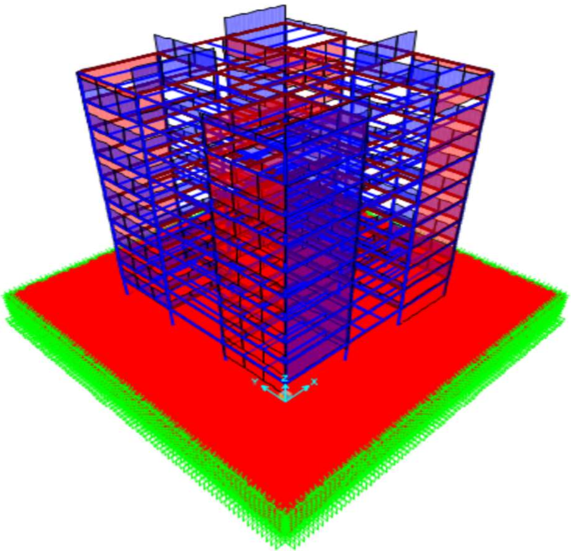


Fig 4.14: TMD (Dead Load)

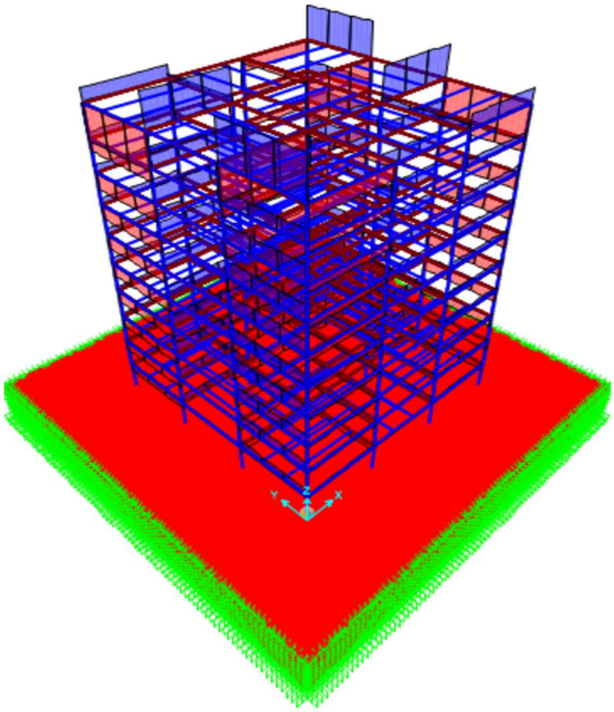


Fig 4.15: TMD (Live Load)

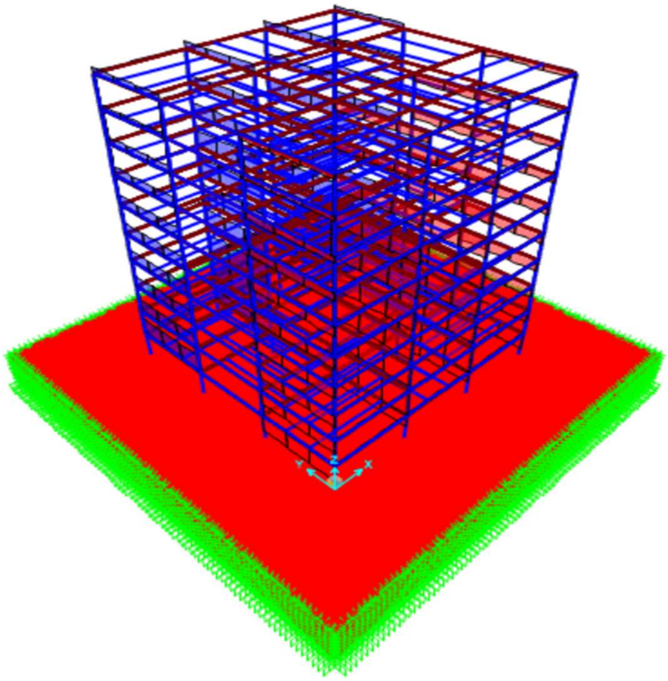


Fig 4.16: TMD (EQX)

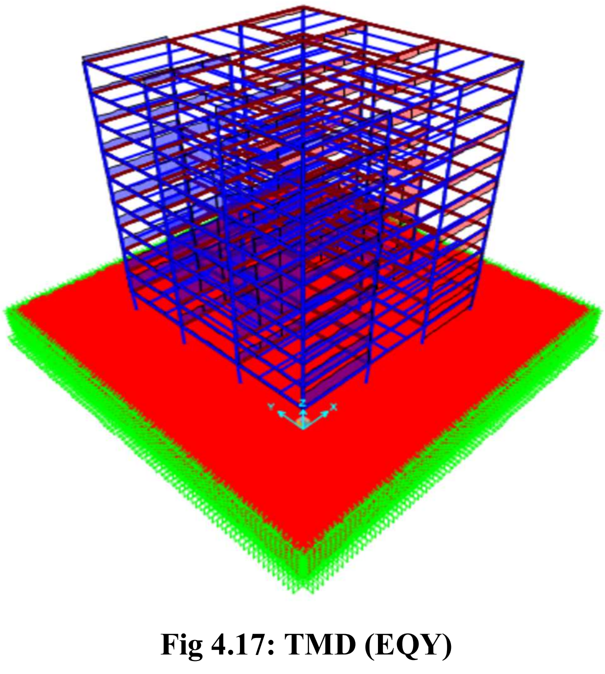


Fig 4.17: TMD (EQY)

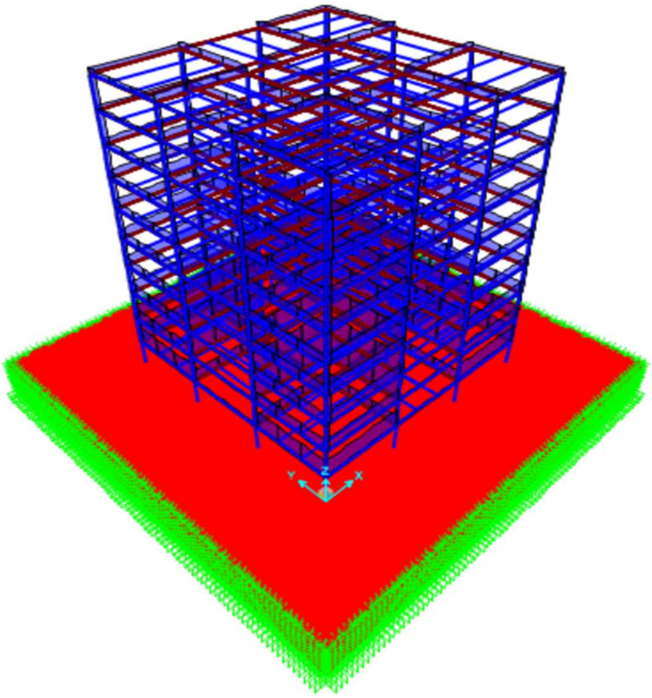


Fig 4.18: TMD (RS)

Twisting Moment Variations (Beam 10 at storey 10 has been taken)

Table 4.6: Twisting Moment Variation at Flexible Base

S. No	Load Conditions	Moment at Flexible Base (KN-m)
1	EQY	0.0226
2	EQX	-0.1088
3	LIVE	1.0739
4	DEAD	0.1434
5	RS	3.9489

CHAPTER 5

RESULTS & DISCUSSION

5.1 BASE SHEAR

The variation in Base Shear between structures with fixed bases (in soil types I, II, and III) and structures with flexible bases (clayey soil) is detailed in the table below.

Table 5.1: Base Shear Comparison

S. No	Base Type	Soil Type	Base Shear (KN)
1	Fixed Base	Soil Type I	416.75
2	Fixed Base	Soil Type II	529.47
3	Fixed Base	Soil Type III	650.16
4	Flexible Base (SSI)	Clayey Soil	1829.9

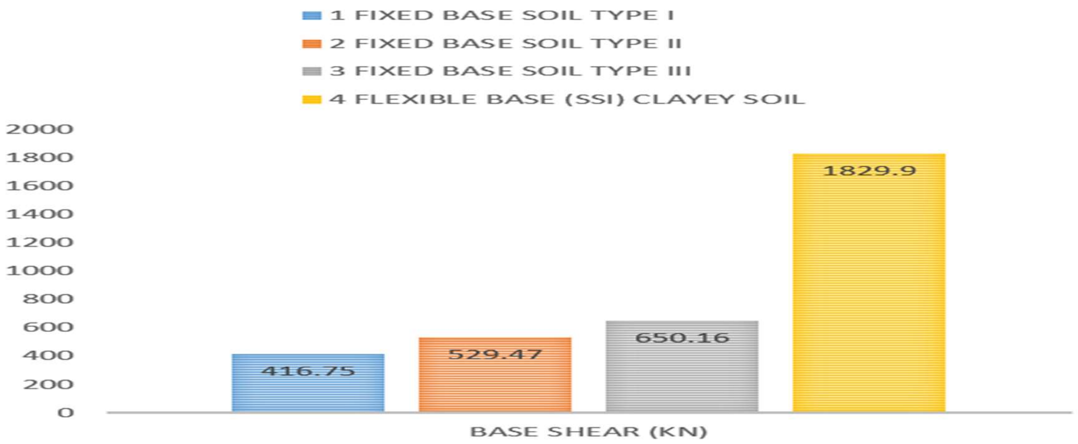


Fig 5.1: Base Shear Comparison

A comparison is made between the base shear under flexible base conditions and fixed base conditions. When SSI effects are accounted for, the value nearly triples, from 650.16 KN to 1829.9 KN.

5.2 NATURAL TIME PERIOD

The comparison of natural time periods in terms of mode numbers for fixed and flexible base conditions is presented in the table below.

Table 5.2: Natural Time Period Comparison

Mode No.	Fixed Base (NSSI) (sec)	Flexible Base (SSI) (sec)
1	2.33	2.64
2	2.31	2.62
3	1.92	2.28
4	0.75	0.83
5	0.74	0.83
6	0.62	0.73
7	0.42	0.46
8	0.41	0.46
9	0.35	0.40
10	0.27	0.31
11	0.26	0.29
12	0.23	0.26

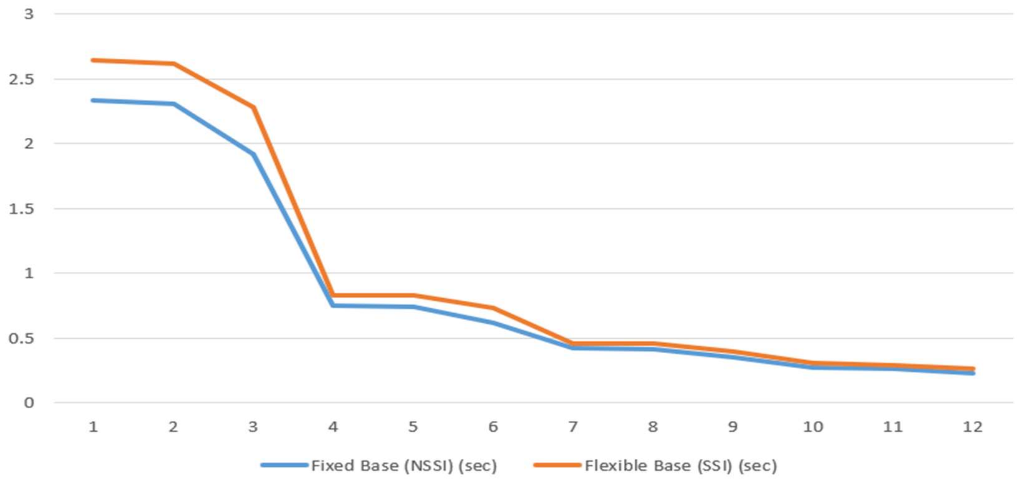


Fig 5.2: Natural Time Period Comparison

Building with a fixed basis on soft soil in the first mode takes 2.33 seconds naturally; on clayey soil, it takes 2.64 seconds, a 14% increase.

5.3 STOREY DISPLACEMENT

The following table illustrates, taking SSI into account, the differences in storey displacement between a building with a flexible basis (in clayey soil) and a fixed base (in soil types I, II, and III).

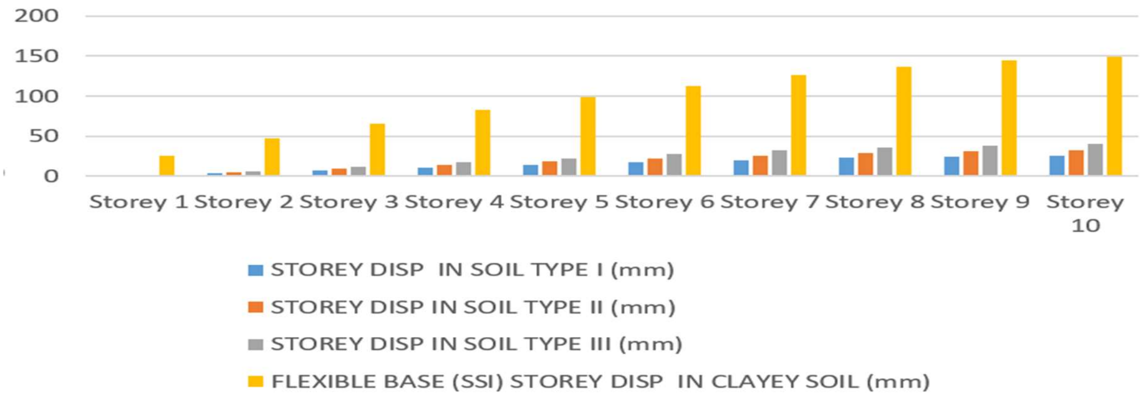


Fig 5.3: Storey Displacement Comparison

Table 5.3: Storey Displacement Comparison

Storey No	Storey Disp. at Fixed Base (Soil Type I) in mm	Storey Disp. at Fixed Base (Soil Type II) in mm	Storey Disp. at Fixed Base (Soil Type III) in mm	Storey Disp. at Flexible Base (Clayey Soil) in mm
1	1.177	1.505	1.849	25.841
2	4.015	5.137	6.308	47.086
3	7.415	9.487	11.649	65.404
4	10.899	13.945	17.123	82.489
5	14.296	18.290	22.459	98.499
6	17.489	22.375	27.475	113.161
7	20.357	26.044	31.980	126.013
8	22.763	29.122	35.760	136.629

9	24.569	31.433	38.598	144.447
10	25.702	32.882	40.378	149.314

- From the table, it is evident that the displacement of building is very high in building resting on flexible base compared to base which is fixed.
- The storey displacement in storey 10 for fixed base in soft soil is 40.378 mm, and for flexible base in clayey soil is 149.314mm. similarly, huge difference in displacement is evident in every storey.

5.4 STOREY DRIFT RATIO

Following table show the variation in storey drift between a building with fixed base (in soil type I, soil type II and soil type III) and flexible base (in clayey soil) considering SSI.

Table 5.4: Storey Drift Ratio Comparison

Storey No	Storey Drift at Fixed Base (Soil Type I)	Storey Drift at Fixed Base (Soil Type II)	Storey Drift at Fixed Base (Soil Type III	Storey Drift at Flexible Base (Clayey Soil)
1	0.000392	0.000502	0.000616	0.007081
2	0.000946	0.001211	0.001486	0.006106
3	0.001134	0.001451	0.001782	0.005695
4	0.001162	0.001487	0.001826	0.005336
5	0.001133	0.001450	0.001780	0.004887
6	0.001065	0.001363	0.001673	0.004284

7	0.000956	0.001224	0.001503	0.003538
8	0.000803	0.001027	0.001261	0.002606
9	0.000603	0.000771	0.000947	0.001622
10	0.000379	0.000485	0.000595	0.001345

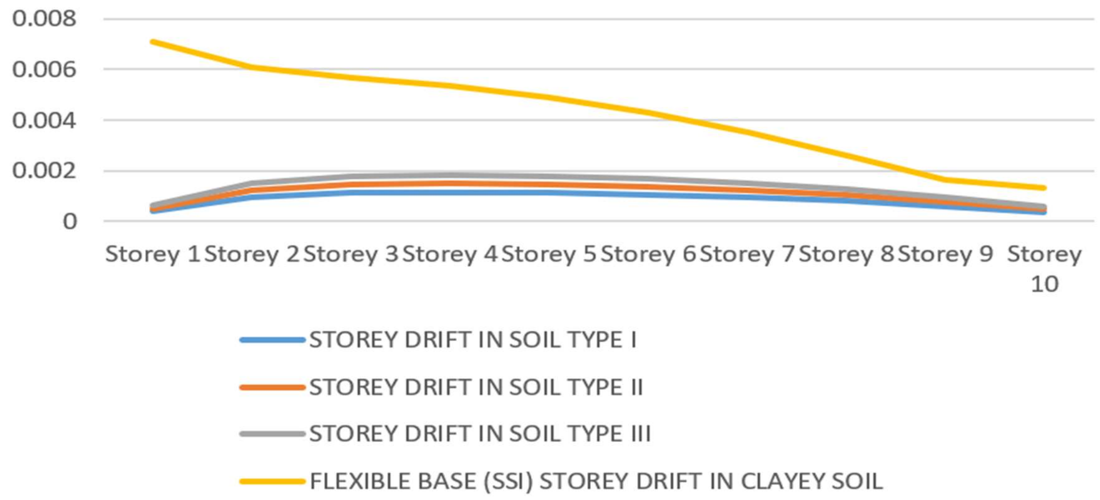


Fig 5.4: Storey Drift Ratio Comparison

In both instances, the variation of storey drift is parabolic, with the greatest drift occurring in the middle storeys. When SSI is taken into account, storey drift in intermediate stories is amplified.

5.5 BENDING MOMENT VARIATION (Beam 10 at storey 10 has been taken for study)

Table 5.5: Bending Moment Comparison

S.No	Load Conditions	Moment at Fixed Base (KN-m)	Moment at Flexible Base (KN-m)
1	EQY	10.6452	35.8634
2	EQX	-0.3127	-0.2935
3	LIVE	-19.3759	-47.4727
4	DEAD	-132.1703	-65.1691
5	RS	1.3687	1265.973

SSI induces a marginal increase in the bending moment of the beam when subjected to seismic load. In a fixed base condition, the bending moment of the beam is greater under the influence of gravitational loads.

5.6 TWISTING MOMENT VARIATION (Beam 10 at storey 10 has been taken for study)

Table 5.6: Twisting Moment Comparison

S.No	Load Conditions	Torsion at Fixed Base (KN-m)	Torsion at Flexible Base (KN-m)
1	EQY	-0.1976	0.0226
2	EQX	-2.1811	-0.1088
3	LIVE	5.2033	1.0739
4	DEAD	22.9563	0.1434
5	RS	0.2865	3.9489

The twisting moment of a beam increases marginally under the influence of seismic load and SSI. Fixed base conditions have a larger twisting moment of the beam under gravity loads.

CHAPTER 6

CONCLUSION

5.1 CONCLUSION

- Ten storey RC building has been examined both with and without taking SSI into account. SSI has been included by soil springs and Mat foundation.
- The structure reaction according to IS 1893 (PART 1) 2016 is analysed using the response Spectrum approach.
- We compare the seismic response findings of flexible base with fixed base for storey drift, bending moment, twisting moment, base shear, and NTP.
- Comparison of responses of both support conditions leads to the following results
    - A building with flexible base has a very high storey drift ratio. Storey drift ratio is parabolic and highest at middle stories for fixed base types.
    - A minor increase in the bending moment of the beam is observed when subjected to SSI in the presence of seismic load. In a fixed base condition, the bending moment of the beam is greater under the influence of gravitational loads.
    - The NTP increases from 2.33 seconds for a building with a fixed foundation in the first mode to 2.64 seconds for one with a flexible base. An increase in the NTP is observed in each mode to a similar degree.
    - The base shear is greater under flexible base conditions than under fixed base conditions. More than doubled in value.
    - The displacement of building is very high in building resting on flexible base compared to fixed base.

  - The response of RC structures has increased substantially in comparison to the conventional method of presuming a fixed base.

- SSI may have detrimental effects on the seismic response of structures, and ignoring it in analysis may result in unconservative design.

5.2 FUTURE SCOPE

- Present study uses Response spectrum analysis; it can be extended to pushover analysis. Pushover Analysis is an effective tool in analysis; brief analysis can be easily carried out with this method.
- In this study simple R.C. Frame with slab is taken, other element like shear wall can be added to check effect. Study also can be done on water tanks, etc.
- In this study analysis is carried out for reinforced concrete building frame. Steel structures can also be analyzed similarly.

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