`

SOIL-STRUCTURE INTERACTION AND

RAFT FOUNDATION FOR RCC CHIMNEY

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I hereby certify that the work which is being presented in the report **"SOIL-STRUCTURE INTERACTION AND RAFT FOUNDATION FOR RCC CHIMNEY**" in partial fulfilment of the requirement for 4th semester dissertation submitted in the Civil Engineering Department, of Assam Engineering College is a bonafide and authentic record of work done by me in the supervision of Dr. Jayanta Pathak and Dr. Sasanka Borah.

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ABSTRACT

The Soil-Structure Interaction (SSI) plays a critical role in the design and performance of tall structures, such as self-supporting Chimneys, which are subjected to various loads such as dead load, seismic load, and wind load. This research project aims to investigate the behaviour of an annular raft foundation supporting a Reinforced Cement Concrete (RCC) self-supporting Chimney under different loading conditions and different soils.

The primary objective of this study is to assess the stability of the chimney-raft foundation system, considering the influence of the soil. The Finite Element Method (FEM) is employed to model the complex interactions between the soil, raft foundation, and chimney structure.

In this project, Standard Penetration Test Report of three sites where taken in to consideration with different types of soils. Displacement of the Raft, displacement of the top of the Chimney and soil pressure for different soil consideration were studied by applying Dead Load, Wind Load and Earthquake Load. The numerical analysis was performed using finite element software ETABS v17. The soil has been modelled with the help of Subgrade Modulus. The results obtained were checked for the critical load for a chimney of height 90 m by comparing the soil pressure and displacement of raft and chimney. It was found that wind load is the critical load. And for sandy type of soil raft alone will not be able to withstand the load we need to provide piles.

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CHAPTER 1

1.0 INTRODUCTION

1.1 SOIL-STRUCTURE INTERACTION

Most of our structures are situated on soil and thus they are in direct contact with soil. Substructure which is the backbone of a particular structure remains in soil support and transmits the load of the superstructure into the soil. Thus, the deformation of the soil and the structure are dependable on each other when an external force is applied to the soil-structure system. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed soil-structure interaction. The external forces are generally earthquakes in most cases but other sources of forces are also there such as dynamic forces. Figure 1.1 shows the Soil-Structure Interaction of the building due to an earthquake load.

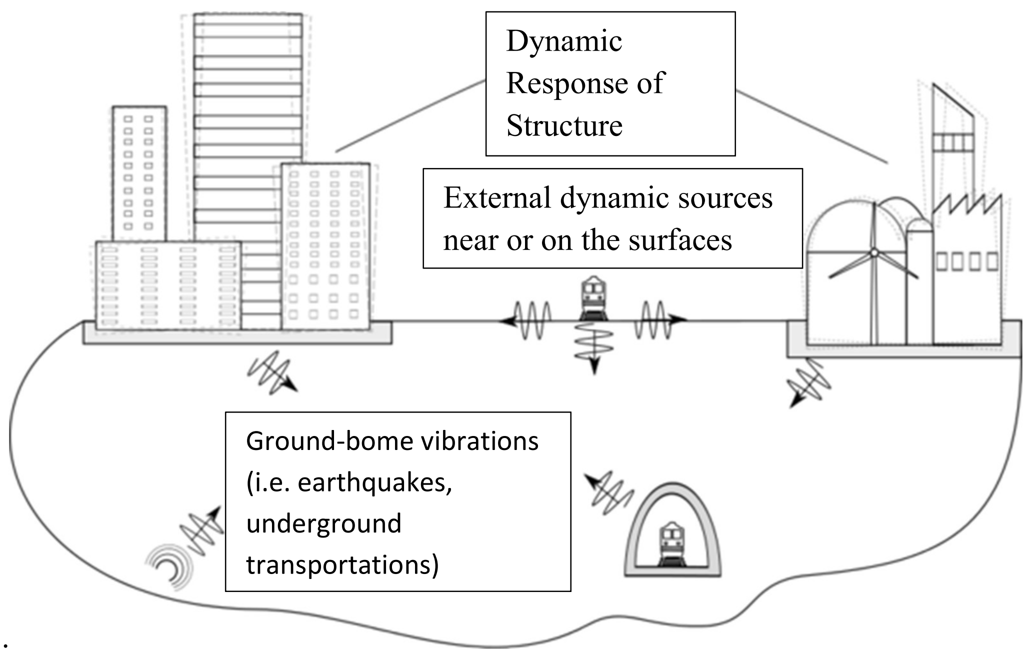

Figure 1.1. Soil-Structure Interaction of the building industry due to an earthquake or any dynamic forces. [21]

Conventional structural design neglects the effect of SSI and it is somewhat reasonable for low-rise buildings which are normally light structures resting on stiff soil.

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However, for heavy structures resting on relatively stiff soil, neglecting this effect of SSI may have a dangerous consequence for the structure, which cannot be ignored in their analysis and design. This effect is also significant for a closely spaced structure that may be subject to pounding when the relative displacement is high. Damage sustained in earthquakes, such as the 1995 Kobe earthquake, has also highlighted that the seismic behaviour of a structure is highly influenced not only by the response of the superstructure but also by the response of the foundation and the ground as well. So, the importance of taking into consideration the interaction between the superstructure, soil, and foundation becomes necessary for a civil engineer while working on the site. [22]

Soil structure interaction is primarily considered in dynamic response and especially in seismic force analysis of a structure. It is conventionally believed that SSI is a purely beneficial effect, and it can conveniently be neglected for conservative design. The SSI provisions of most of the seismic design codes are optional and allow designers to reduce the design base shear of buildings by considering soil-structure interaction (SSI) as a beneficial effect. The main idea behind the provisions is that the soil-structure system can be replaced with an equivalent fixed-base model with a longer period and usually a larger damping ratio. Most of the design codes use simplified average design spectra, which attain constant acceleration up to a certain period, and thereafter decrease monotonically with period. Considering soil-structure interaction makes a structure more flexible and thus, increases the natural period of the structure compared to the corresponding rigidly supported structure. Moreover, the SSI effects, while considered, increase the effective damping ratio of the system. The smooth idealization of the design spectrum suggests a smaller seismic response with the increased natural periods and effective damping ratio due to SSI, which is the main justification of the seismic design codes to reduce the design base shear when the SSI effect is considered. [18] When a structure is subjected to earthquake excitation, it interacts with the foundation and the soil and thus changes the motion of the ground just underside of the foundation and thereby its dynamic properties.

1.2 OVERVIEW OF SOIL-STRUCTURE INTERACTION

In a structure-foundation-soil system, when analyzed for seismic forces, the evaluation consists of the response and behavior of the structure, the foundation, and the geologic/geotechnical media underlying and surrounding the foundation, to a specified

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free-field ground motion. The term free-field means the motion of the ground that is not affected by the structural vibration. The SSI effects are normally categorized as inertial interaction effects, kinematic interaction effects, and soil-foundation flexibility effects which can be related to the following phenomenon of soil and foundation occurring in the system-

1. **Foundation stiffness and damping**: While a dynamic force creates vibration in a structure, the inertia developed in the structure produces base shear, moment, and torsion which generates displacement and rotation at the soil-foundation interface. These displacements and rotations are due to the flexibility in the soil foundation system which contributes significantly to the overall structural flexibility of the system. Along with it, these displacements create energy dissipation through damping, which affects the overall damping system. Since these effects are related to structural inertia, they are termed inertial interaction effects.
2. **Variations between foundation input motions and free-field ground motion**: It occurs because stiff foundation elements placed at or below the ground surface cause foundation motions to deviate from free-field motions. And also because of the relative displacements and rotations between the foundation and the free field associated with structure and foundation inertia.
3. **Deformations in foundations**: Because of the forces and displacements applied by the superstructure and the soil, there are deformations in the foundation such as axial, flexural, and shear deformations. These deformations set the criteria for the design of foundation components and they can be significant, especially for flexible foundations such as rafts and piles.

Figure 1.2 shows the Soil-Structure Intraction of a building-foundation-soil system with the limit of boundary up to which this interaction will act.

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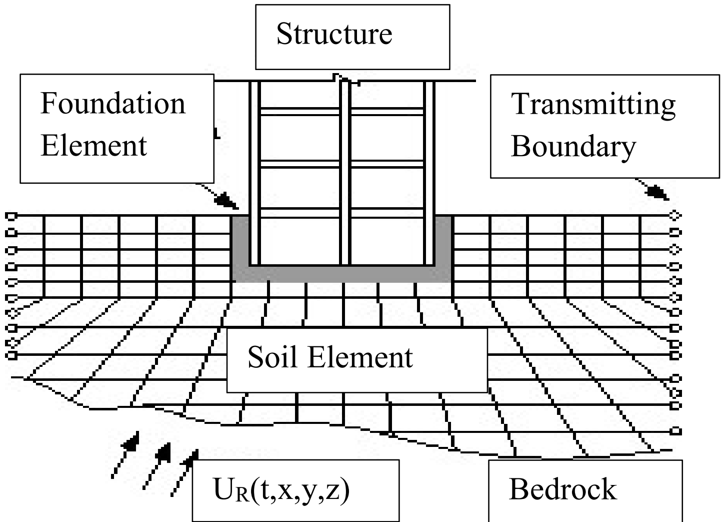

Figure 1.2. Soil-structure interaction of a building-foundation-soil system with the limit of boundary up to which this interaction will act. [18]

1.3 DESCRIPTION OF SOIL-STRUCTURE INTERACTION

1.3.1 TYPES OF SSI

Soil-structure interaction broadly can be divided into two phenomena: a) kinematic interaction and b) inertial interaction. Different types of SSI are shown in the Figure 1.3. and 1.4.

These two types of SSI are being explained in later chapters.

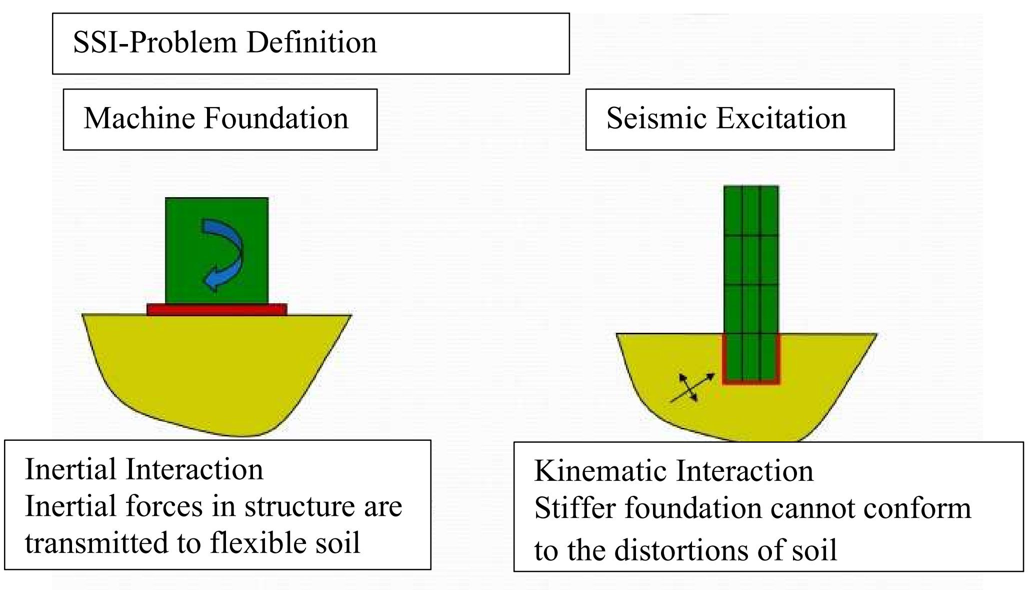

Figure 1.3. Inertial interaction occurring in a machine foundation due to dynamic excitation of machine and kinematic interaction in a foundation and soil due to seismic excitation. [21]

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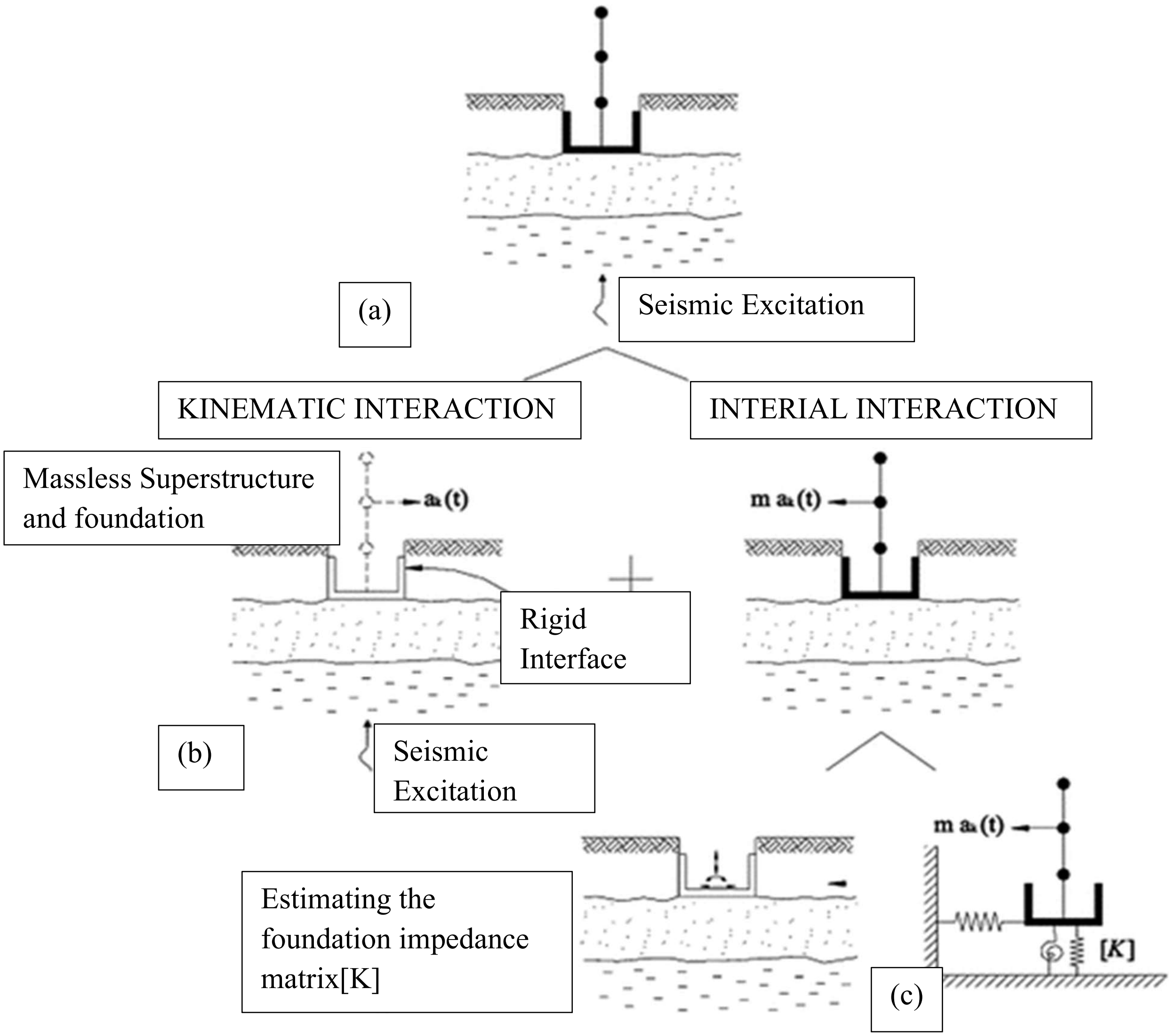

Figure 1.4. (a) seismic excitation is occurring in a soil-structure-foundation system (b)the two diagram showing the difference kinematic (rigid interface) and inertial (free-field motion) interaction (c) the foundation impedance matrix(K) is showing with spring and dashpot for inertial interaction. [21]

1.3.2 BACKGROUND

In the past, during the design/analysis processes of engineered structures, it was assumed that the foundation of a structure was fixed to a rigid underlying medium. In the last four decades, however, it has been recognized that SSI alters the response

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characteristics of a structural system. In important engineered structures, detailed numerical and closed-form-solution methods are applied to perform soil-structure analyses. To date, the strong-motion data from instrumented buildings are insufficient to confirm the validity of the soil-structure interaction analysis methods and procedures as applied to structures other than nuclear power plant structures. The SSI was introduced in the ATC-3 tentative provisions and was incorporated into the NEHRP provisions in 1980 [12].

Since the 1960s, Soil-Structure Interaction (SSI) has been recognized as an important factor that may significantly affect the relative building response, the motion of the base, and the motion of the surrounding soil. The conventional structural design practice for most of the ordinary or non-critical structures neglect the SSI effects. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils, for example, nuclear power plants, high-rise buildings, and elevated highways on soft soil [22].

Damage sustained in recent earthquakes, such as the 1995 Kobe earthquake, has also highlighted that the seismic behavior of a structure is highly influenced not only by the response of the superstructure but also by the response of the foundation and the ground as well. Hence, the modern seismic design codes, such as Standard Specifications for Concrete Structures: Seismic Performance Verification JSCE 2005 stipulate that the response analysis should be conducted by taking into consideration a whole structural system including superstructure, foundation, and ground [22].

1.3.3 EFFECT OF SOIL-STRUCTURE INTERACTION ON GROUND RESPONSE

The soil-structure interaction makes a structure more flexible thus, increasing the natural period of the structure compared to the corresponding rigidly supported structure. The SSI effect increases the effective damping ratio of the system. The smooth idealization of the design spectrum suggests a smaller seismic response with the increased natural periods and effective damping ratio due to the SSI effects.

It has been lately realized from the performance of some of the structures during various earthquakes that, the SSI can have a detrimental effect on the structural response, and neglecting SSI in the analysis may lead to an unsafe design for both the superstructure and the foundation.

`

The stress and deformation in the supporting soil cause vibration of structure generate base shear, moment, and displacement, and alter the natural period since in reality it does not fix the base structure, the deformation of soil further modifies the response of the structure. Figure 1.5 show the typical response spectral curves.

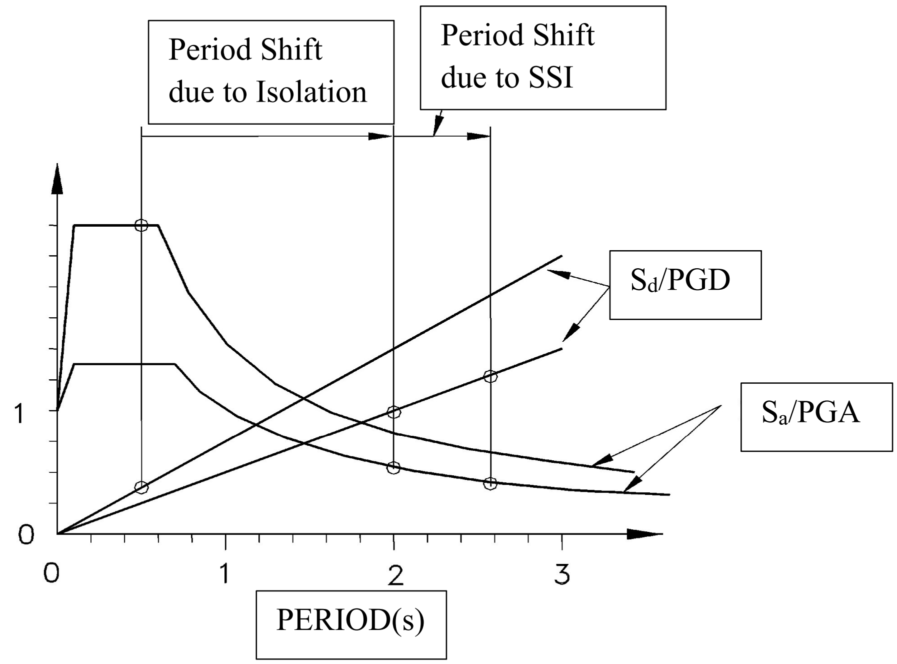

Figure 1.5. Typical Response Spectral curves showing the standard response of building to earthquake. [21]

1.3.4 DETRIMENTAL EFFECT OF SSI

Using rigorous numerical analyses, Mylonakis and Gazetas have shown that an increase in the natural period of the structure due to SSI is not always beneficial as suggested by the simplified design spectrums. Soft soil sediments can significantly elongate the period of seismic waves and the increase in the natural period of the structure may lead to the resonance for the long period ground vibration. Additionally, the study showed that ductility demand can significantly increase with the increase in the natural period of the structure due to the SSI effects. The permanent deformation and failure of soil may further aggravate the seismic response of the structure [22].

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1.3.5. NEED FOR STUDY OF SSI

It has been realized from various studies observed damages that, soil -structure interaction (SSI) effects may be either beneficial or detrimental to the performance of structures. When beneficial, by incorporating SSI effects in the seismic code calculations, more cost-effective designs are possible. For some situations, such as the design or retrofitting of bridges, dams buried structures, etc., an appropriate inclusion of SSI effects in seismic calculations may bring large design cost savings. There is an urgent need for performing comparative cost-benefit reviews for different types of constructions with and without considering rigorously the SSI effects. On the other hand, when it is determined by calculations that SSI effects can be detrimental to the performance of structures, by mere recognition and taking effective measures, safety, and better performance can be achieved.

Experimental research should not be limited to the confirmation of SSI system response behavior. It must be designed and conducted in a manner to improve the SSI system modeling and to facilitate assessment of the SSI system performance up to its performance limit. To facilitate practical applications, SSI researchers must also develop and make available to practicing engineers a set of reliable and easy-to-use computer software for them to conduct realistic SSI evaluations [11].

There has been considerable interest in research finding the effect of irregularities on dynamic response and they have discussed mainly plan irregularities because of their mass distribution, non-uniform stiffness, and strength in the horizontal direction. Even though the structures are of the same region, same configuration, and same earthquake magnitude, the damages that occur during the earthquake are not of the same pattern. This means that some factors affect the damage pattern like earthquake characteristics, structural system of the plan, mass, stiffness, and vertical irregularities.

The study on SSI is interdisciplinary involving geotechnical and structural engineering and hence tends to be partially understood by both sides at times. There is a big gap between state-of-the-art and the knowledge of practicing engineers. The Single-degree-of-freedom (SDOF) structure with a rigid foundation is the most common type of research topic or problem. The multi-degree-of-freedom (MDOF) structures with flexible foundations are difficult to analyze and there are limited research efforts on this topic.

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There is virtually no field performance data on SSI and the existing data is inadequate. Interpretation of field data from earthquakes is important to verify methodologies [12].

From the above discussion, the following queries may be enumerated -

1. Is SSI a necessary aspect of the design process If it is, then how do we demonstrate that we need more practical information than period lengthening and foundation damping; These are not used for practicing engineers.
2. It is required that the wide research results are translated into better design demand predictions for structures.
3. In general, the linear elastic analysis is good for (a) buildings on surface foundations (b) building-soil-building interaction (c) single buildings with embedded foundation
4. However, a few recent earthquakes show that there is a high level of nonlinearity in soil over a broad area. This nonlinearity may have led to SSI effects, which saved these buildings. This area may be well investigated. The nonlinear SSI may be very important for severe earthquakes. We need simple models for nonlinear SSI.
5. There is a need to address the large uncertainty associated with SSI. It is known that the earthquake motions are random; the soil properties are random; the local motion spatial variation is random, etc. so, there is an objective need in the future to approach these aspects more consistently using probabilistic models.
6. In addition, for improving a seismic design or for a costly retrofit of a highway concrete bridge, it is essential to do some probabilistic SSI analyses and try to calibrate the deterministic design based on risk assessment comparisons.

1.4 SOIL-STRUCTURE INTERACTION ON THE RAFT OF SELF SUPPORTING REINFORCED CONCRETE CHIMNEYS

While designing a raft of tall reinforced concrete chimneys, it is very difficult to analyse the chimneys with transient wind loads precisely by available analytical procedures because of the uncertain variability of wind, and therefore a designer is forced to use approximate design techniques [Manohar (1985)]. The simplified form of transient wind load is available in most of the design wind codes for chimneys such as IS:4998 (Part 1)-1992, CICIND (2005), ACI 307-2008, etc. Many simplified formulations were derived for computing the along wind load [Davenport (1967), Simiu (1976) and Solari (1982)] and

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across wind load [Davenport (1995) and Melbourne (1997)]. It is essential to analyse the foundation and soil interaction i.e. how the various loads acting on the chimney affect the soil beneath it and how the properties of the soil are reacting back to the foundation. Ignorance of this interaction may lead to unsatisfactory results. In Figure 1.6 self-supporting R.C.C. chimney is shown.

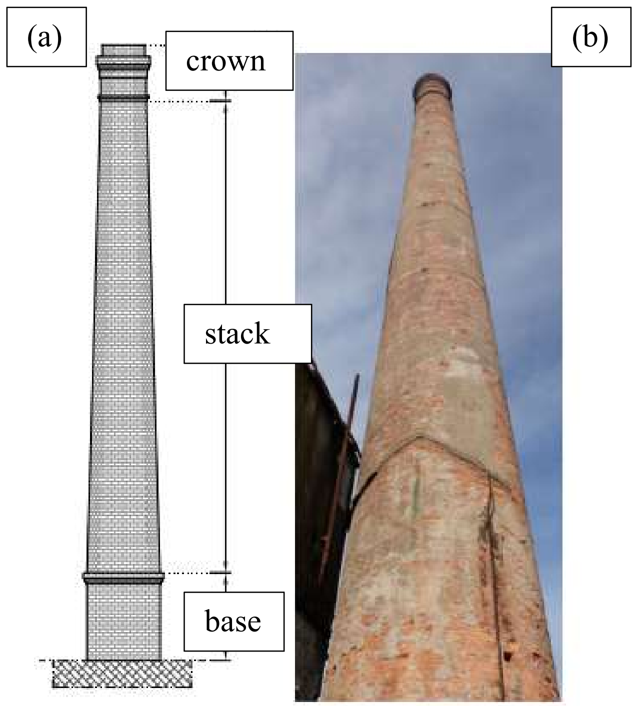

Figure 1.6. RCC Chimney [21]

1.5 SCOPE OF THE THESIS

The objectives of the project are:

1. To Conduct an extensive review of existing literature, research papers, and case studies related to soil-structure interaction, tall chimney design, annular raft foundation analysis, and numerical modeling techniques.
2. To collect SSI data from consultancy and find the allowable bearing pressure.
3. To calculate the air pressure coefficient for the chimney as per IS Code.
4. To develop a sophisticated numerical model using ETAB 17.
5. To conduct a parametric study to explore the effects of various parameters on the behavior of the chimney-raft foundation system for three different soils.

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6. To provide design recommendations for optimizing the stability, safety, and performance of the chimney-raft foundation system, based on the numerical simulations, parametric study.

1.6 OUTLINE OF THE THESIS

1. CHAPTER 1: It gives the details of Soil-Structure Interaction
2. CHAPTER 2: It provides the various literatures.
3. CHAPTER 3: It gives details of Chimney.
4. CHAPTER 4: It provides the information of Raft.
5. CHAPTER 5: It shows the steps followed for modelling the R.C.C Chimney and Raft.
6. CHAPTER 6: It outlines the methodology for analysing the raft and R.C.C Chimney.
7. CHAPTER 7: Results are presented in the chapter.
8. CHAPTER 8: Conclusion and Future scope has been depicted in the chapter.

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CHAPTER 2

2.0 LITERATURE REVIEW

2.1 GENERAL

In this chapter an attempt has been made to understand the Soil Structure Interaction (SSI), raft foundation and self-supporting RCC chimney through numerical analysis and following papers of various different researchers has been referred to get the knowledge of various research work going on. Few major works are briefly reviewed in the following sections.

2.2 BRIEF REVIEW OF FEW MAJOR REFERENCES

Yingcai Han et.al (2008) made a study on non-linear analysis of Soil-Pile-Structure Interaction under seismic loads in which they used two commercial software packages considering the nonlinear soil-pile-structure interaction. Stiffness and damping of the pile foundation are generated from a computer program DYNAN and then input into a finite element model by SAP2000 program. The seismic response of a vacuum tower structure supported on pile foundation was examined in a high seismic zone, including response spectrum analysis and time history analysis. The vacuum tower with the weight of 5,600 kN and height of 35 m set on a steel frame. To illustrate the effects of soil-pile-structure interaction on the seismic response of the structure, three different base conditions are considered, rigid base, i.e. no deformation of the foundation; linear soil-pile system; and nonlinear soil-pile system. The case of pile foundation with liquefaction of sand layer is discussed. This method and procedure introduced can be applied to the design of tall buildings, bridges, industrial structures and offshore platforms with soil-pile-structure interaction under seismic, blast, sea wave and other dynamic loads. [6]

Mohammad M. Ahmadi et.al (2008) made a study on dynamic analysis of piles in the sand based on Soil-Pile Interaction in which a Finite Element Model of a three-dimensional geometric model was used to represent the soil-pile system. The Soil and pile were modeled using eight-noded block elements. The pile is completely embedded in the soil and it is assumed to have bearing on the bedrock. Therefore, all the bearing nodes were taken as fixed. It is assumed that the soil and pile were perfectly bonded. The side boundaries were constrained against horizontal direction and the bottom boundaries were

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Method. A parametric study is conducted to understand the pile-soil behavior (Soil-Foundation Interaction (SFI)) by changing various parameters, like pile and soil modulus, pile length, pile diameter and a number of piles of the pile group. In each case, the response is converted to the frequency domain to understand the shift in frequency. [12]

Yasser Khodair et.al (2014) studied numerical analysis of Pile-Soil Interaction under axial and lateral loads and here an analysis of the composite pile-soil system was performed using the finite difference (FD) software LPILE. Two three dimensional, finite element (FE) models of pile-soil interaction have been developed using Abacus / Cae and SAP2000 to study the effect of lateral loading on pile embedded in clay. A lateral displacement of 2 cm was applied to the top of the pile, which is embedded into the concrete pile cap while maintaining a zero slope in a guided fixation. A comparison between the bending moments and lateral displacements along the depth of the pile obtained from the FD solutions and FE was performed. A parametric study was conducted to study the effect of crucial design parameters such as the soil's modulus of elasticity, radius of the soil surrounding the pile in Abacus / Cae, and the number of springs in SAP2000. A close correlation is found between the results obtained by the FE models and the FD solution. The results indicated that increasing the amount of clay surrounding the piles reduces the induced bending moments and lateral displacements in the piles and hence increases its capacity to resist lateral loading. [10]

M Roopa et.al (2015) performed Soil Structure Interaction analysis on an RC Building with Raft foundation under Clayey Soil Condition. The study has been made to understand that, during seismic activity, the response of structures is influenced by Soil-Structure Interaction (SSI) which is the process where the response of soil particles to earthquake ground motion affects the motion of structure and the response of structure affects the motion of soil mass. In design offices, the base of multi-story buildings is taken as fixed and analyzed for earthquake response using provisions IS 1893-2002 with the aid of response spectrum given for soft, medium and hard soils in the foundation. But in reality, the type of soil present in and around the foundation structure also participates in the seismic response and the assumption of the fixed base becomes conservative. This study is mainly concentrated on in-situ clayey soil conditions. The RC building considered to analyze SSI is an apartment of G+12 Storey with an elevation of 40.15m and with the plan

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shape of 28.2m X 16.1m proposed at Mambakkam, South Chennai, Tamil Nadu state, India. The study has used the finite element tools ETABS 9.7.4 for modeling and SAP2000 ver17 for SSI analysis. [13]

Janardhan Shanmugam et.al (2015) made a study on the analysis of Soil-Structure Interaction in framed structure, where the effect of soil-structure interaction on a four-storeyed, two bay frame resting on pile and embedded in the cohesive soil is examined, the slab provided for all storeys were idealized as three dimensional four nodded shell elements. The beams and columns of the superstructure frame are idealized as three dimensional two nodded beam elements. Pile of the sub-structure is idealized as three dimensional two nodded beam elements. The finite element based software program ANSYS is used for the purpose of analysis. The effect of different pile diameters on the response of superstructure is evaluated. And it is found that the effect of soil- structure interaction on the top displacement of the frame is quite significant. The displacement is less for the conventional analysis, i.e., fixed base condition and increases in the range of 210 – 441 % when the effect of SSI is taken into consideration, and the displacement at top of frame decreases with increase in pile diameter. The general trend observed for all the pile diameters considered in this investigation is that horizontal displacement is on the higher side when the effect of soil structure interaction (SSI) is considered. For 300 mm pile diameter, at top of the subsequent stories, the percentage increase in displacement is found to be 441% and 304% for 400mm diameter piles and 211% for 500mm diameter piles. [14]

Aswathi A et.al (2016) investigated SSI analysis of a 200m reinforced concrete chimney with annular raft foundation under along-wind load. To study the effect of geometrical properties of chimney, different ratios of height to base diameter (slenderness ratio) are selected. The ratio of outer diameter to thickness of raft were also varied. To understand the effect of flexibility of soil, variable soil profile is considered below the foundation. The following observations were made Raft settles non-uniformly with maximum settlement near the inner edge of the chimney. Maximum settlement occurs at the leeward side of the chimney, with maximum settlement at the inner edge of the raft. When the stiffness of soil below the raft increases value of maximum settlement decreases. [4]

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Raksha Khare et.al (2016) studied the analysis of a building frame Considering Soil-Structure Interaction and, here they modeled a typical four (G+3) building frame resting on pile foundation and embedded in cohesive soil mass using the finite element based software ETABS. Two groups of piles comprising two and three piles, with series and parallel arrangement are considered. The slab of the frame is idealized as three-dimensional four-nodded shell elements. Beams and columns of the superstructure frame are idealized as three-dimensional two-nodded beam elements. The piles of the substructure are idealized as three-dimensional six-nodded beam elements. A parametric study is carried out to investigate the effect of various parameters of the pile foundation, such as spacing in a group and number of piles in a group, on the response of superstructure. It has been observed from the study that the consideration of the soil-structure interaction on the top displacement of the frame is significant. The displacement at the top is less for fixed base condition and increases when SSI is taken into account by 39 % -80 %, and also by increasing the spacing between individual Piles in a group, the displacement at top of frame decreases. Displacement obtained is on the higher side for the parallel arrangement as compared to the series for a group of two. [9]

Srinivas K et.al (2018) have studied detailed FE analysis of a Foundation raft by considering the spring stiffness both for static and dynamic conditions. The obtained maximum and minimum bearing pressures are presented and it is observed that the maximum bearing pressure is within the allowable bearing pressure of the study region. It is observed that when the foundation stiffness is reduced to 0.67shear modulus the bearing pressure increases when compared to 1.0shear modulus and hence governs the designs. [15]

Vijaykumar P. Bhusare et.al (2019) have studied various literature and came to conclusion that there is a number of published works on steel and concrete chimneys. But in comparison to concrete, very less work is done on steel chimneys. However, a very less research effort is found on the Comparative analysis of Self-supporting steel chimney with and without soil structure interaction and vibration analysis for the steel chimneys. Also concluded that manhole opening in the analysis is important to select. [16]

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CHAPTER 3

3.0 CHIMNEY

3.1 INTRODUCTION TO CHIMNEY

Chimney, as we know them today, are tall slender structures which fulfil an important function. They had a humble beginning as household vents and over the years, as vents grew larger and taller, they came to be known as chimneys. A chimney is a vertical structure designed to provide a passage for smoke, hot gases, and other by-products of combustion to escape from a building, structure, or industrial facility into the atmosphere. Chimneys are commonly associated with heating systems, fireplaces, and industrial processes that involve burning fuels.

Key functions of a chimney include:

1. **Exhaust:** The primary purpose of a chimney is to exhaust the smoke, gases, and pollutants produced during combustion. In residential settings, this ensures that indoor air quality is maintained, while in industrial settings, it helps prevent the build-up of harmful emissions within the facility.
2. **Drafting:** Chimneys use the principle of natural convection to create a draft, which pulls air through the combustion process. This draft helps ensure efficient combustion by supplying oxygen to the fire and carrying away combustion by-products.
3. **Heat Dissipation:** In addition to expelling smoke and gases, chimneys help dissipate excess heat generated during combustion. This prevents overheating of the heating system or surrounding structures.
4. **Airflow Regulation:** The design and construction of a chimney can influence the rate of airflow through the combustion process. Properly designed chimneys help regulate the burn rate of the fuel and contribute to the overall efficiency of the system.

Chimneys come in various shapes, sizes, and materials, depending on the intended use and architectural considerations. They can be constructed from materials such as brick, concrete, metal, or ceramic tiles. The diameter, height, and design of a chimney are

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influenced by factors such as the type of heating appliance, the fuel being burned, local building codes, and environmental regulations.

Overall, chimneys play a crucial role in safely channelling combustion by-products away from inhabited spaces while facilitating effective and efficient combustion processes in various applications.

3.2 HISTORICAL REVIEW

The historical evolution of industrial chimneys is closely tied to the development of industrialization, technological advancements, and changing societal needs. Here's a historical review of industrial chimneys:

1. **Pre-Industrial Era:** Prior to the Industrial Revolution, early industrial processes often occurred on a small scale and didn't require extensive chimney systems. Localized industries such as blacksmithing and pottery used rudimentary chimneys to vent smoke and fumes. However, large-scale industrial facilities were relatively uncommon.
2. **Industrial Revolution (18th-19th Centuries):** The advent of the Industrial Revolution brought about a rapid expansion of industries such as textiles, mining, metallurgy, and manufacturing. These industries required large-scale machinery powered by steam engines and fuelled by coal. As a result, the demand for effective exhaust systems grew, leading to the construction of tall, brick or stone chimneys that could carry away the immense volumes of smoke and pollutants generated by these processes.
3. **Tall Brick Chimneys:** During the 19th century, the construction of tall brick chimneys became a defining feature of the industrial landscape. These chimneys could reach impressive heights, often exceeding 100 feet, and were necessary to create a strong draft for efficient combustion and to disperse the emissions produced by the burning of coal. They became a symbol of industrial progress and were often located in factory complexes and manufacturing towns.
4. **Architectural Integration:** In addition to their functional role, industrial chimneys were sometimes designed with architectural considerations in mind. Some factories incorporated decorative features into their chimney designs, showcasing the artistic influences of the era.

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5. **Environmental Awareness:** As concerns about air quality and pollution increased during the late 19th and early 20th centuries, there was a growing recognition of the environmental impacts of uncontrolled emissions from industrial chimneys. This led to the development of early air pollution regulations and the implementation of technologies to reduce emissions.
6. **20th Century:** The 20th century saw advancements in industrial chimney design and engineering. Materials like steel and reinforced concrete allowed for taller and more stable chimney structures. Improved combustion technologies and air pollution control measures were developed to minimize the release of harmful pollutants.
7. **Modern Times:** In contemporary times, industrial chimneys continue to evolve with the implementation of even more advanced emission control technologies. Many industrial facilities now employ scrubbers, filters, and catalytic converters to remove pollutants before they are released into the atmosphere. The emphasis on sustainable and environmentally friendly practices has led to more efficient combustion processes and reduced emissions.

The historical trajectory of industrial chimneys reflects the interplay between industrialization, technological progress, environmental awareness, and the ongoing need to balance economic growth with environmental responsibility.

3.3 TYPES OF CHIMNEY

Industrial chimneys come in various types, designs, and configurations to accommodate different industrial processes, fuels, and emission control requirements. Here are some of the different types of industrial chimneys:

1. **Single Flue Chimney:** This is the most common type of industrial chimney. It consists of a single vertical channel through which the exhaust gases from industrial processes are released into the atmosphere. Single flue chimneys can vary in height and diameter based on the specific requirements of the facility and the type of processes being carried out.
2. **Multi-Flue Chimney:** In facilities with multiple processes or multiple heating systems, a multi-flue chimney might be used. This type of chimney has multiple channels or flues within a single structure, allowing for the exhaust of gases from

various sources. Each flue can be dedicated to a specific process or heating system. Multi-Flue Chimney is shown in the Figure 3.1

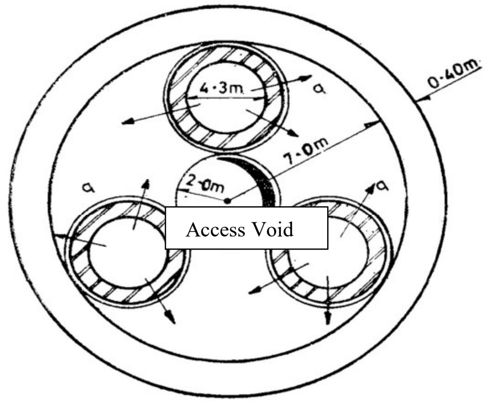

Figure 3.1. Multi-Flue Chimney [17]

3. **Steel Stack:** Steel stacks are commonly used in industries where corrosion resistance is important. They are often found in power plants, refineries, and chemical processing plants. These chimneys are made from steel and can be designed to handle high temperatures and corrosive environments.
4. **Concrete Stack:** Concrete stacks are used in industries where durability and resistance to extreme temperatures are essential. They are often used in cement manufacturing, waste incineration, and industrial boilers. Reinforced concrete stacks are capable of withstanding high temperatures and the effects of harsh chemicals.
5. **Guyed Stack:** For very tall chimneys that might become unstable due to wind loads, guyed stacks are used. These chimneys are supported by guy wires or cables to provide additional

Stability. Guyed stack is shown in the Figure 3.2

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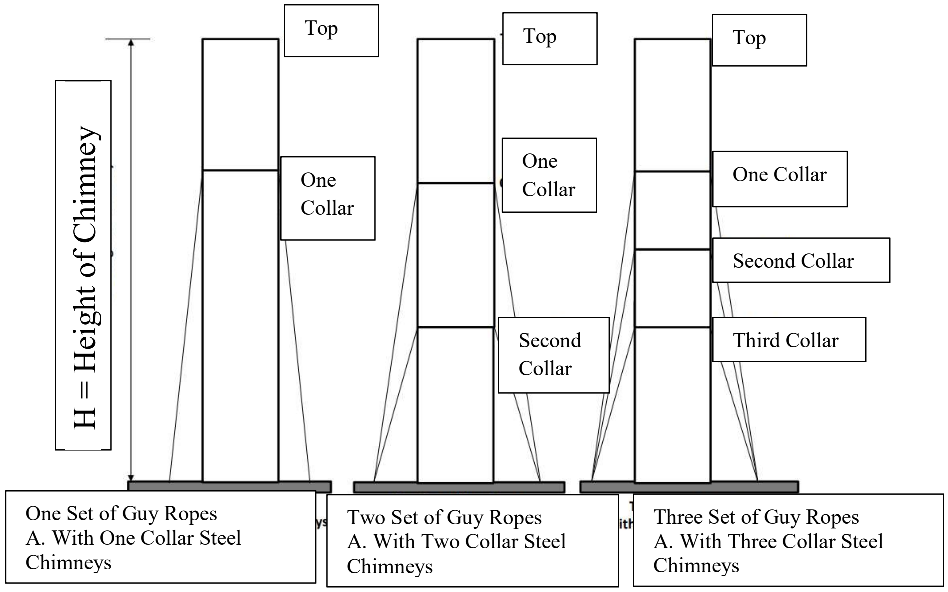

Figure 3.2. Different types of Chimney [17]

6. **Self-Supporting Stack:** Self-supporting stacks are designed to stand independently without the need for external support like guy wires. These stacks are often used in industries that require tall chimneys, such as power plants.

3.4 DESIGN CODES

IS 4998: Criteria for Design of Reinforced Concrete Chimneys

IS 6533: Code of Practice for Design and Construction of Code of Practice for Design and Construction of Chimneys

IS 456: Code of Practice for Plain and Reinforced Concrete

IS 800: Code of Practice for use of structural steel in general Building Construction

IS 875: Code of Practice for Design Loads for Buildings and Structure (Part-3: Wind Loads)

IS 1893: Criteria for Earthquake Resistant Design of Structures.

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CHAPTER 4

4.0 RAFT FOUNDATION

4.1 INTRODUCTION TO RAFT FOUNDATION

A raft or mat is a combined footing that covers the entire area beneath a structure and supports all the walls and columns. Raft foundation are required on soils of low bearing capacity, or where structural columns or other loaded areas are close in both directions that individual pad foundations would nearly touch each other. These are useful in reducing differential settlement on variable soils or where there are large variations in loading between columns.

Circular tower shaped structures find common application in a variety of modern fields like TV towers, microwave towers, chimneys, cooling towers, above ground tank and overhead water tanks etc. The main loads to which these structures are subjected are gravity loads, wind forces and seismic forces. Vertical loads to be transferred in the first four types of towers listed above are relatively much smaller as compared to those in overhead water towers. All these loads to which the towers are subjected are ultimately to be transmitted to the foundation and from foundation to the earth. Thus the selection of suitable type of foundation is as important as the shape of tower itself for economical and safe design of overall structure. Economy and ease of construction determine the suitability of the foundation. The raft foundations are, therefore, most suitable for the towers transferring moderate loads to foundation and for towers of medium height. Thus, they find an extensive application in foundations for water towers. Bearing capacity of soil is an important parameter to decide the size of raft foundation. The raft may be either solid or annular. For relatively large horizontal forces the use of annular raft foundation will be more economical than solid raft because it offers more resistance to overturning.

In the annular raft the location of ring beam through which the loads are transferred to the raft is another important factor which governs the economy of such rafts. Location of ring beam is generally fixed and depends upon the size of tower staging. Thus fixing the location of ring beam indirectly leads to proportioning of the raft in such a way that the resultant of soil pressure exerted on the raft does not become eccentric to the ring beam

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and the moments in the raft slab are minimized. In Figure 4.1 a typical raft foundation has been depicted.

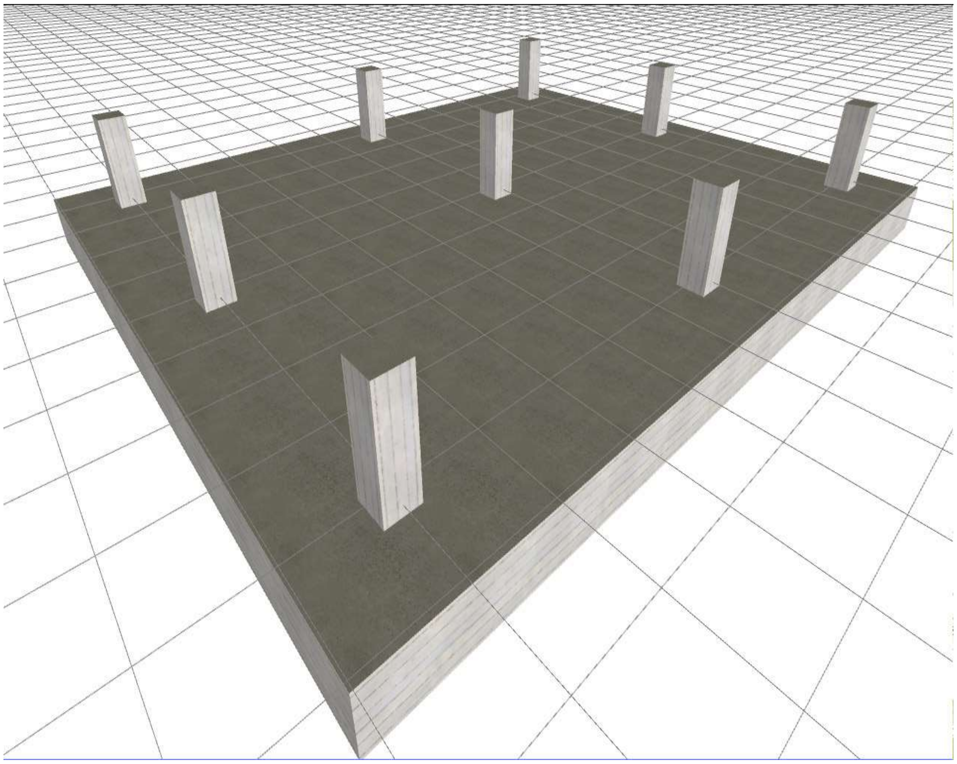

Figure 4.1. Typical Raft foundation [23]

4.1 CLASSIFICATIONS OF RAFT FOUNDATION

Raft foundation can be divided into two different types plain slab type and slab and beam type:

1. Plain slab type: For fairly small and uniform column spacing and when the supporting soil is not too compressible a flat slab having uniform thickness throughout is most suitable. Plain Slab Raft has been shown in the Figure 4.2

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Figure 4.2. Plain slab type foundation [24]

2. Annular circular slab with a ring beam type raft is likely to be more economical for large column spacing when the soil is very compressible. Annular foundations are generally used for structures like smoke stacks, water towers etc. These foundations are preferred to circular ones in view of full utilization of soil capacity and no tension condition under the foundation. Figure 5.3 shows the annular raft foundation.

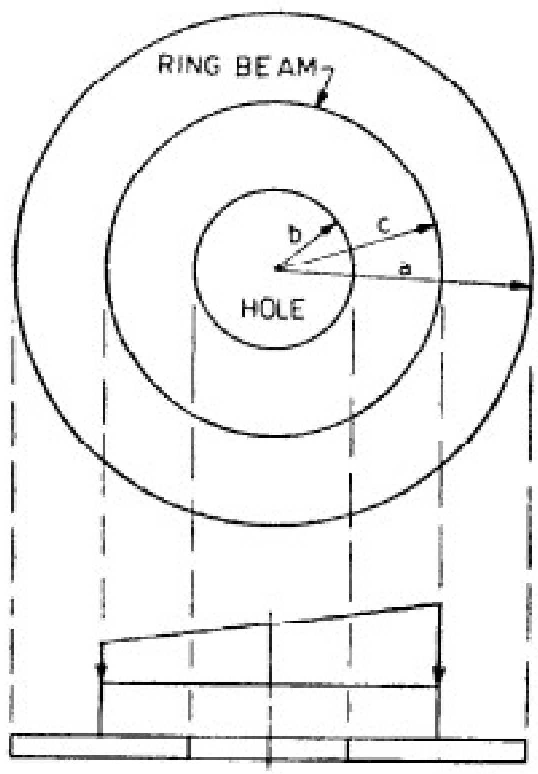

Figure 4.3. Annular circular slab with a ring beam type [19]

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4.2 METHODS OF ANALYSIS FOR RAFTS

4.2.1. Rigid foundation (Conventional method): This is based on the assumption of linear distribution of contact pressure. The basic assumption of this method are:

- The foundation is rigid relative to the supporting soil and the compressible soil layer is relatively shallow.
- The contact pressure distribution is assuming to very linearly throughout the foundation.

  Pressure distribution has been shown in Figure 5.4.

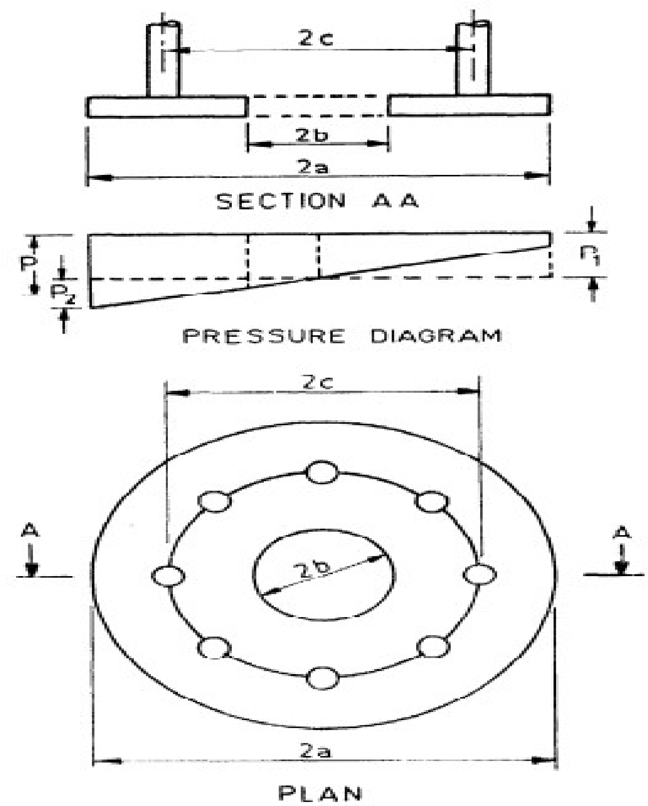

Figure 4.4. Pressure distribution with annular raft [19]

4.2.2 Flexible ring foundation: in this method, it is assumed that –

- The subgrade consists of an infinite array of individual elastic springs. The spring constant is equal to modulus of subgrade reaction.
- The contact pressure is therefore linearly proportional to the settlement at that point.

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CHAPTER – 5

5.0 MODELLING OF RCC CHIMNEY AND RAFT FOUNDATION

5.1 GENERAL

The RCC Chimney and Raft foundation are designed and analysed in ETAB v.17 (Extended Three-dimensional Analysis of Building System). The analysis is done by representing the soil with the help of spring constants as area spring. The effect of wind load, earthquake load and dead load is being studied. The modelling of the soil is one of the key points in the wind load analysis.

5.2 PROPERIES USED FOR MODELLING OF THE RCC CHIMNEY AND RAFT FOUNDATION.

5.2.1. Dimensioning of RCC Chimney

- Height of Chimney = 90 m (from Emission Regulation part 1)
- Ratio of height to base ratio = 15 (ASSUMED AS PER SN MOHAN LITERATURE)
- Therefore, Base Diameter = 6 m
- Slope = 1/50 (From S.N Mohan- Tall Chimneys Design & Construction)
- Slope=Rise/Run=1/50
    - Rise=90/50=1.8 m
- Top diameter = 2.4 m
- Assuming a shell thickness of 0.15 m

5.2.2 Dimensioning of Raft Foundation

- Raft of diameter = 10 m(assuming)
- Assuming slab thickness of raft 0.3 m

5.2.3 Numerical Modelling Using ETAB v17

Four noded shell element has been used for modelling the chimney and three and four noded shell element has been used for modelling the raft as shown in Figure 5.1. Shell element for the RCC Chimney has a thickness of 150 mm and Raft has a thickness of 300 mm. RCC Chimney is made up of 240 joints and 216 shells. And Raft has 121 joints and 120 shells. RCC Chimney and Raft Foundation is model in ETAB 17 which has the following properties:

1.Compressive Strength, f_{ck} = 30 MPa

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2.Modulus of Elasticity of concrete, E =27386.13 MPa

3.Poisson's Ratio, μ = 0.2

4.Unit weight of concrete, ρ = 24 kN/m^2.

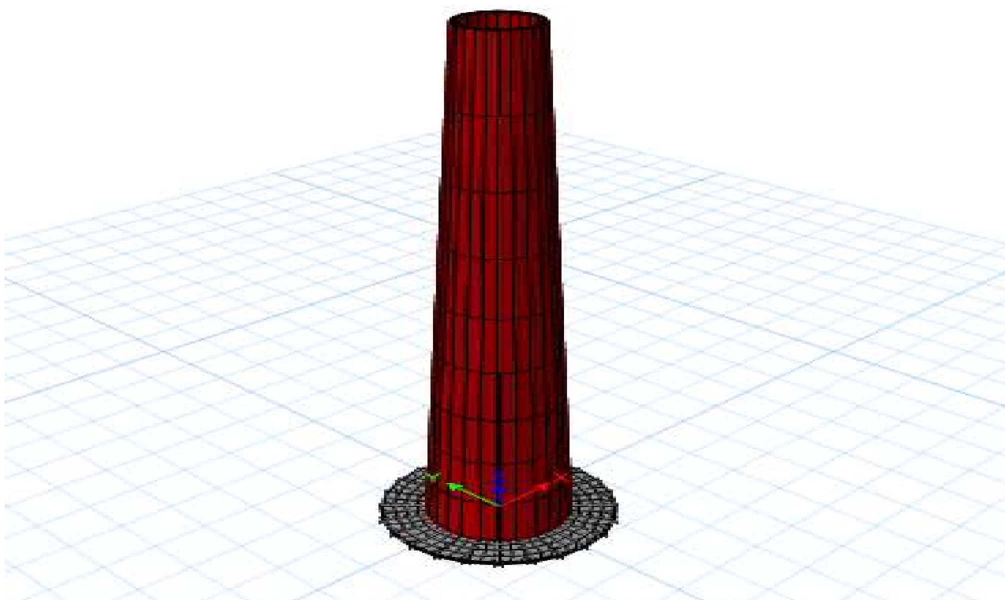

Figure 5.1. Model of RCC Chimney and Raft from ETAB v17

5.2.4 Boundary Conditions

- For Z direction area springs were used as shown in Figure 5.2

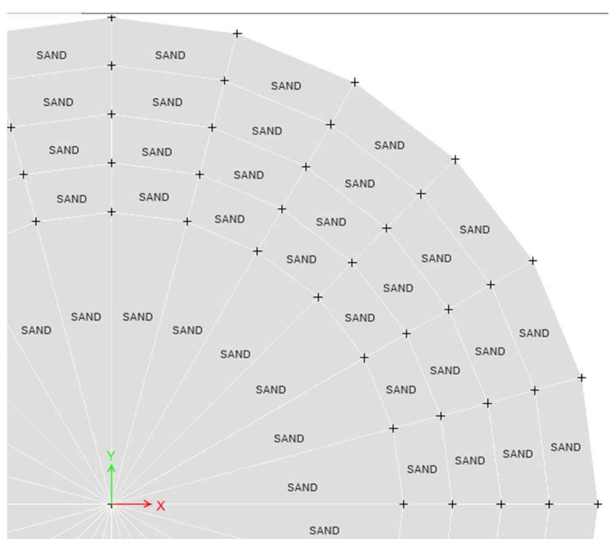

Figure 5.2. Model of RCC Raft from ETAB 17

- For X and Y direction horizontal restraints were provided as shown in Figure 5.3.

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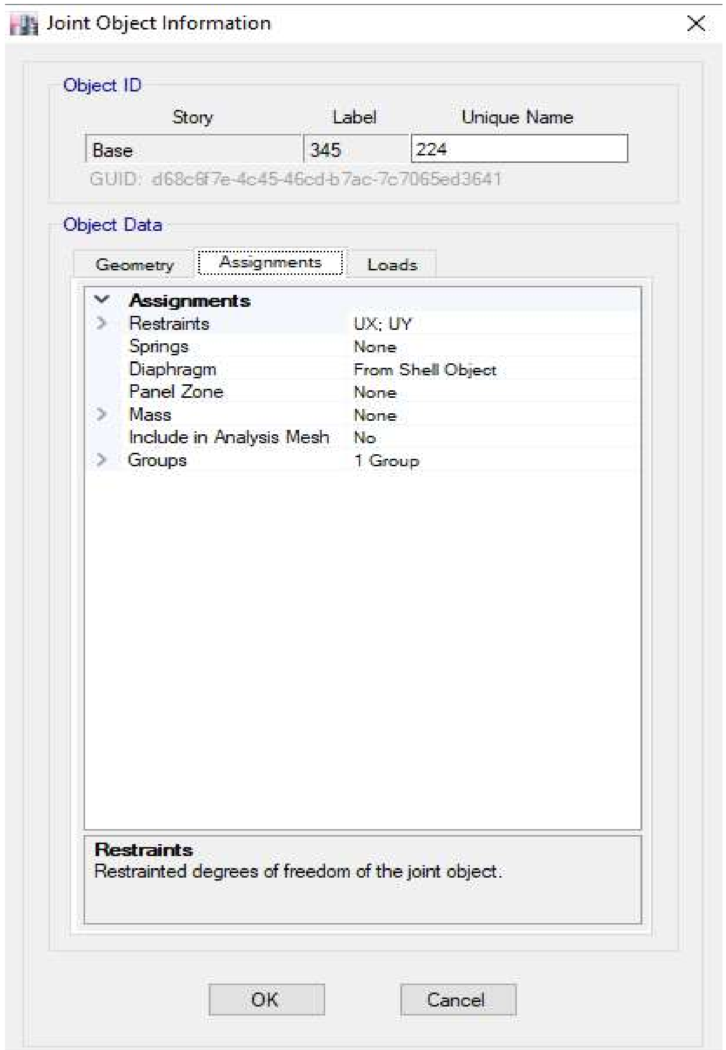

Figure 5.3. Shows the support conditions in the raft in the ETAB v.17 window

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5.3 SOIL PROPERTIES

CALCULATION OF SBC BY IS CODE FROM SUB SOIL INVESTIGATION REPORT

Table 5.1 The soil properties of the Site.

Table 5.1*

B.H. No.	Sample Type	Depth (m)	Sp. Gravity	Bulk Density (g/cc)	Natural moisture content (%)	Dry Density (g/cc)	Grain Size Analysis			Plasticity Properties		DS test		CU test		UCS test	Soil Type
							Gravel (%)	Sand (%)	Silt + Clay (%)	Liquid Limit	Plastic limit	C	ϕ	C	ϕ	Cu in Kg/sq.cm	
1	R	0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	UDS_1	1.5	---	1.79	31.7	1.36	---	---	---	---	---	---	---	0.18	5.9	---	---
	R	3	2.63	---	---	---	0	6.3	93.7	36.4	27.0	---	---	---	---	---	MI
	UDS_2	4.5	---	1.8	30.8	1.38	---	---	---	---	---	---	---	0.25	8.3	---	---
	UDS_3	6	---	1.8	30.2	1.38	0	8.0	92.0	39.2	25.6	---	---	0.24	7.6	---	MI
	R	7.5	---	1.73	18.4	1.46	---	---	---	NP	NP	0	30 *	---	---	---	SP
	R	9	---	1.73	18.4	1.46	0	90.4	9.6	NP	NP	0	30 *	---	---	---	SP
	R	10.5	---	1.73	18.4	1.46	---	---	---	NP	NP	0	30 *	---	---	---	SP
	R	12	---	1.73	18.4	1.46	0	92.6	7.4	NP	NP	0	30 *	---	---	---	SP
	R	13.5	---	1.73	18.4	1.46	---	---	---	NP	NP	0	30 *	---	---	---	SP
	R	15	---	1.73	18.4	1.46	---	---	---	NP	NP	0	30 *	---	---	---	SP

Note:

* ϕ value obtained from correlation with SPT value as per IS 6403-1981 ** Cu value obtained from Table 1, IS 13365 (Part I) : 1998

R = Representative Sample; UDS = Undisturbed Sample; UCS = Unconfined Compressive Strength Test;

UU = Unconsolidated Undrained Tri-axial Test; SC = Sandy Clay; -- Data not available

CI = Clay with intermediate plasticity; CL = Clay with low plasticity; CH= Clay with high plasticity; SP = Poorly graded sand;

MI= Silt with intermediate plasticity; ML = Silt with low plasticity; MH= Silt with high plasticity;

*source: score consultancy

Table 5.2 shows the average soil properties of two layers

Table 5.2 Average soil properties of two layers.

LAYER	C(kg/cm^2)	φ (°)	γ_t in g/cc	Water content(%)	Thickness(m)
1	0.22	7.27	1.8	30.9	7.3
2	0.00	30.00	1.73	18.4	8.2

Depth of influence zone from G.L. (Ground Level) = 15 m

Depth of footing, d_f =0 m

Diameter of footing = 10 m

Depth of water table from N.G.L. (Natural Ground Level) = 2.4 m

IS: 6403-1981 suggests the net ultimate bearing capacity of shallow footing as follows:

a) In case of general shear failure as given by

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$$cN_c s_c d_c i_c + \gamma D_f(N_q-1)\, s_q d_q i_q + 0.5\, B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$$

b) In case of local shear failure as given by, q'_d

$$2/3cN'_c s_c d_c i_c + \gamma D_f(N'_q-1)\, s_q d_q i_q + 0.5\, B\gamma N'_\gamma s_\gamma d_\gamma i_\gamma W'$$

Given data

Depth of pressure bulb from footing base = 15 m

C = 0 kN/m^3, ϕ = 30.00^0 W_n = 18.40 %, e = 0.80

Υ_t = 1.80 gm/cc = 17.61 kN/m^3, G_s = 2.6 , Υ_{sub} = 0.80

Since ϕ = 30 ° < 36 °

Therefore, Local shear failure mode applies and, φ' = 20.00 °

Bearing capacity factors, N'_c = 14.85 N'_q = 6.40 N'_γ = 5.39

Shape factors, S_c = 1.30 S_q = 1.20 S_Υ = 0.60

Depth factors, d_c = 1.00 d_q = 1.00 d_Υ = 1.00

Inclination factors, i_c = 1.00 i_q = 1.00 i_Υ = 1.00

Water table correction factor = W' = 0.63, F.O.S = 3.00

Effective surcharge at the base level of foundation, q = Υ x D_f = 0 kN/m^2

Net ultimate bearing capacity at a depth of 0 M from GL for a footing of size 6M DIA = 179.39 kN/m^2 = 2/3 x 0 x 14.85 x 1.3 x 1 x 1 + 0 x (6.40 -1) x 1.2 x 1 x 1 + 1/2 x 10 x 17.61 x 5.39 x 0.6 x 1 x 1 x 0.63

Net safe bearing capacity = (Net Ultimate bearing capacity / FOS) = 179.39 / 3 = 59.80 kN/m^2

SETTLEMENT CRITERIA

Total settlement = Sc + Si

Consolidation settlement, Sc

Bearing capacity at G.L = 59.80 kN/m^2

Qs = 11080.85 kN (for dead load from ETABS)

Influence zone of the footing is up to 20 m from footing base

No. of layers covered up to a depth of 20 m from ground surface = 2

Depth of compressible soil layer = 20 m

`

For calculation of settlement, 2 layers are considered to be one single layer with consolidation parameters as the average of 2 layers Cc = 0, e_o = 0.80

Effective overburden pressure at mid depth, σ_o = 7.18 t/m2

Assuming a load dispersion of 2:1

$\Delta\sigma$ = 11080 x 1.5/ $(15+10+15)^2$ t/m2 =10.38 t/m2

$$Sc = H\,X\,\frac{Cc}{1+eo}\log 10\,\frac{\sigma o + \Delta\sigma}{\sigma o}$$

=15 x (0/1+0.8) x $\log_{10}$ (7.18+10.38/7.18) = 0 mm

Immediate Settlement

Modulus of deformation of soil = 11166.7 kN/m^2, μ = 0.50

Influence factor, I = 0.85

=59.8 x 10 x {(1-0.502)/ (11166.7)} x 0.85 = 34.14 mm

Water table correction factor for settlement, w' = 0.88 Fig. 9 of IS: 8009 (Part I)-1976

Corrected settlement of sandy soil =0.88 x 34.14 =30.04 mm

Total settlement = 0 + 30.04= 30.04 mm < 75 mm, permissible settlement for shallow raft foundation as per IS: 1904-1986

Net safe bearing capacity =5.98 t/m^2

Allowable bearing pressure = 5.98 t/m^2

Considering 5.36 mm of settlement.

For soil representation as area spring we have used modulus of deformation of soil 11166.7 kN/m^2 for sandy type of soil. Similarly, for other two soil we have calculated the modulus of deformation of soil an inputed as area spring in ETAB v.17.

5.4. LOAD CALCULATIONS

Wind load calculation as per IS 875 Part 3 2015

Considering Assam for all calculation

Parameters from IS 875 Part 3 for the chimney

Basic Wind Speed = 50 m/s (from Annexure A)

Probability factor or (risk coefficient), K_1 = 1.08 (from table 1)

Terrain category 1 (take K_2 from table 2)

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Topography factor, $K_3 = 1$ (upwind slope is taken to be less than 3 degree)

Calculation of Design Wind Pressure

For 0 m (from bottom)

$K_1 = 1.08$, $K_2 = 1.05$, $K_3 = 1$, $V_b = 50$ m/s

Design wind speed, $V_z = 50 \times 1.08 \times 1.05 \times 1$ (Clause 6.3)

$= 56.7$ m/s

Design wind pressure, $P_z = 0.6 \times V_z^2$

$= 0.6 \times (56.7)^2$

$= 1928.93\ N/m^2$

$= 1.93\ kN/m^2$

Similarly, for 5m, P_z= 1.93kN/m^2, 10m, P_z=1.93kN/m^2, 15m, P_z=2.08kN/m^2, 90m, P_z=2.73kN/m^2

Internal Pressure Coefficient, C_{pi}

From Clause 7.3.2, 7.3.2.1, and 7.3.2.2

Internal air pressure in a building depends upon the degree of permeability of cladding to the flow of air.

So, in the chimney we have no opening

Therefore, $C_{pi} = 0$

External Pressure Coefficient, C_{pe}

From Clause 7.3.3.7 (Table 19)

We have considered H/D = 90/6 =15

Windward Direction

For 0^0Here, $C_{pe} = 1$, For 15^0, $C_{pe} = 0.8$, For 30^0, $C_{pe} = 0.1$, For 45^0, $C_{pe} = -0.84$, For 60^0, $C_{pe} = -1.79$, For 75^0, $C_{pe} = -2.33$, For 90^0, $C_{pe} = 2.38$

Leeward direction

For 105^0, $C_{pe} = -1.79$, For 120^0, $C_{pe} = -0.84$, For 135^0, $C_{pe} = -.64$, For 150^0, $C_{pe} = -.54$, For 165^0, $C_{pe} = -0.54$, For 180^0, $C_{pe} = -0.54$

As calculated from IS 875 Part 3 2015 wind pressure coefficient were applied in the model of ETAB 17 as shown in figure 5.5.

Figure 5.4 shows wind direction as per IS CODE to be taken

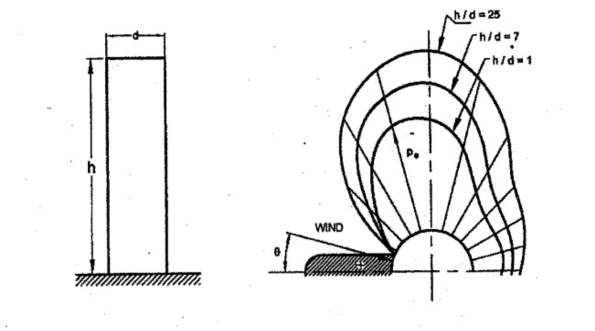


Figure 5.4. Shows the wind direction [20]

Figure 5.5 Shows the application of External Pressure Coefficients, C_{pe} in the chimney in the ETAB v.17

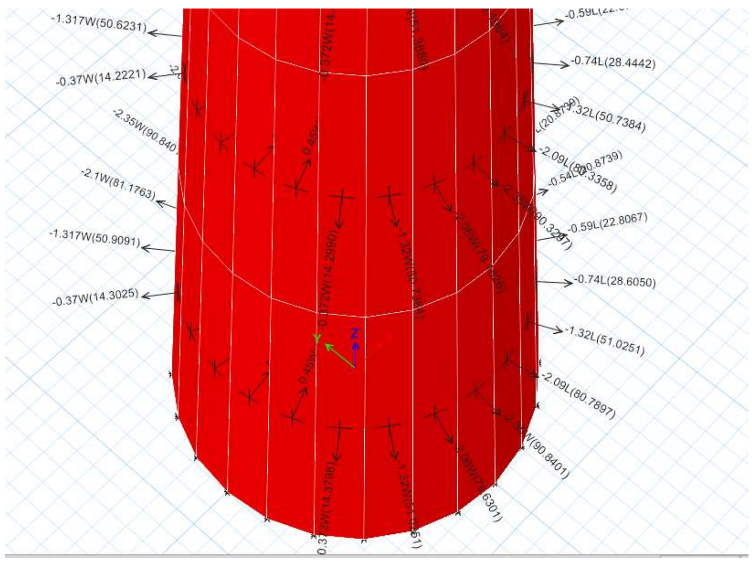


Figure 5.5. Application of Wind Load Coefficients

Earthquake load calculation as per IS 1893 Part 1 2016

Considering Assam for all calculation

Parameters from IS 1893 Part 1 2016 for the chimney

Zone – V, Seismic Zone factor = 0.36(Table 3)

Site type = 1 (Table 2)

Importance Factor, I = 1(Table 8)

Response Reduction Factor = 5 (Table 9)

Loads are applied by defining a Response Spectrum Function.

Calculation of Time period

The fundamental period of vibration for a self-supporting chimney can be calculated as per IS-1893 Part-4:2005 as follows:

$T = C_T\sqrt{\frac{Wt\ x\ h}{Es\ x\ A\ x\ g}}$

Where, C_T = Coefficient depending upon slenderness ratio, W_T = Total weight of the chimney, h = total height of the chimney. E_s = Modulus of elasticity of the material of structural shell and A_{base} = Area of cross section at base of chimney shell

Radius of gyration,$r_e = \frac{1}{\sqrt{2}}(\frac{Dbase}{2}) = \frac{1}{\sqrt{2}}(\frac{6}{2})$=2.12, Height of Chimney= 90 m

Therefore, $k = \frac{h}{re} = \frac{90}{2.12} = 42.45$

Therefore, C_T= 78.3 (from Table 6 of IS 1893 1984)

Modulus of Elasticity of material of the structural shell, E_s= 2.74 x 10^7 kN/m^2

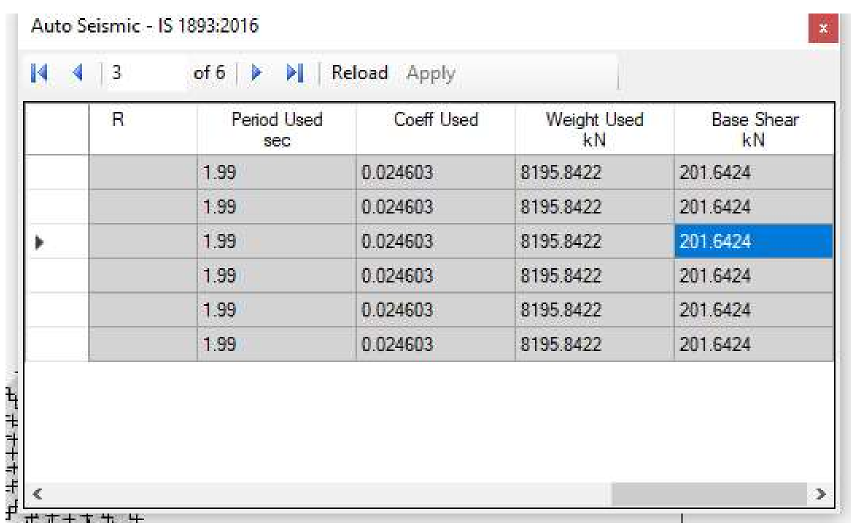
Area of cross-section at the base of the structural shell, $A = \frac{\pi}{4}$ X 6^2 = 28.27 m^2,

Acceleration due to gravity, g = 9.81m/sec

Total weight of structure including weight of lining and contents above the base, Wt = Volume X Density =2175 X 25 = 54382 kN

Therefore Time Period, $T = 78.3\sqrt{\frac{54382\ x\ 90}{2.74\ x\ 10000000\ x\ 28.27\ x\ 9.81}} = 1.99$

Fundamental period of vibration for a self-supporting chimney need to be taken to check the base shear of the chimney. Figure 5.6 shows the time period applied and corresponding base shear in the model. Maximum Base Shear should be considered from automatic calculated time period and time period calculated from IS Code.



R	Period Used sec	Coeff Used	Weight Used kN	Base Shear kN
	1.99	0.024603	8195.8422	201.6424
	1.99	0.024603	8195.8422	201.6424
	1.99	0.024603	8195.8422	201.6424
	1.99	0.024603	8195.8422	201.6424
	1.99	0.024603	8195.8422	201.6424
	1.99	0.024603	8195.8422	201.6424

Figure 5.6. Show the application of Time Period in ETABS

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CHAPTER – 6

6.0 METHODOLOGY

6.1 GENERAL

The methodology for this project is to analysis of the Self Supporting RCC Chimney and Annular Raft Foundation for Sandy Soil, Clay with low plasticity and Stiff Clay in ETAB 17. The dead load gets automatically calculated in the ETAB 17. The wind load has been applied as per IS 875 Part 3 2015 on all the shell of chimney model. Earthquake loads were applied with the help of response spectrum method. The soil is represented with the help of area spring.

6.1.1 RCC CHIMNEY AND RAFT FOUNDATION FOR SANDY SOIL

A RCC Chimney of height 90 m, base diameter 6 m and annular raft of 10 m is shown in the Figure 6.1.

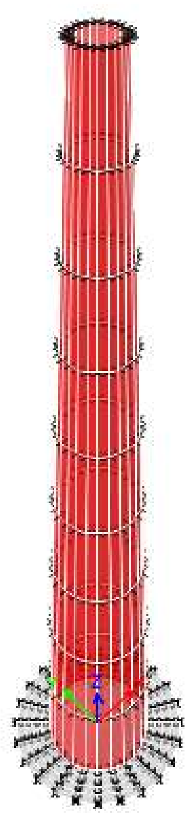

Figure 6.1. RCC Chimney with Raft

Sandy Soil is represented with the subgrade modulus as area spring as shown in Figure 6.2 and Figure 6.3. Subgrade for Clay and Stiff Clay has been applied similarly.

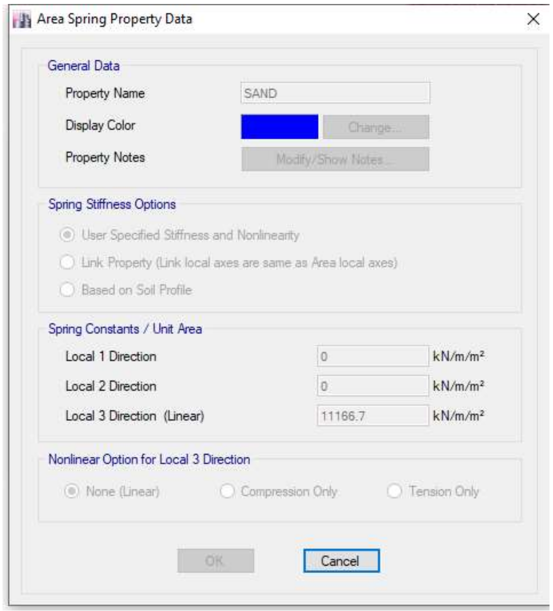

Figure 6.2. Application of Modulus of Subgrade with Area Spring

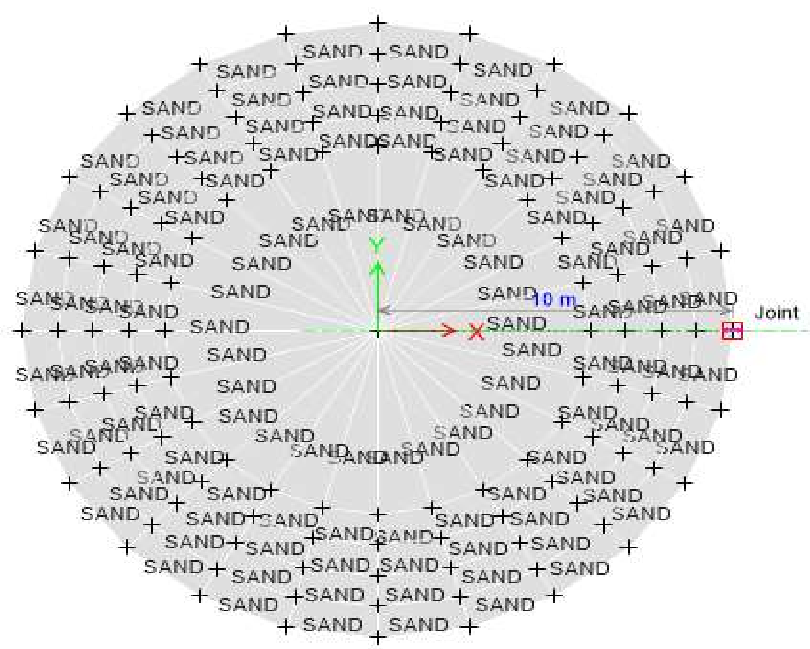

Figure 6.3. Representation of Sandy Soil with area spring

Pressure Coefficients is applied as per IS 875 Part 3 2015 as shown in Figure 6.4

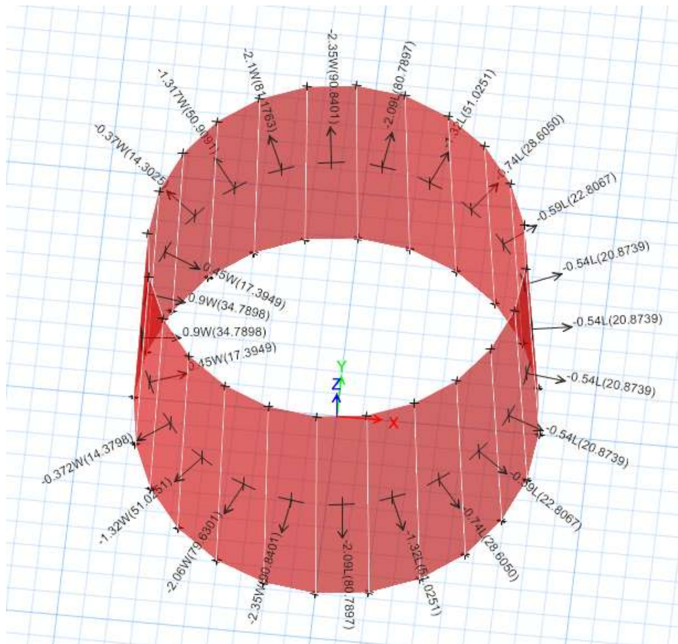

Figure 6.4. Application of Wind Pressure Coefficients

6.1.2 RCC CHIMNEY AND RAFT FOUNDATION FOR LOW PLASTIC CLAY

Clay with low plasticity is represented with the subgrade modulus as area spring as shown in Figure 6.5 and Figure 6.6.

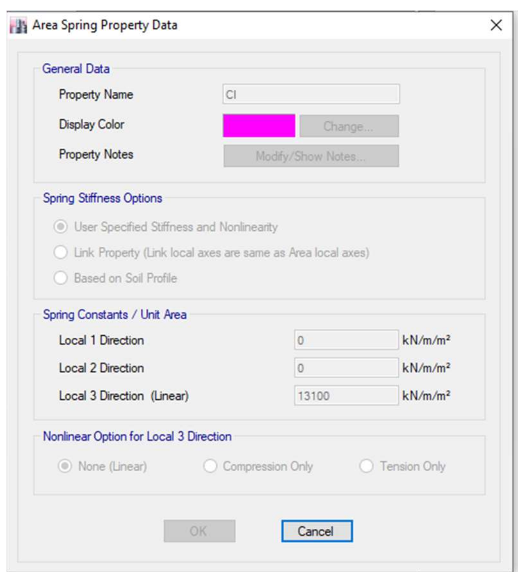

Figure 6.5. Application of Modulus of Subgrade with Area Spring

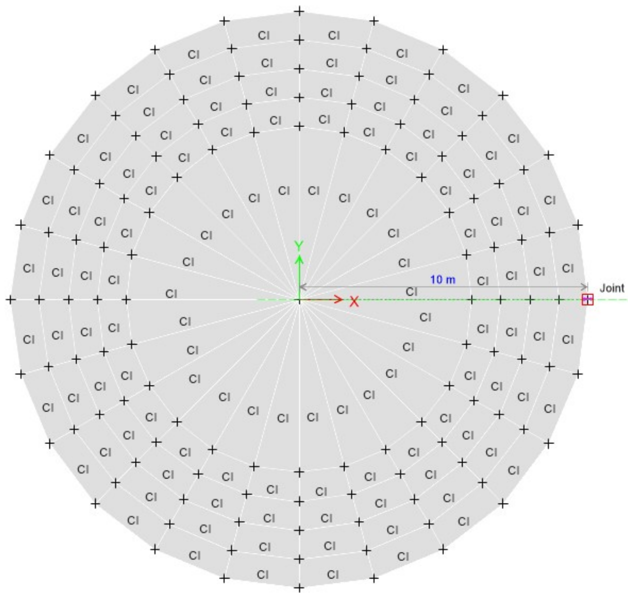

Figure 6.6. Representation of Clay with Low Plasticity with Area Spring

6.1.3 RCC CHIMNEY AND RAFT FOUNDATION FOR STIFF CLAY

Stiff Clay is represented with the subgrade modulus as area spring as shown in Figure 6.7 and Figure 6.8

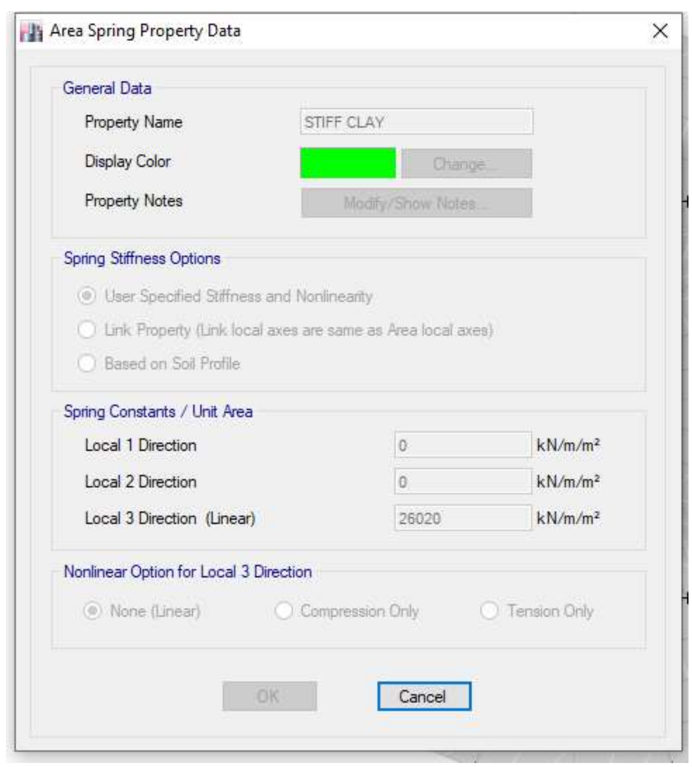

Figure 6.7. Application of Modulus of Subgrade with Area Spring

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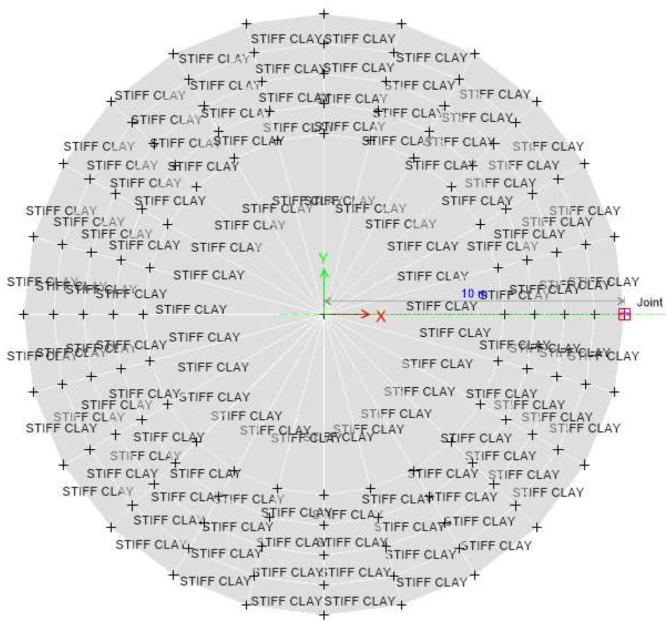

Figure 6.8. Representation of Stiff Clay with Area Spring

6.1.4 ANALYSIS TREE FOR THE PROJECT CAN BE SHOWN IN THE FIGURE 6.9

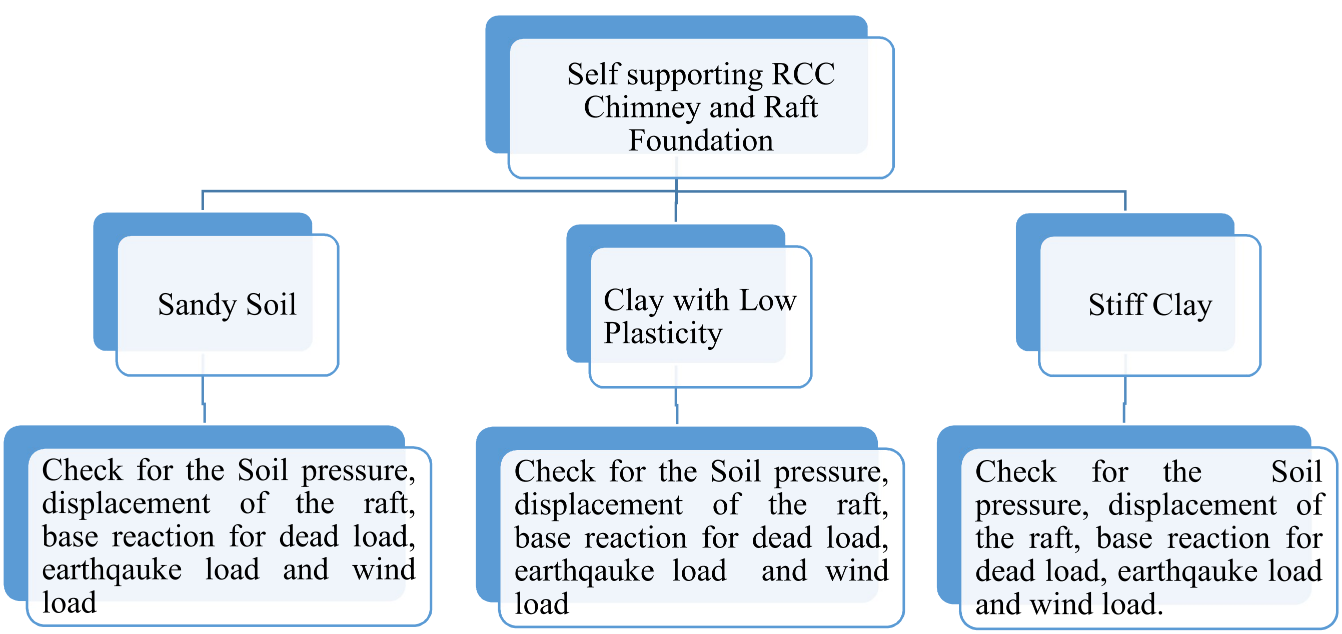

Figure 6.9. Analysis Tree for the SSI Study

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6.1.5 STEP BY STEP PROCESS FOR ANALYSIS IN ETABS 17 CAN BE SHOWN IN THE FIGURE 6.10

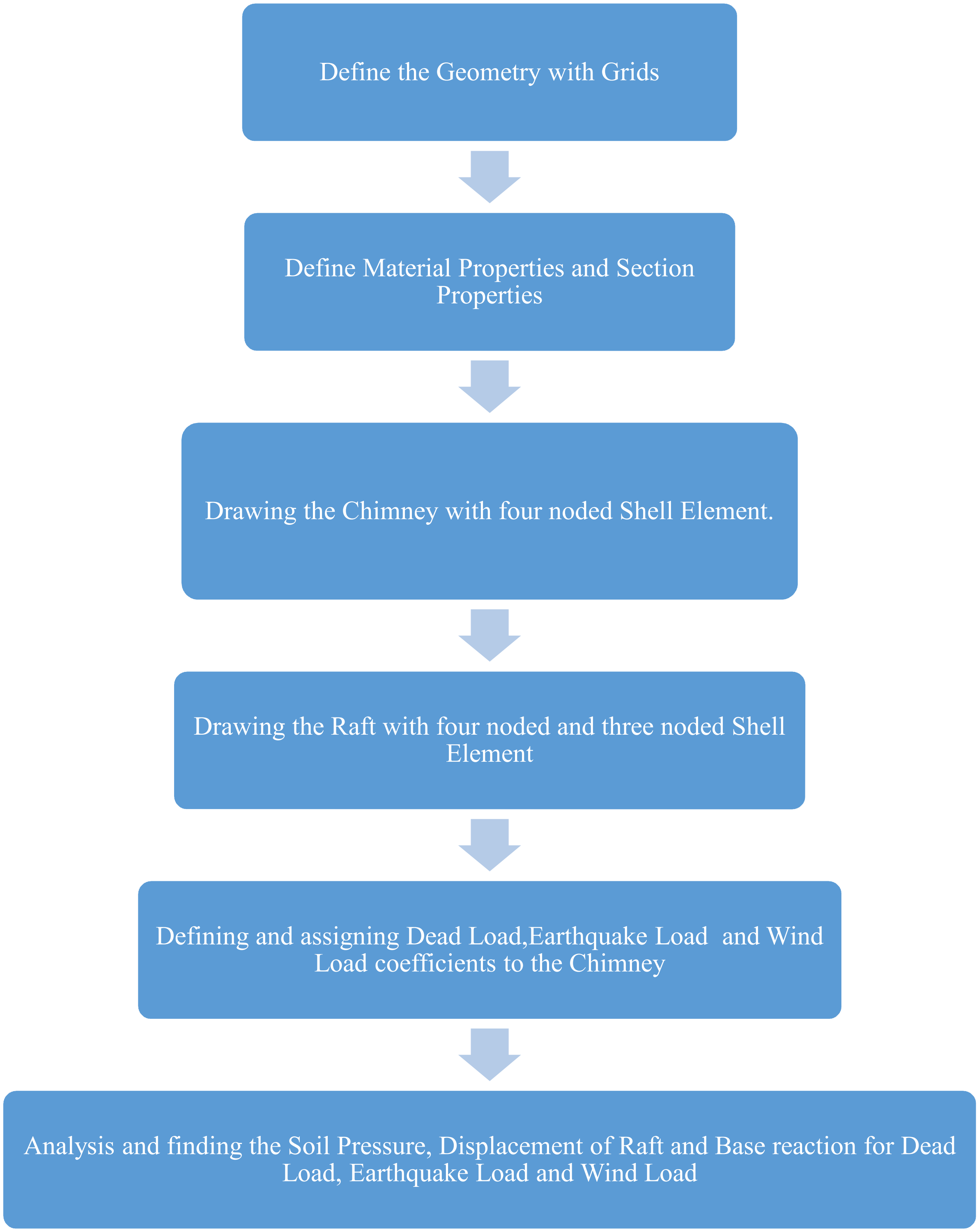

Figure 6.10. Flow Chart for analysis in ETABS 17

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CHAPTER – 7

7.0 RESULTS AND DISCUSSIONS

7.1 GENERAL

The model is analysis in ETABS 17 by taking height by diameter ratio of 15. The soil is modelled as a sandy soil, clay with low plasticity and stiff clay. The chimney and raft is made of concrete of M30. Chimney slab as a thickness of 150 mm and Raft has a thickness of 300 mm. The analysis is firstly carried out for sandy soil after that for CL and stiff clay.

7.2 RCC CHIMNEY WITH SANDY SOIL

7.2.1 Displacement of the Chimney

Figure 7.1 shows the displacement of the chimney when dead load is applied and has a maximum joint displacement as 8.16 mm in downward Z-direction at 90 m height of Chimney.

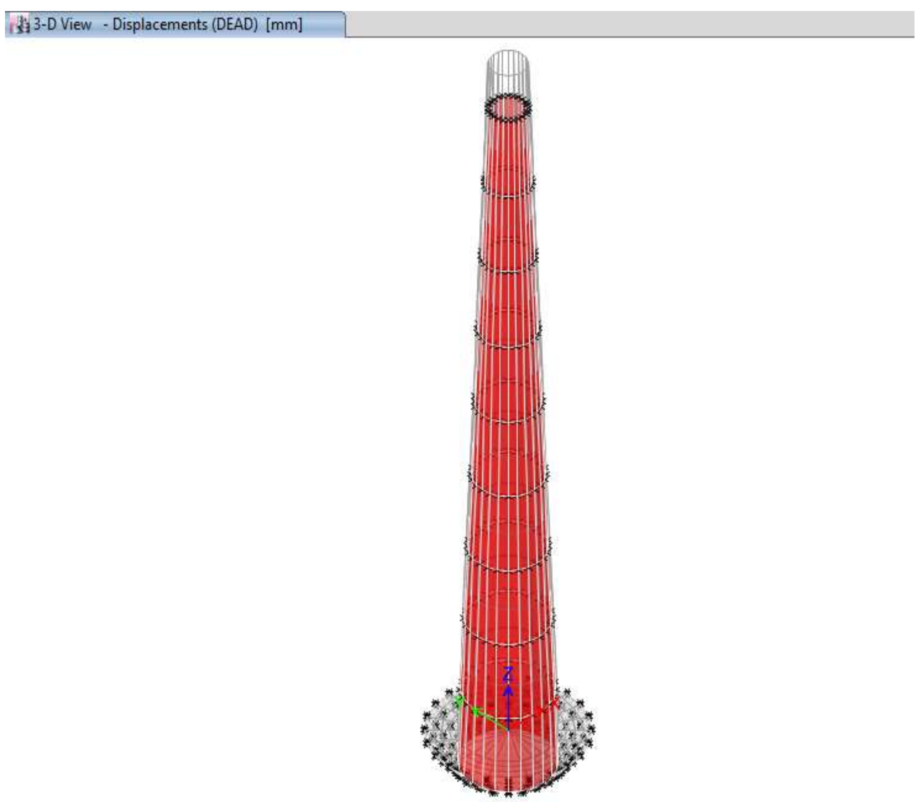

Figure 7.1. Displacements of the Chimney for Dead Load

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When applied load is Wind, maximum displacement is 178.02 mm in the positive X-direction at a height of 90 m as shown in Figure 7.2.

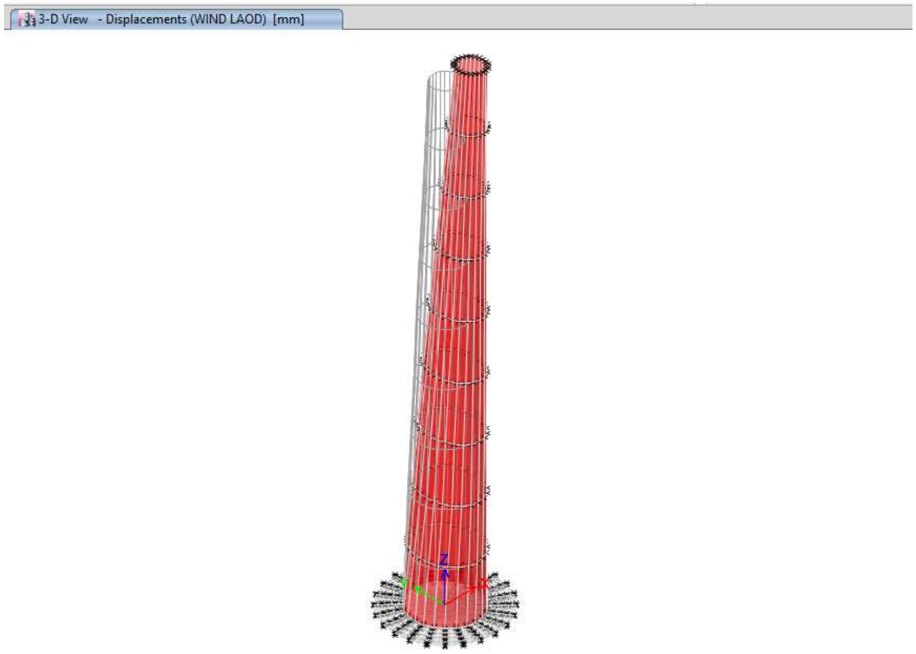

Figure 7.2. Shows the Displacements of the Chimney for Wind Load

When applied load is earthquake in the X-direction, the maximum displacement observed is 63.39 mm in the positive X-direction at a height of 90 m as shown in Figure 7.3

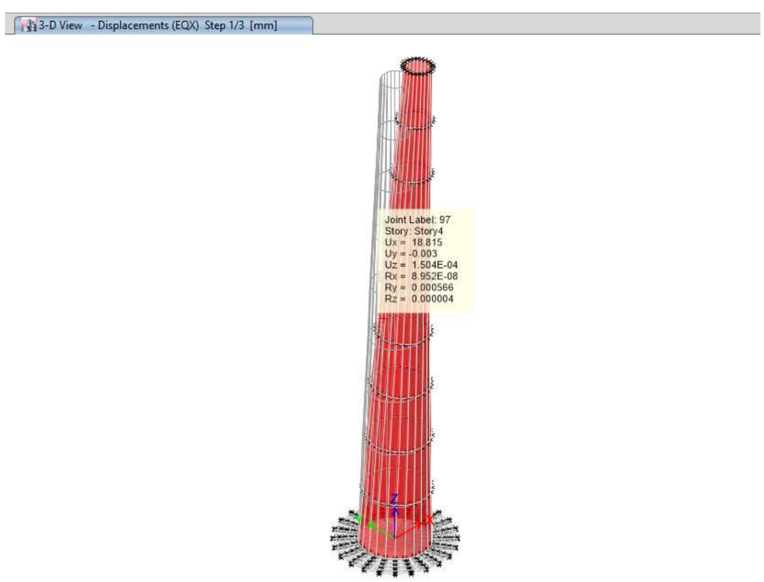

Figure 7.3. Shows the Displacements of the Chimney for Earthquake Load in X-direction

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When applied load is earthquake in the Y-direction, the maximum displacement observed is 51.59 mm in the positive X-direction at a height of 90 m as shown in Figure 7.4.

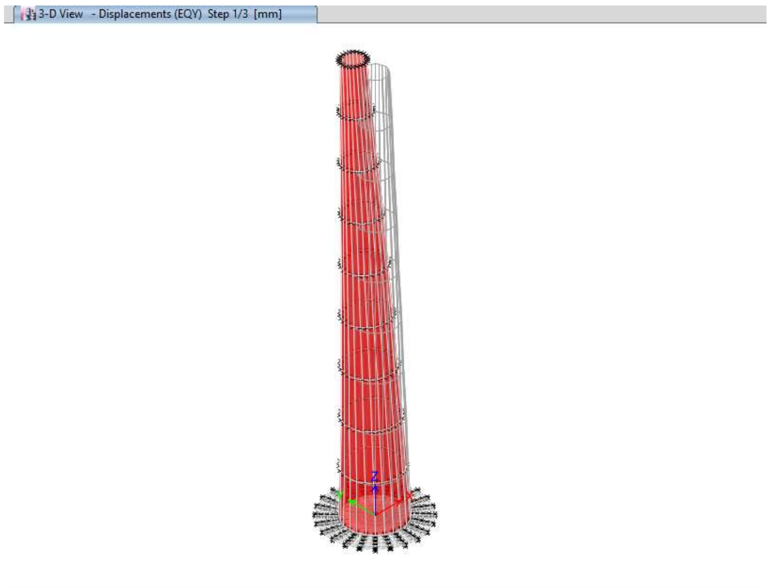

Figure 7.4. Shows the Displacements of the Chimney for Earthquake Load in Y-direction

From Figure 7.1, 7.2, 7.3, 7.4 it is clear that displacement in the case of wind load is maximum for a chimney of height 90 m. So it can be said that wind load is the governing load for designing a chimney.

7.2.3 Soil Pressures of the Raft for different Load.

Soil Pressure on the raft is shown by the contour diagram for the Dead Load as in Figure 7.5. Maximum soil pressure is 6.4 t/m^2.

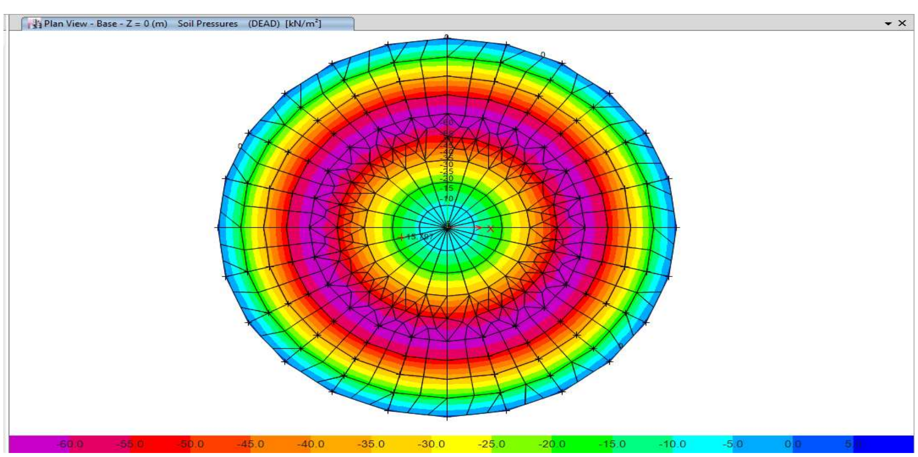

Figure 7.5. Soil Pressure for the Dead Load

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Soil Pressure on the raft is shown by the contour diagram for the Wind Load as in Figure 7.6. Maximum soil pressure is 10.7 t/m^2.

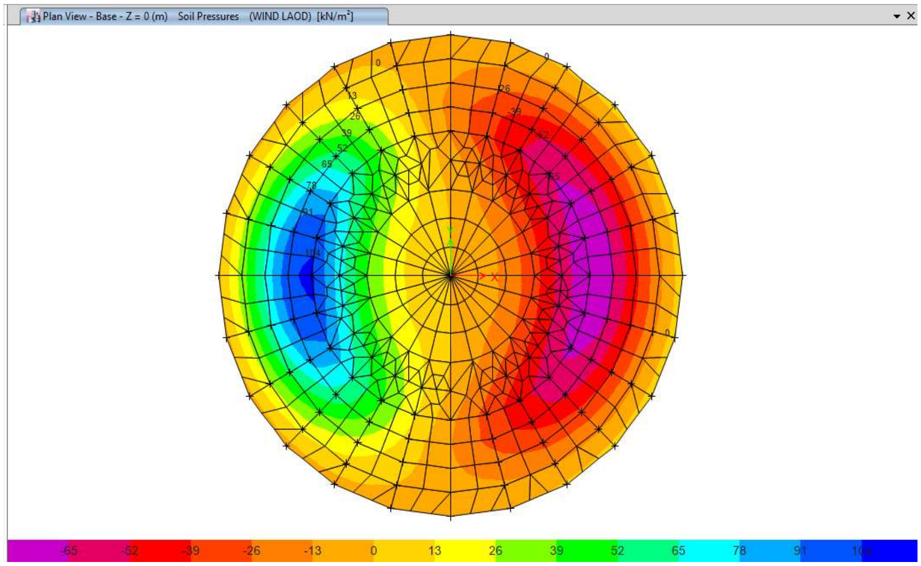

Figure 7.6. Soil Pressure for Wind Load

Soil Pressure on the raft is shown by the contour diagram for the Earthquake Load applied in the x-direction as in Figure 7.7. Maximum soil pressure is 2.4 t/m^2.

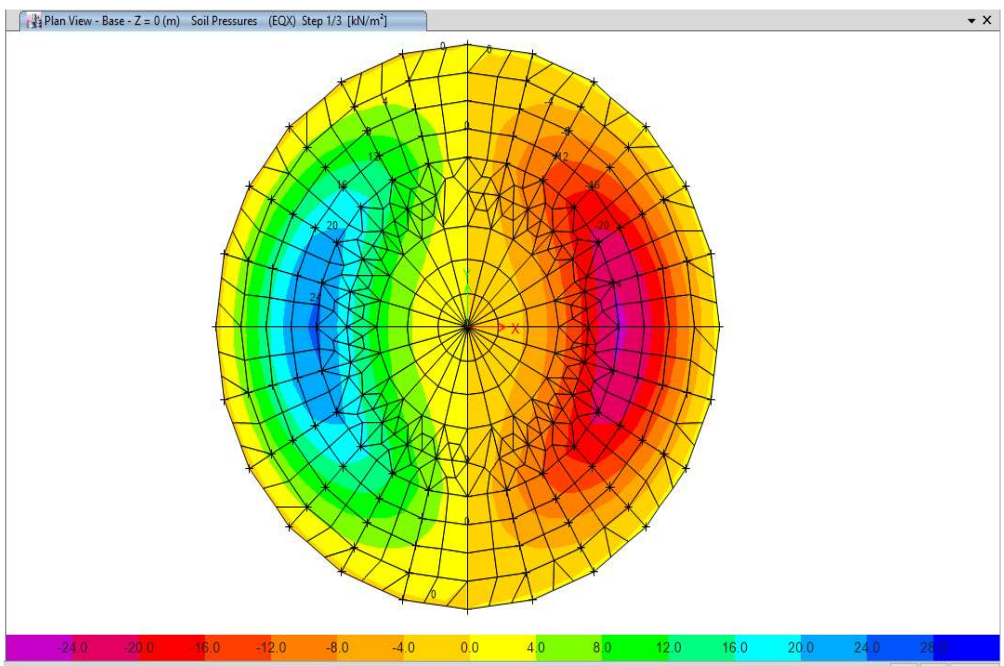

Figure 7.7. Soil Pressure for the Earthquake Load in X-direction

Soil Pressure on the raft is shown by the contour diagram for the Earthquake Load applied in the y-direction as in Figure 7.8. Maximum soil pressure is 2.47 t/m^2.

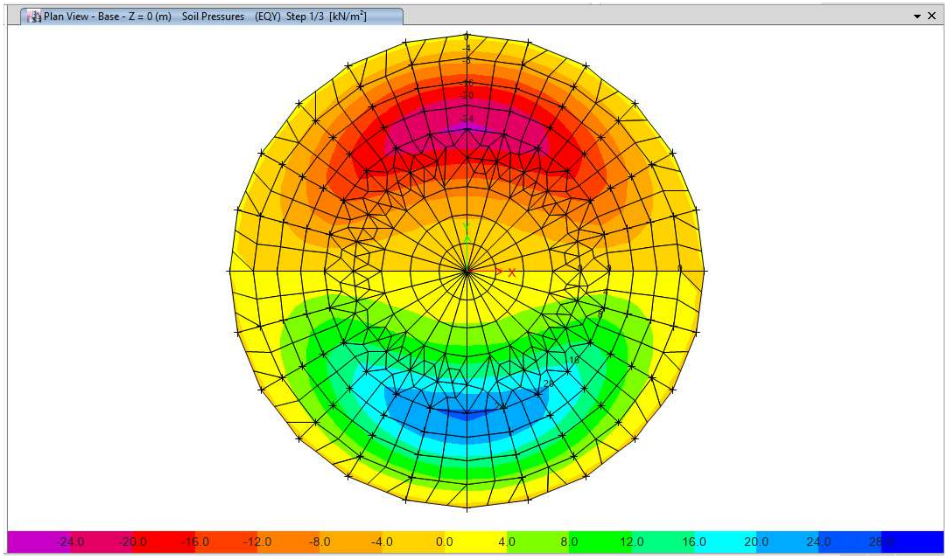

Figure 7.8. Soil Pressure for Earthquake Load in y-direction

It can be concluded from above soil pressure diagram that for wind load we get the maximum soil pressure i.e. 10.7 t/m^2. So, for design a chimney wind load need be considered as the critical load.

7.3 RCC CHIMNEY UNDERLYING CLAY WITH IMMEDIATE PLASTICITY

7.3.1 Displacement of the Chimney.

Figure 7.9 shows the displacement of the chimney when dead load is applied and has a maximum joint displacement as 7.93 mm in downward Z-direction at 90 m height of Chimney.

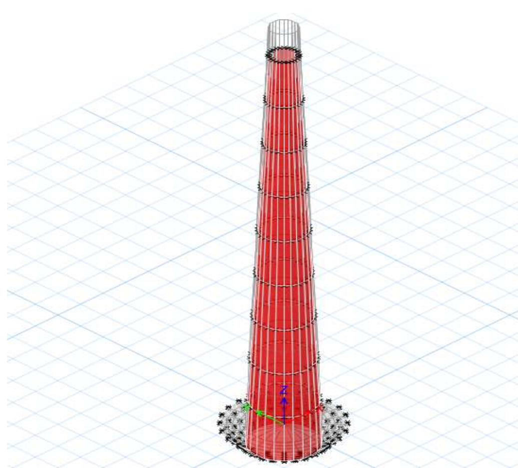

Figure 7.9. Displacement of the Chimney in Y-direction

When applied load is Wind, maximum displacement is 165.12 mm in the positive X-direction at a height of 90 m as shown in Figure 7.10.

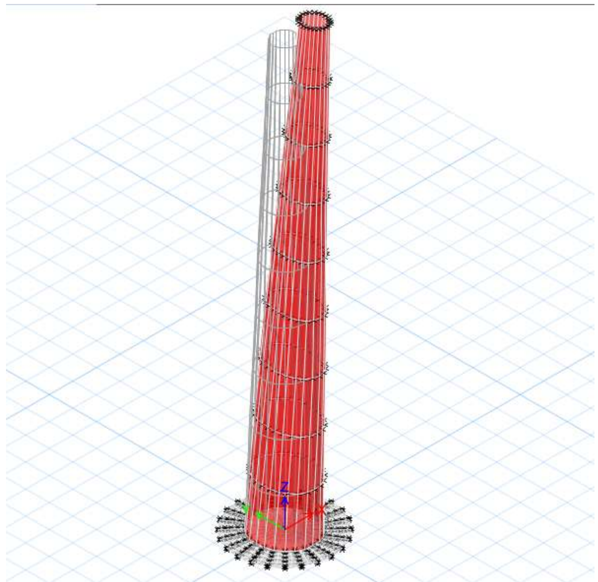

Figure 7.10. Displacements of the Chimney for Wind Load

When applied load is earthquake in the X-direction, the maximum displacement observed is 57.03 mm in the positive X-direction at a height of 90 m as shown in Figure 7.11.

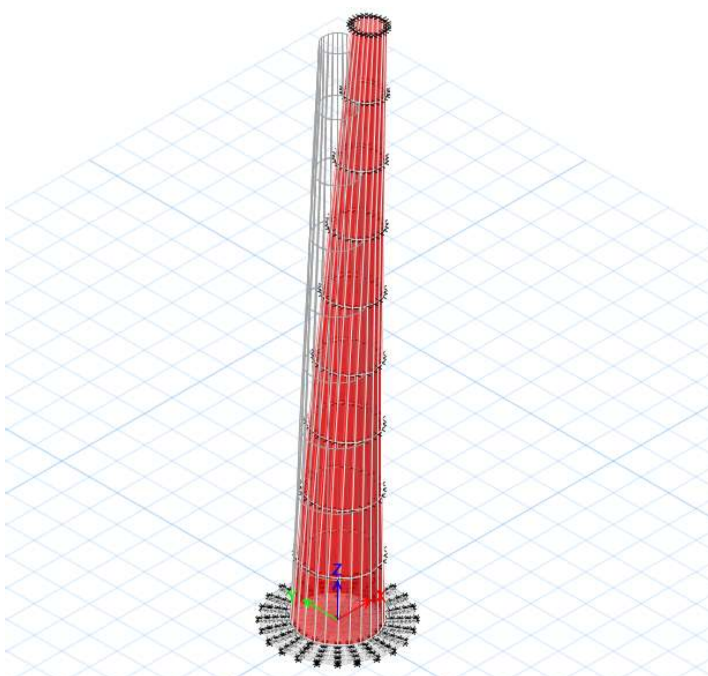

Figure 7.11. Displacements of the Chimney for Earthquake Load in X-direction

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When applied load is earthquake in the Y-direction, the maximum displacement observed is 57.02 mm in the positive Y-direction at a height of 90 m as shown in Figure 7.12.

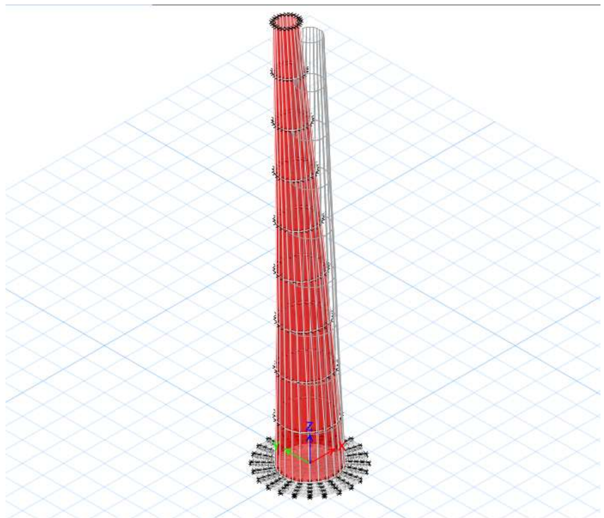

Figure 7.12. Displacements of the Chimney for Earthquake Load in Y-direction

From Figure 7.9, 7.10, 7.11, 7.12 it is clear that displacement in the case of wind load is maximum for a chimney of height 90 m. So it can be said that wind load is the governing load for designing a chimney.

7.2.3 Soil Pressures of the Raft for different Load.

Soil Pressure on the raft is shown by the contour diagram for the Dead Load as in Figure 7.13. Maximum soil pressure is 6.7 t/m^2.

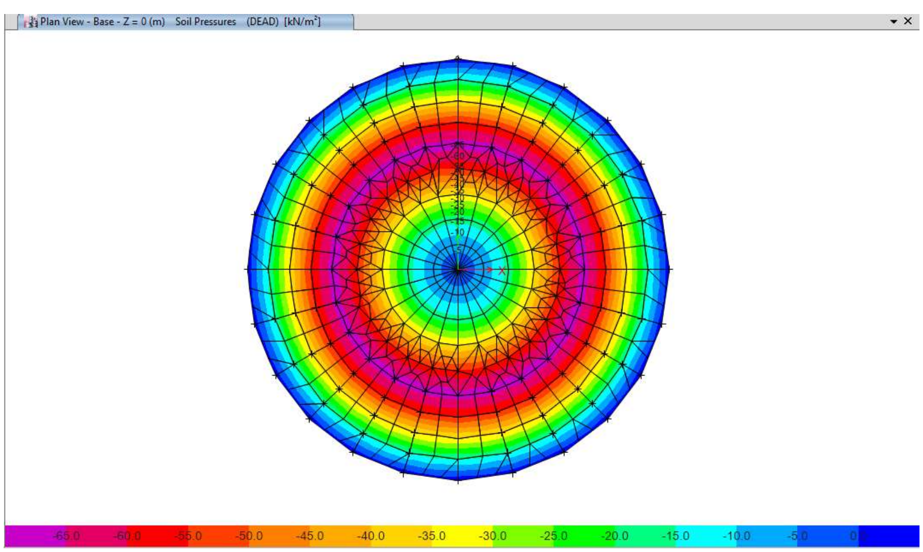

Figure 7.13 Soil Pressure for Dead Load

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Soil Pressure on the raft is shown by the contour diagram for the Wind Load as in Figure 7.14. Maximum soil pressure is 11.4 t/m^2.

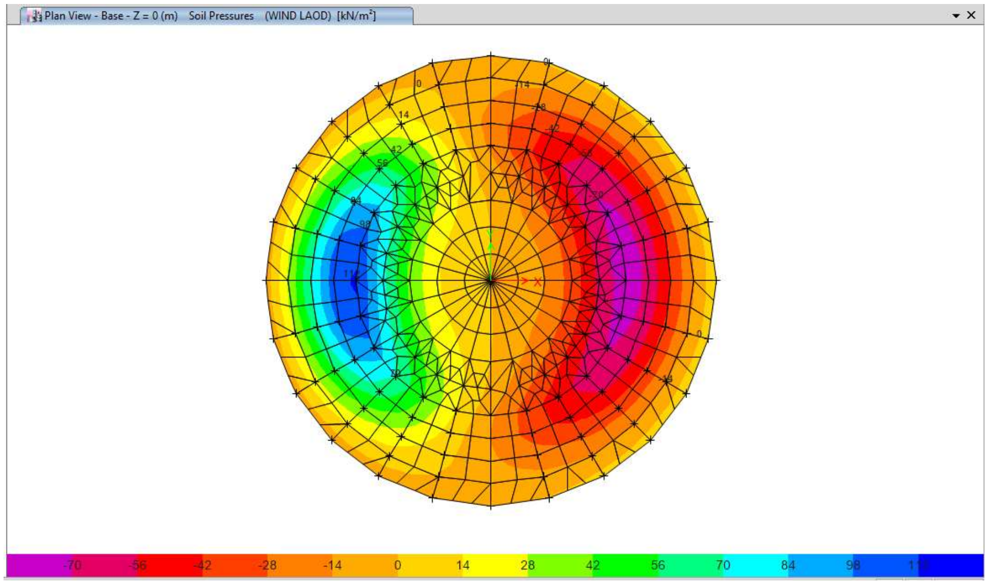

Figure 7.14. Soil Pressure for Wind Load

Soil Pressure on the raft is shown by the contour diagram for the Earthquake Load applied in the x-direction as in Figure 7.15. Maximum soil pressure is 3.08 t/m^2.

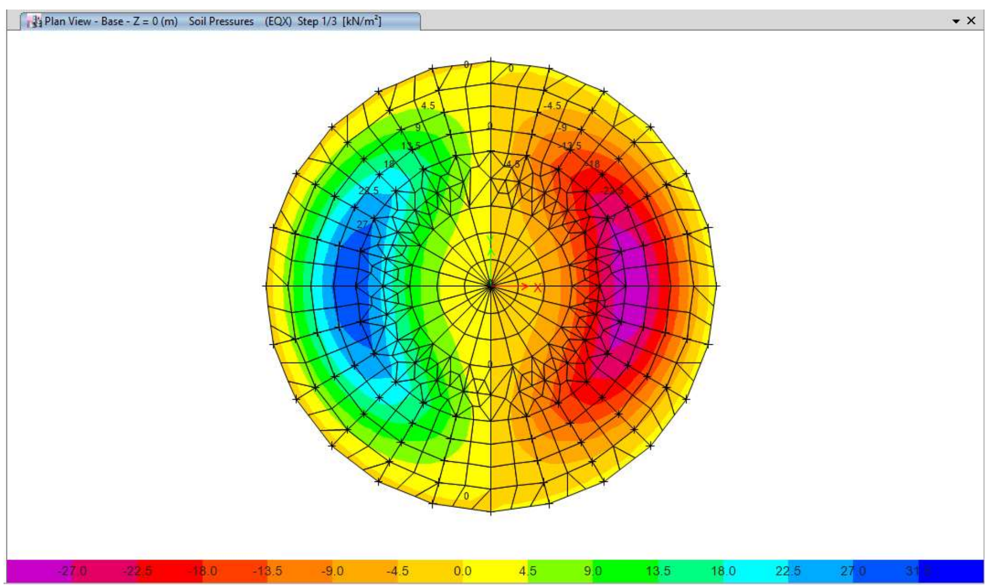

Figure 7.15. Soil Pressure for Earthquake Load in X-direction

Soil Pressure on the raft is shown by the contour diagram for the Earthquake Load applied in the y-direction as in Figure 7.16. Maximum soil pressure is 3.08 t/m^2.

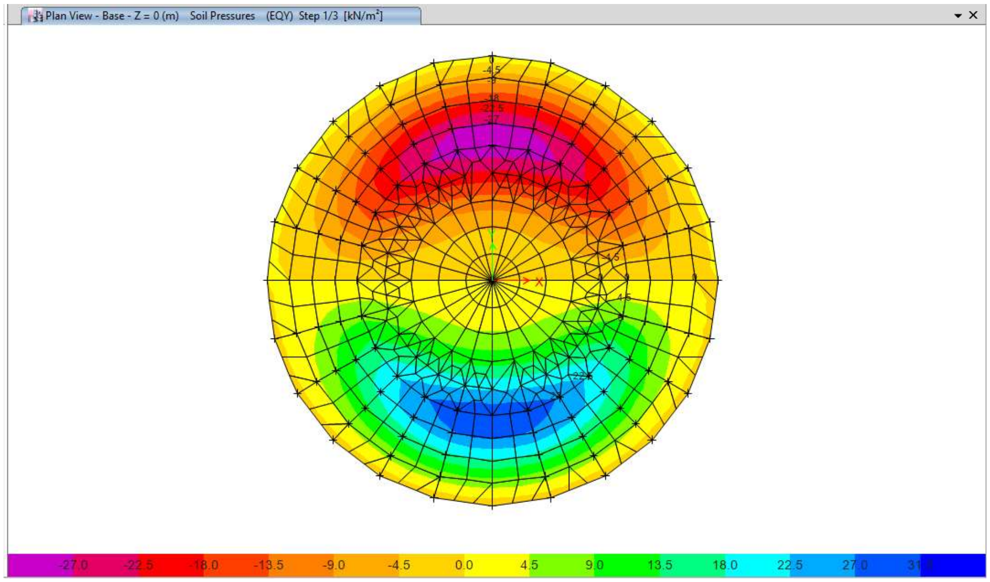

Figure 7.16. Soil Pressure for Earthquake in Y-direction

It can be concluded from above soil pressure diagram that for wind load we get the maximum soil pressure i.e. 11.4 t/m^2. So, for design a chimney wind load need be considered as the critical load.

7.4 RCC CHIMNEY UNDERLYING WITH STIFF CLAY

7.3.1 Displacement of the Chimney.

Figure 7.17 shows the displacement of the chimney when dead load is applied and has a maximum joint displacement as 5.79 mm in downward Z-direction at 90 m height of Chimney.

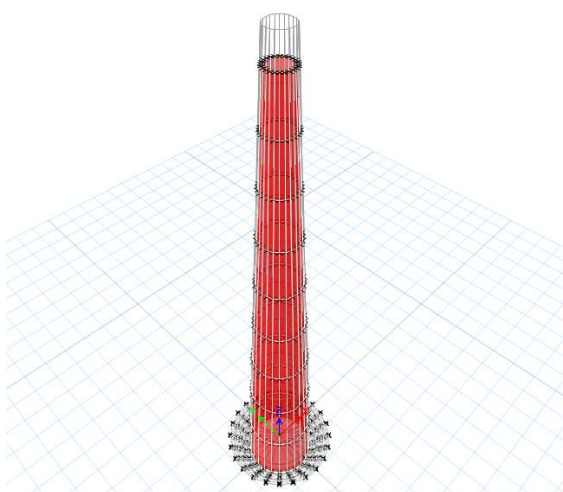

Figure 7.17. Displacement of the Chimney due to Dead Load

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When applied load is Wind, maximum displacement is 122.84 mm in the positive X-direction at a height of 90 m as shown in Figure 7.18.

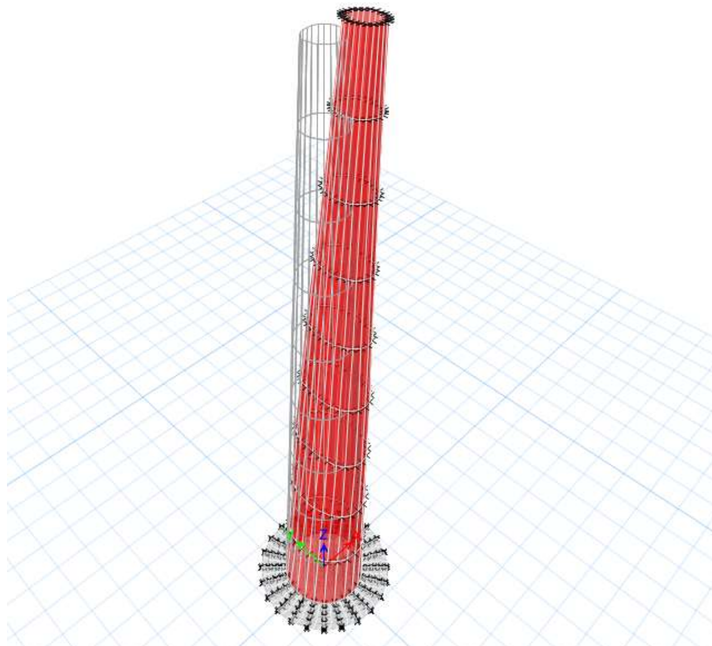

Figure 7.18. Displacement of the Chimney due to Wind Load

When applied load is earthquake in the X-direction, the maximum displacement observed is 37.21 mm in the positive X-direction at a height of 90 m as shown in Figure 7.19.

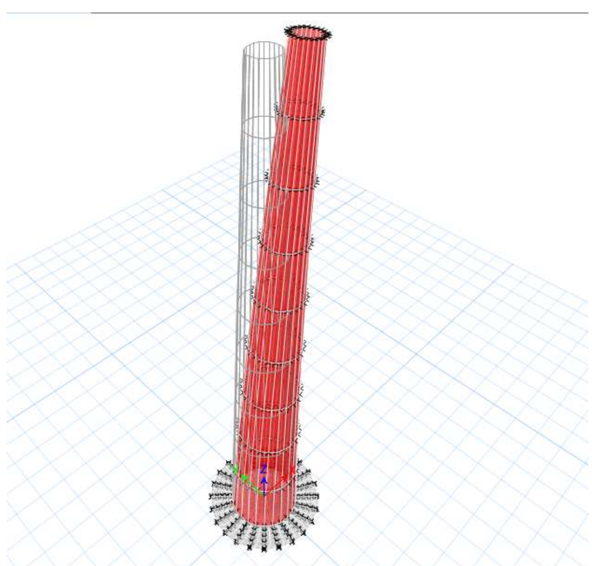

Figure 7.19 Displacement of the Chimney due to Earthquake Load in X-direction

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When applied load is earthquake in the Y-direction, the maximum displacement observed is 37.2 mm in the positive Y-direction at a height of 90 m as shown in Figure 7.20.

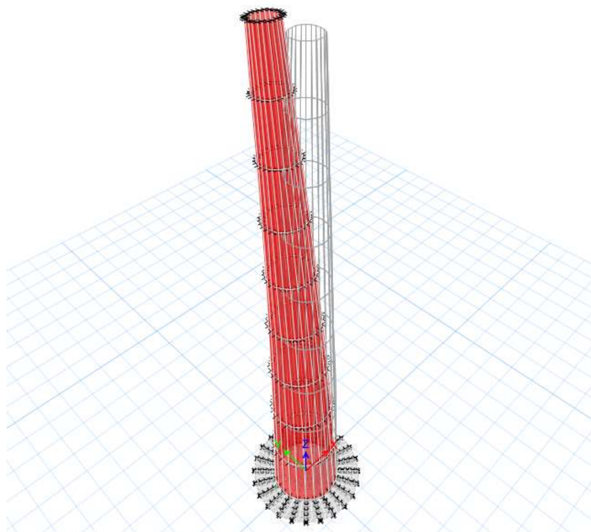

Figure 7.20. Displacement of the Chimney due to Earthquake Load in Y-direction

From Figure 7.17, 7.18, 7.19, 7.20 it is clear that displacement in the case of wind load is maximum for a chimney of height 90 m. So it can be said that wind load is the governing load for designing a chimney.

7.2.3 Soil Pressures of the Raft for different Load

Soil Pressure on the raft is shown by the contour diagram for the Dead Load as in Figure 7.21. Maximum soil pressure is 7.75 t/m^2.

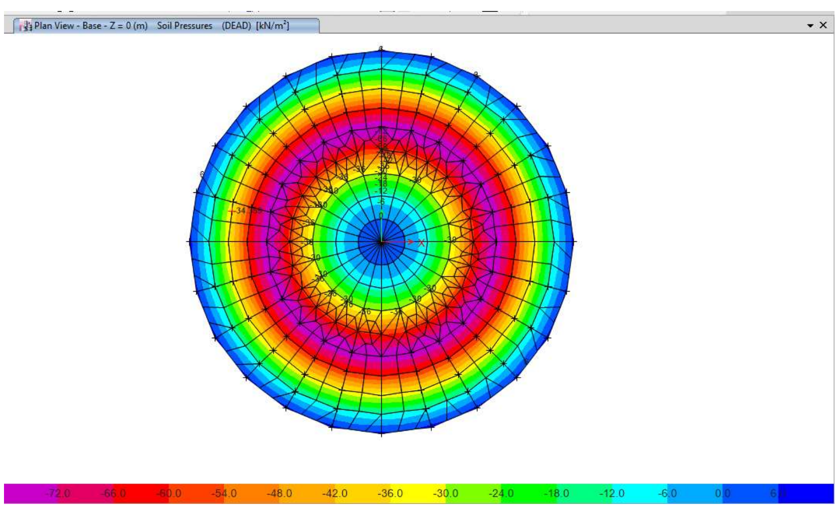

Figure 7.21 Soil Pressure due to Dead Load

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Soil Pressure on the raft is shown by the contour diagram for the Wind Load as in Figure 7.22. Maximum soil pressure is 14.84 t/m^2.

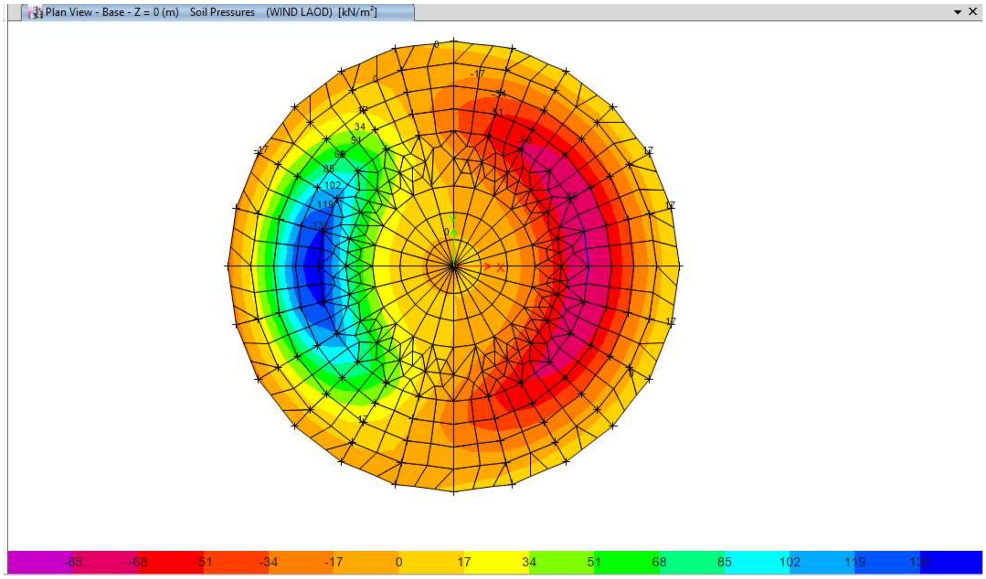

Figure 7.22 Soil pressure due to Wind Load

Soil Pressure on the raft is shown by the contour diagram for the Earthquake Load applied in the x-direction as in Figure 7.23. Maximum soil pressure is 3.21 t/m^2.

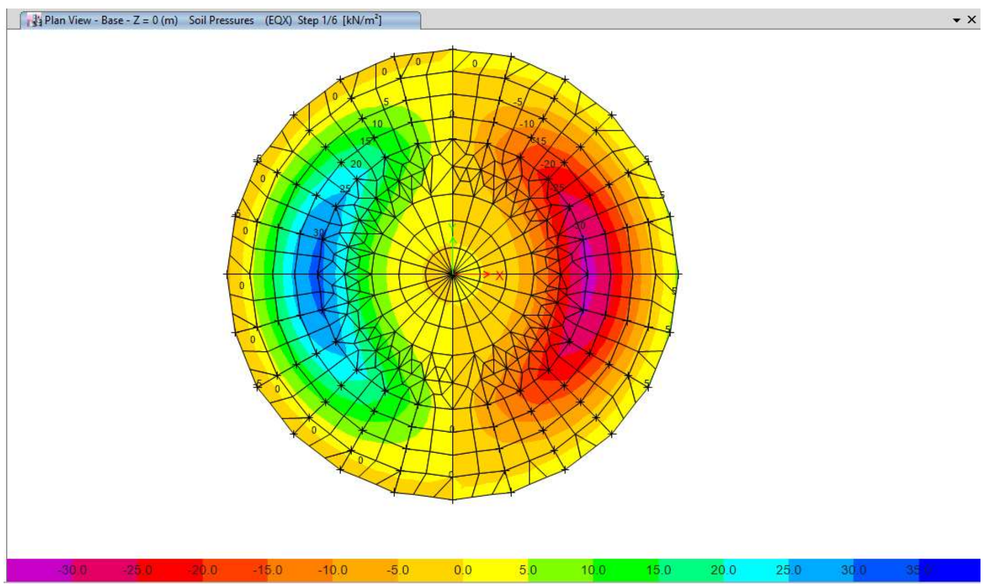

Figure 7.23 Soil Pressure due to Earthquake Load in X-direction

Soil Pressure on the raft is shown by the contour diagram for the Earthquake Load applied in the y-direction as in Figure 7.24. Maximum soil pressure is 3.21 t/m^2.

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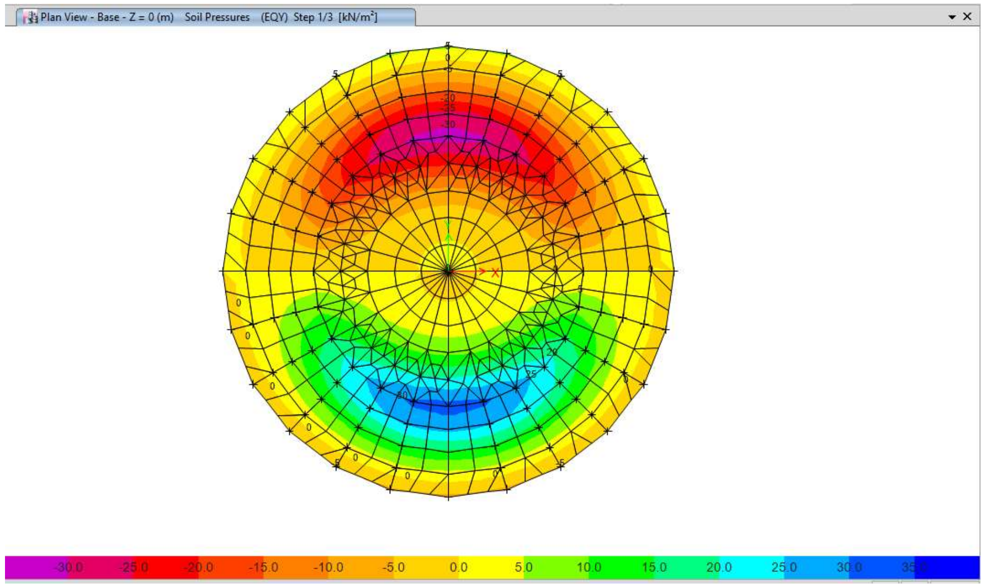

Figure 7.24 Soil Pressure due to Earthquake Load in Y-direction

It can be concluded from above soil pressure diagram that for wind load we get the maximum soil pressure i.e. 14.84 t/m^2. So, for design a chimney wind load need be considered as the critical load.

The bar chart as shown in Figure 7.25 shows the variation of displacement of the Chimney in the positive x- direction at a height of 90 m in the chimney for Loose Sand, Clay with Immediate Plasticity and Stiff Clay.

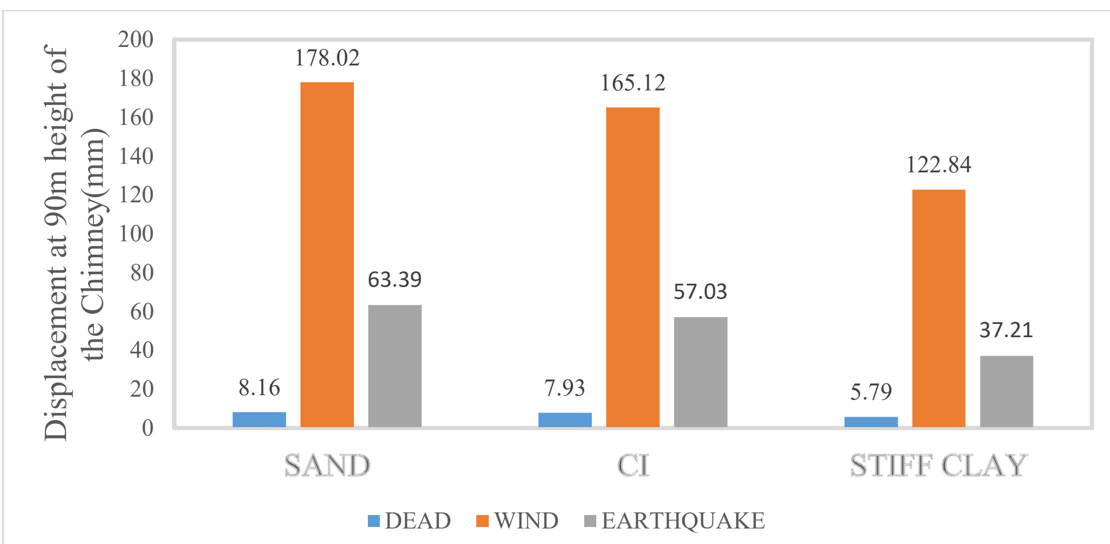

Figure 7.25 Displacement of the top of the chimney due to application of different of Loads and for different type of soil

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It can be seen from the Figure 7.25 as the load is changed from dead load, earthquake load and wind load the displacement in the chimney at the height of 90 m is increasing respectively, also as we are increasing the subgrade modulus of soil the displacement is decreasing for different loads.

The bar chart as shown in Figure 7.26 shows the variation of displacement of the Raft in the negative z- direction of the raft in the chimney for Loose Sand, Clay with Immediate Plasticity and Stiff Clay.

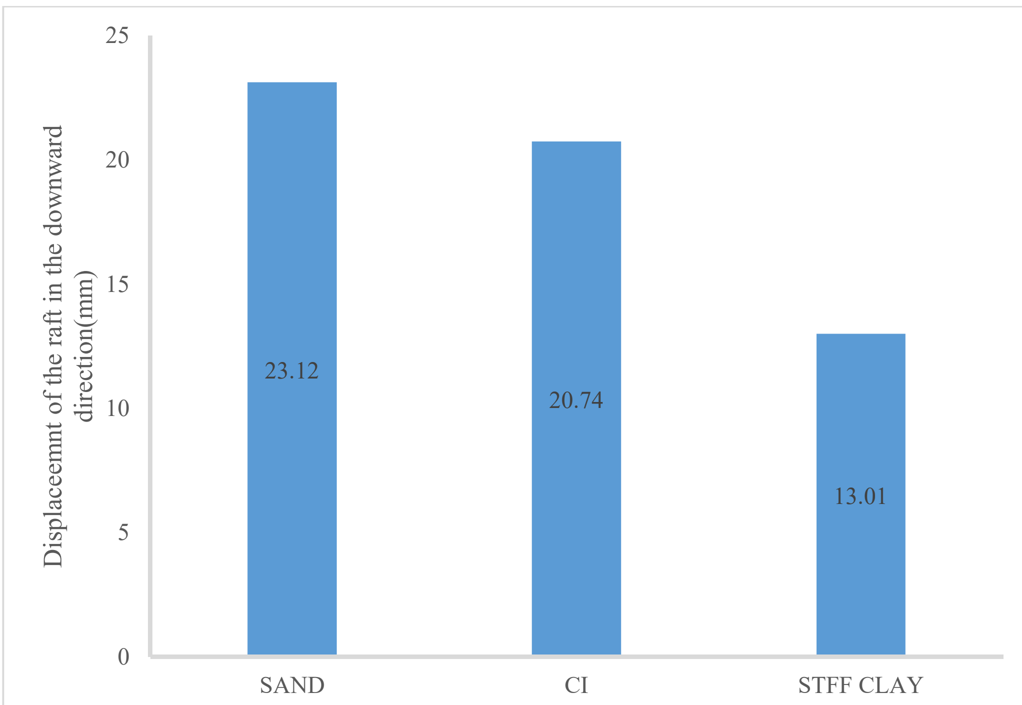

Figure 7.26 Maximum Displacement of raft due to combination of different Loads

Maximum displacement of raft has been shown in the Figure 7.26 which shows that as the soil is getting stiffer the displacement is decreasing in the raft.

Soil Pressure Variation of the raft in the soil for different load is shown in Figure 7.27.

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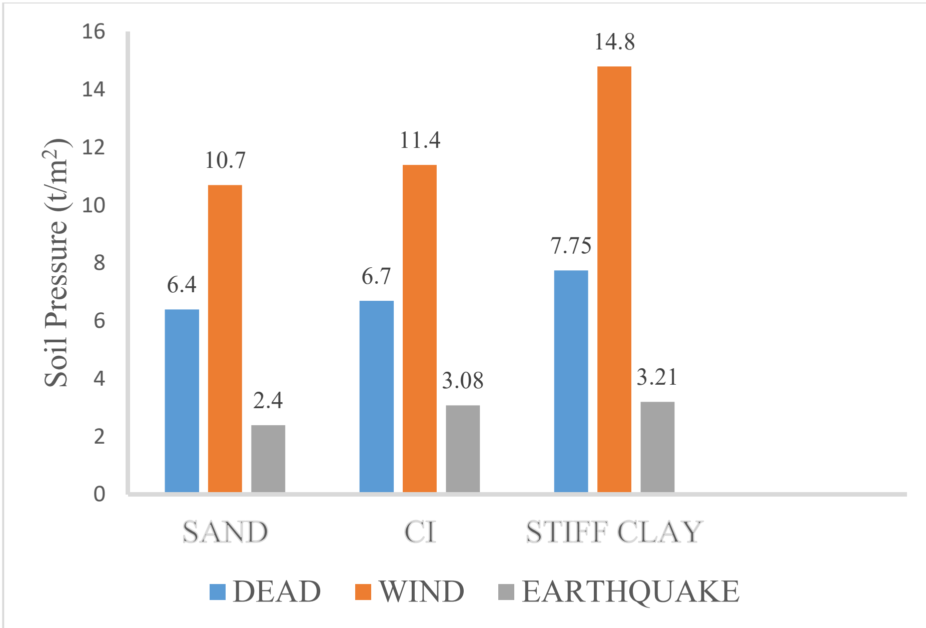

Figure 7.27. Soil Pressure for different type of Loads and for three different Type of Soils

Soil pressure variation has been shown in the Figure 7.27 which shows that maximum soil pressure is for wind load and least soil pressure is for earthquake load and as the soil is becoming stiffer soil pressure is increasing.

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CHAPTER 8

8.0 CONCLUSION

From the results it can be concluded that:

1. In the present study three loads were considered Wind Load, Dead Load and Earthquake Load. As seen from Figure 7.27, for sandy type of soil, soil pressure is maximum in case of wind load by 4.3 t/m^2 as compared to dead load and by 8.3 t/m^2 as compared to earthquake load. So it can be concluded that wind load is the critical load for designing an RCC Chimney of height 90 m.
2. Wind load is critical from displacement point of view also as it can be seen that wind load as maximum displacement of the chimney at 90 m height. As for Stiff Clay, wind load causes a displacement of 122.84 mm, for dead load and earthquake load top displacement is 37.21 and 5.79 respectively.
3. As the Subgrade Modulus of the soil is increased, the displacement at the top of the chimney decreases, so it can be concluded that for stiff clay, a chimney of greater height can be constructed.
4. As per IS Code Soil Pressure has been less than the soil pressure found by modeling the raft-soil system so it can be concluded that for dead, wind, and earthquake loads, the raft alone will not be able to withstand the loads we need to provide piles for loose soil i.e. for sandy type of soil.
5. As the soil becomes stiffer the raft alone can withstand the load without providing any piles, as the soil pressure which has been found from modeling (7.75 t/m^2 for Dead load) is less than the soil pressure (13.9 t/m^2) calculated as per IS Code.
6. For soil of lesser Sub-Grade Modulus, we need to construct a raft of greater diameter but for a stiffer soil, we can construct a raft of smaller size to dissipate the load.

8.1 FUTURE SCOPE

1. The chimney can be modelled by varying the height of the chimney and find a suitable height for a particular soil condition.

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2. The chimney of same height can be modelled and checked for the soil pressure by using piles by varying the soil properties.

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