ANALYSIS OF DIFFERENT TYPES OF RAFT FOR DIFFERENT SOIL CONDITIONS FOR A MULTI STORIED BUILDING

A project submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

STRUCTURAL ENGINEERING

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CERTIFICATE

This is to certify that this report entitled **"Analysis of Different Types of Raft for Different Soil Conditions for a Multi Storied Building"** is an authentic report of the Major project part-II done by the undersigned. This is a bona fide record of her own work carried by her under the guidance of Dr. Awadhesh Kumar in partial fulfillment of the requirement for the award of the Degree of Master of Technology in Structural Engineering at the Delhi Technological University, Delhi.

The matter embodied in this project has not been submitted for the award of any other degree.

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ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my project guide *Dr. AWADHESH KUMAR* for giving me the opportunity to work on this topic. It would never be possible for me to complete this project without his precious guidance and his relentless support and encouragement.

I would also like to present my sincere regards to my Head of Civil Engineering Department and faculty members, for their support and encouragement throughout the program.

I am also thankful to all my classmates for the support and motivation during this work. Last but not least, I specially thank all the people who are active in this field.

PRIYANKA SINHA
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ABSTRACT

Raft foundations are large inverted concrete slabs supporting superstructure through pedestals and walls. The choice of Raft slab can be made under following circumstances:

1) The bearing capacity of soil is low,
2) The columns are spaced so close that the isolated footings overlap
3) The column loads are heavy so that most of the area(>50%) is covered by spread footings.
4) At some locations, there is soft soil.

Raft foundations are best suited to use for deep basements, both to spread the column loads uniformly, and to provide basement floor slab. Raft foundations are useful in reducing the differential settlements and sustaining large variations in loads on the individual columns. In conventional analysis of raft foundation, the reactive soil pressures due to the loads from the structure is important as the raft is subjected to bending due to loads from the structure and also from the reactive pressure offered by the soil. These effects considerably alter the forces and the moments in the structural members. In the present work, analysis is carried out for six different types of raft(i.e., flat plate raft, slab beam raft, flat plate raft thickened under column, flat plate raft with pedestal, box type raft and pile raft) on six different soils. These raft foundations are analyzed by using SAFE-v12software for a fifteen storied building on six different soil conditions. This fifteen storied building of 3 bay x 3 bay is analysed to get base reactions under columns using ETABS software. The deflections, punching shear, shear force and bending moments obtained for these rafts on various soils are compared. The result indicates the significant effects of shape of the flat plate thickened under column and flat plate with pedestal raft in resisting punching shear is more efficient among these types. Box type raft and Beam slab raft is more efficient in resisting shear force and bending moments.

Chapter1
Introduction

1.1 General

As we know that, now a day's multistoried building are the most viable solution to the space constraints, especially in metropolitan cities. In multistoried buildings, loads are concentrated over a small area. Raft foundations are sometimes the most suitable foundation system for such type of structures. Raft foundation(also known as Mat Foundations) is a substructure supporting an arrangement of columns or walls in a row or rows and transmitting the loads to the soil by means of a continuous slab with or without depressions or openings.

1.2 Raft Foundation

Raft foundations are a large inverted concrete slab which can support a number of columns and walls. This is a footing that covers the entire area under the structure or at least a large part of it. This footing is used when very heavy loads of building are to be transmitted to the underlying soil. It is ideally suited where the foundation soil is having very low and differential bearing capacities. In comparison with spread footings, raft/mat foundations spread load of super structure over a large area, inducing pressure on soils which does not exceed its bearing capacity. Raft brings deeper soil layer in effective zone. Raft foundation equalizes the differential settlements. Due to its rigidity, it minimizes differential settlement. It is ideally best suited foundations for deep basements, because it can spread the structural loads evenly over a large area and provide rigid floor slab for the basement. Generally raft foundations are directly supported by the sub soil. Raft foundation lowers differential settlement, which is an additional considerable concern to the structural design of foundations. However in some situations, such as when ground water level is high or when foundation soil is prone to large settlements, raft foundations may be supported by piles also.

1.3 Requirements of Raft Foundations

Raft foundation is provided in following situations:

1. Bearing capacity of the sub soil is low.

2. Whenever building loads are so heavy or a allowable pressure on soil is so small that individual footings cover most of the floor area of a building.
3. In multistory structures, where basement is to be provided.
4. Columns of structure are closely spaced.
5. Below retaining walls.
6. In submerged structures.
7. Below chimneys, silo clusters and various tower structures.
8. When the soil is weak and difficult to assess the each weak pocket and cavities.
9. Building where basement is to provide below ground water table.

1.4 Objectives and Scope of Study

The object of the study is to conduct a comprehensive analysis on six different types of raft foundations for six different soil conditions. Behaviour of these different types of rafts have been compared. These rafts are analysed for a fifteen storied building loads. The building is modelled and analysed using ETABS software. For the modelling and analysis of these raft foundations, SAFE-v12 software is adopted. These all raft foundations considered in this study are square in plan. Effects of creep and consolidation on foundation behaviour were not considered. To study the behaviour of these rafts analysis is carried out and results are compared for overall settlements, differential settlement, punching shear, shear force and banding moments.

Chapter 2
Literature Review

2.1 Introduction

Foundations can be divided into two broad categories: shallow foundations and deep foundations. Shallow foundations transmit the structural loads to the near surface soils, whereas deep foundations transmit partial or all of the structural loads to deeper soils. Raft foundations alone behave as shallow foundations. Raft with piles, on the other hand, function as deep foundations. It is common to consider first the use of a shallow foundation system such as raft foundation in foundation design practice and then, if it is not adequate, to consider the use of a deep foundation system such as pile or cassion foundation. In a deep foundation system, the entire design loads are supported by the piles or cassion. When a raft foundation alone cannot satisfy the design requirements, it is possible to improve the performance of the raft by adding piles to the foundation system. Raft foundation are of various shapes or geometry. Some related studies on the behaviour of different raft foundations have already been made.

2.2 Theoretical and Experimental Studies

Tayade et al.(2014), attempted to study the raft foundation and raft with pile foundation on refilled manmade soil. He studied few possible alternatives of providing foundation on refilled strata which will serve as a guide to consider the parameters for construction of any structure on refilled strata in safe and economic way. To compare the settlement behavior of simple raft and piled raft , both the types of foundation were modeled in SAFE software. He compared the settlement of different points on a raft for different configurations of pile, some arbitrary points on raft selected and their total settlement and differential settlement with respect to each other were observed. After conforming the satisfactory properties of refilled soil, the type of foundation i.e. raft foundation, deep foundation, or piled raft foundation were adopted. As settlement is one of the major criteria to decide type of foundation and piles can be used as settlement reducers. It was found that the part of total load shared by raft goes on decreasing with increase in length of pile hence depending on the depth of refill the proper selection of depth for piled raft foundation is necessary.

Thulaseedharan et al.(2013) compared the performance of flat plate raft and folded plate raft foundation. The flat and folded raft models were analyzed using Winkler soil model with 3 values of modulus of sub-grade (ks) (12500, 25000 and 50000 kN/m²/m). The continuum analysis was carried out in two steps. In one step, E was the only variable with values of 15000, 30000 and 60000kN/m². In the second case, E and ϴ were varied for analysis with Mohr-Coulomb model. Variations of base pressure, settlement below raft, Bending Moment(BM) in rafts, Shear and Impact of raft projections were studied. Staad Pro 2008 version and SAFE 2009 version softwares were used to model the Winkler Foundation. Continuum modeling was carried out using Abaqus 2011 version, Plaxis 3D 2004 version and Staad Pro 2008 version. They found that maximum top and bottom moments were found to reduce with increase in 'ks' values for both flat and folded plate foundations. Winkler method is sufficient for the design of flat rafts and in the case of folded plates, lateral stiffness of soil needs to be considered in the analysis. As the fall of the folded raft increases, settlement reduces due to the increase in stiffness of foundation.

Dubey et al. (2013), studied various type of foundations to select the best one suitable for black cotton soil of Jabalpur area for the construction of multi-storied building with technical as well as economical parameters. A study has been conducted on black cotton soil samples taken from two different localities. In first phase, index properties of normal soil from laboratory test according to IS codes were determined. These index properties again tested by adding 4% and 6% lime. A Ground + 5 floors structure was considered and analysed in Struds software. In case of expansive soils, it was suggested to go for raft foundation. The other option was ground improvement but economy has to be checked among available options of going deep foundation or ground improvement or raft foundation.

Reese et al. (1993), Sommer (1993) and Yamashita et al. (1993) indicated that the piled raft foundations can reduce the overall settlement and differential settlement. Yamashita, et al. (1994) conducted study on a pile-supported-raft foundation supporting a five-storey building and found that a piled raft foundation on stiff clay at large spacing is also effective in reducing the total and differential settlements. Through several field studies, the behaviour of pile-supported-raft foundations has been increasingly understood. Also, it is commonly recognized that the use of a pile-supported-raft foundation can be an economical solution to reduce foundation settlement.

Wiesner and Brown (1980) performed some laboratory tests on four model pile-supported-raft foundations in a large circular pot having an internal diameter of 590 mm and a depth of 480 mm, the pot was filled with over consolidated clay. The rafts were made of brass plates, and the piles were solid brass rods and solid Perspex rods. The rafts were connected to the piles with brass screws through holes in the raft. The raft was in direct contact with the surface of the clay. It was assumed that the connection between the raft and piles cannot transfer moment. The load was applied to the rectangular rafts by a loading device. They determined that, for a pile-supported-raft foundation, the load is actually shared between the piles and raft. The results of settlement and moment data obtained from these laboratory tests were compared with the results determined from theoretical analysis, in which the Young's modulus values were obtained through back calculation from the test results of piles supporting small rigid circular raft. The comparison indicated a satisfactory agreement between the experimental and theoretical data over the range of loads tested.

Yamashita et al. (1994) conducted field monitoring of a pile-supported-raft foundation on stiff clay with piles at large spacing to support a five-storey building structure. The piles in the foundation system were designed to be fully mobilized under working load condition. The field test showed that the foundation system was very effective in reducing both the overall and differential settlements. At the time of completion of the building, the total settlement reached about 10-20 mm and the load carried by the piles on the tributary area reached 49% of the total building load. Kuwabara's (1989) research indicated that settlement reduction due to the presence of the raft is very small although the raft transmits 20-40% of the applied load directly to the soil.

Based on the studies on large buildings in London, Cooke (1986) stated that up to 30% of the building load is carried by the raft, even when it is assumed in the design that the entire building load is carried by the piles. His research data further indicated that, while rafts are less likely to contribute more than 30% of the support. But, considerable contribution of the raft to the ultimate bearing capacity of the foundation can be expected. Furthermore, Cooke's model tests suggested that pile spacing could be increased and the numbers of piles substantially reduced without a significant increase in overall settlements. Cooke also observed that the load distribution between piles in piled raft foundations depends on the number and spacing of piles. He observed that settlement at the centre of the raft foundation is larger than those at the edges of the raft.

There is a need to understand the general behaviour of different types of raft foundations in a broad range of field conditions with soil having different modulus of sub-grade(ks) and soil bearing pressure values.

2.3 Considerations for Design of Raft Foundation

Many factors must be considered in the design of raft foundations. These considerations include following:

1. Ultimate load capacity
2. Maximum settlement and differential settlement
3. Raft moments and shears for the structural design of the raft

2.4 Considerations for Design of Pile Raft Foundation

The most effective application of the pile-supported-raft foundation is when the raft has to provide adequate load capacity, but the settlement and/or differential settlement of the raft alone exceed allowable values. After examining a number of idealized soil profiles, Poulos (1991) has found that the favourable situations in which to use pile raft foundation system are when the soil profiles consist of relatively stiff clays and/or dense sands. Meanwhile, the unfavourable situations for such a foundation system are when the soil profiles contain soft clays or loose sands near the surface, or soft compressible layers at relatively shallow depths, or when the soil profiles will likely undergo consolidation settlement or swelling movements due to external causes. However, some of these unfavourable situations can be easily eliminated by excavations.

The pile group contains short and long piles. The short piles are constructed of flexible materials such as soil-cement columns or sand-gravel columns, and are used mainly to strengthen the shallow soft soil; the long piles, which are made of relatively rigid materials such as concrete, and are mainly for reducing settlement.

Poulos (2001) suggested a rational design procedure that involves the following three stages:

1) The first stage is to assess the feasibility of using a piled raft, and the number of piles required to satisfy design requirements.
2) The second stage is to assess where piles are required and the general characteristics of the piles.
3) The final stage is to determine the optimum number, location, as well as configuration of piles.

2.5 Design Criteria

In the practice of foundation design, the most important criteria to be considered are allowable total (overall) settlement, allowable differential settlement, and ultimate bearing capacity. Therefore, it is necessary to have a clear understanding of the design criteria in order to achieve the ultimate objectives of the foundation.

2.5.1 Total settlement

Total settlement is defined as the magnitude of downward movement of the building structure. Many structures can tolerate substantial downward movement or settlement without structural damage or collapse.

2.5.2 Differential settlement

Differential settlement is defined as the difference in vertical movement between various locations of a building structure. Differential settlement, which causes distortion of and damage to structures, is a function of the uniformity of the soil, stiffness of the structure, stiffness of the soil, and distribution of loads within the structure. Similar to total settlement, limitations to differential settlement also depend upon the function and type of structure.

2.5.3 Ultimate bearing capacity

The function of a foundation is to transfer structural load to soils on which it is rests. A well designed foundation should transfer the structural load throughout the soil without overstressing the soil. Overstressing the soil can result in either excessive settlement or shear failure of the soil, both of which will cause damage to the structure. Thus, evaluating the bearing capacity of the foundation system is vitally important for foundation designs.

2.6 Depending on the Structure and Soil Encountered, Various Types of Foundations

1) If the structure load is less and soil is medium to dense, then shallow foundation is provided,
2) If the structural load is high and soil is loose then deep foundation or raft may used,
3) If the footing area is greater than 50 percent of plinth area, raft foundation may be used,
4) If the structure load is high and the foundation is constructed in running water like river, stream, channel, etc then well foundation may be provided,
5) If the soil is expansive (i.e., shows swelling and shrinkage). Hence, floating foundation/balanced foundation or under rammed pile may be provided and
6) If the soil is loose saturated sand which is prone to liquefaction then compaction pile may be provided.

2.7General Requirement of a Foundation

A foundation must be able to satisfy deformation and stability requirements as:

i. Depth of foundation must be sufficiently below the zone of seasonal volume changes in soil by freezing, thawing and plant's root growth.
ii. It must be safe against sliding, overturning, soil rupture and rotation.
iii. It must be safe against deterioration due to harmful elements present in soil specially in the area of sanitary landfills and marine beds.
iv. The foundation and its construction process should meet environmental protection standards.
v. The foundation should be economical in terms of the method of installation and maintenance.
vi. Total or differential settlement of foundation must be within tolerable limits for the superstructure and foundation elements.

2.8 Classification of Footings

The type of footing for any particular structure is influenced by many factors. These main factor are: the strength and compressibility of various soil strata at the site, the magnitude of the column load, the position of water table and the depth of footing of adjacent buildings.

We can classify footingsaccording to their depth as follows:

- **Shallow footings**: This type of foundation transfer super structure's load to the soil at a lesser depth below the existing ground level. Depth(D) is usually less then or equal to the width(B) of foundation(i.e., $D \leq B$) according to Terzaghi. But, according to Skempton depth of foundation is less than 2.5 times its width (i.e., $D \leq 2.5B$). It provides base resistance.
- **Deep footings**: These foundations transfer super structures load to a greater depth. Geotechnical engineers suggests deep foundations over a shallow foundation because of many regions. These regions may be presence of poor soil at a shallow depth or due to heavy loads of the structure. If depth of foundation(D) is more than four to five times the width of foundation(B).Those foundations are known as deep foundations.

Various types of footings can be broadly classified as shown in Fig. 2.1

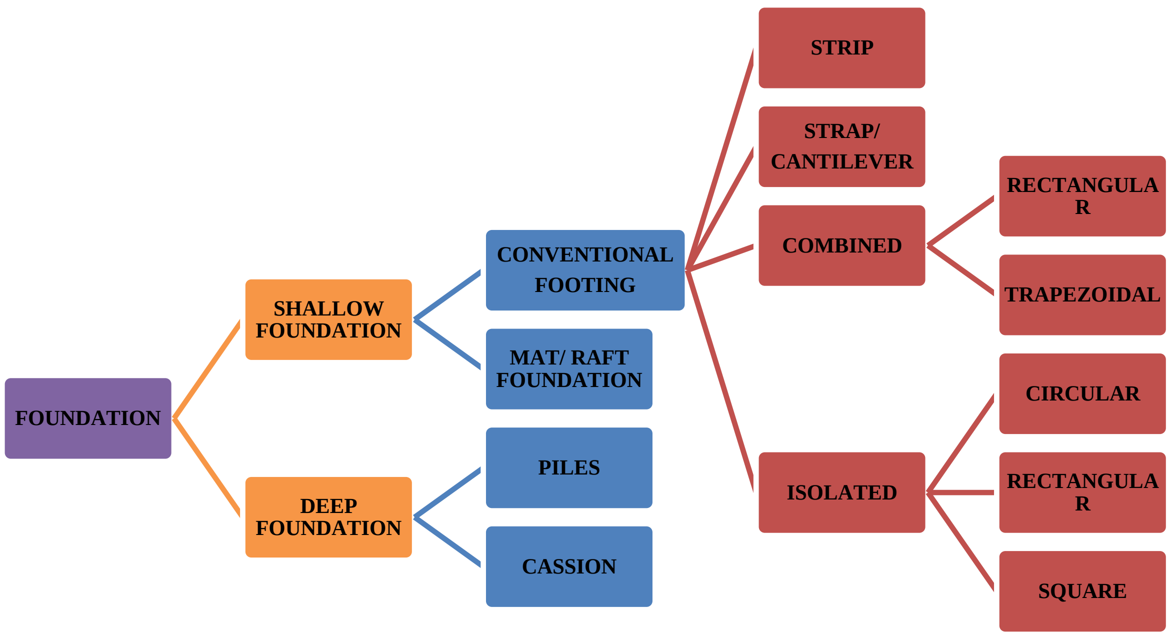


Figure 2.1: Classifications of foundations

❖ **<u>Conventional footing</u>:** These are further classified as**:**

1) **Strip Footing:** A strip footing is used or provided below load bearing walls or below a row of closely spaced columns. In these cases , it is economical to provide strip footing in place of providing isolated footings in a line. Continuous footing is also a name of strip footing. The plan and elevation view of a strip footing is shown below in Fig. 2.2

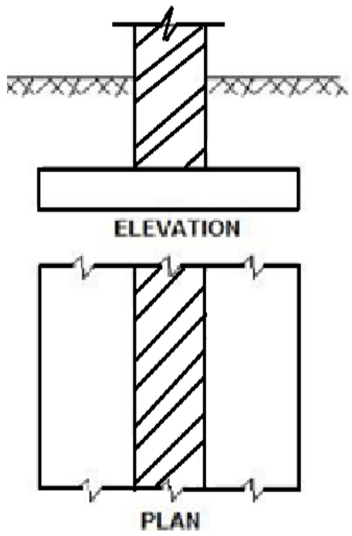


Figure 2.2: Plan and elevation of strip footing

2) **Strap / cantilever Foundation:** In case of strap footing, two isolated footings are connected with a rigid beam or strap of RCC so that they will behave like a single unit. This footing is provided where one column is at boundary and other one is farther inside the building. The plan and elevation view of strap/cantilever footing is shown in Fig. 2.3.

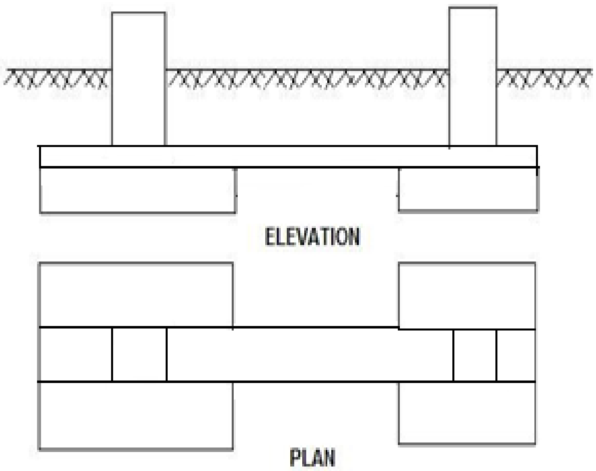


Figure 2.3: Plan and elevation of strap/cantilever footing

3) **Combined footing:** It is used to support generally two or more columns on a single foundation. It is of two types i.e., rectangular or trapezoidal. It is necessary to provide combined footing when

- Two columns are at a close spacing so that there will be overlapping of their individual footing,

- Property line is very close to a column. So, to avoid projection beyond the property line, combined footing is provided.

  The plan and elevation view of a combined footing is shown in figure 2.4.

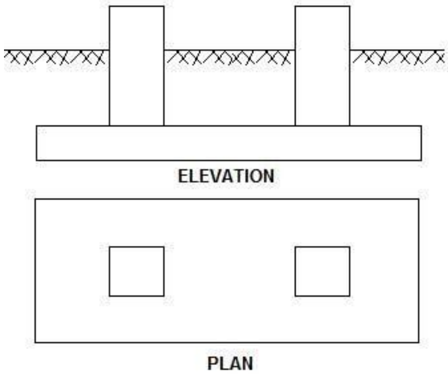


Figure 2.4: Plan and elevation of combined footing

Isolated or spread or pad footing: This type of footing supports a single column. It distribute the column load to an area of soil around the column. Isolated footing are of various types, i.e. rectangular, square, circular of uniform thickness. sometimes, isolated footings are hunched or stepped type alsoto spread the load from a heavily loaded column. The plan and elevation view of an isolated footing is shown in figure 2.5.

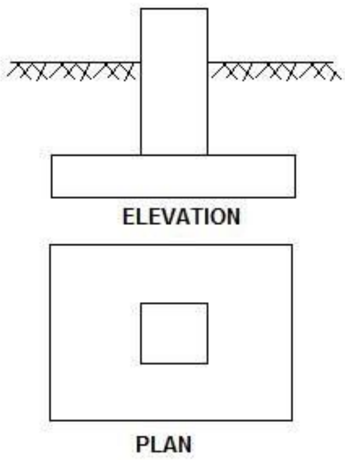


Figure 2.5: Plan and elevation of isolated/spread footing

- **<u>Mat/ Raft foundation</u>:** A raft foundation is a type of shallow foundation. It is a large inverted concrete slab used to support one or more than one column in several rows and walls as a single unit. It may be on only a portion or the entire foundation area. These foundations are mostly used below multi-storied buildings, retaining walls, chimneys, overhead water tanks, several industrial equipments, silo clusters and various tower structures. This foundation is broadly explained in chapter-3

  .

❖ **<u>Pile foundation:</u>** Pile foundation comes under the category of deep foundations. A pile is a cylinder column like structure made up of concrete, wood or steel. It is a costly type of foundation because of its construction and installation procedure. Therefore, this type of foundation is used in case of very poor soil and very heavy loads. The plan and elevation view of a pile foundation is shown in figure 2.6.

Classification of pile foundation:

a. Based on load transfer:
   - Friction piles
   - End bearing piles
   - Friction cum end bearing piles.

b. Based on construction method:
   - Precast driven piles
   - Driven and cast -in-situ piles
   - Bored and cast-in-situ piles

c. Based on function or purpose:
   - Compression piles
   - Tension piles
   - Anchor piles
   - Batter piles
   - Dolphin and fender piles

d. Based on material used:
   - Concrete piles
   - Steel piles
   - Timber piles
   - Composite piles

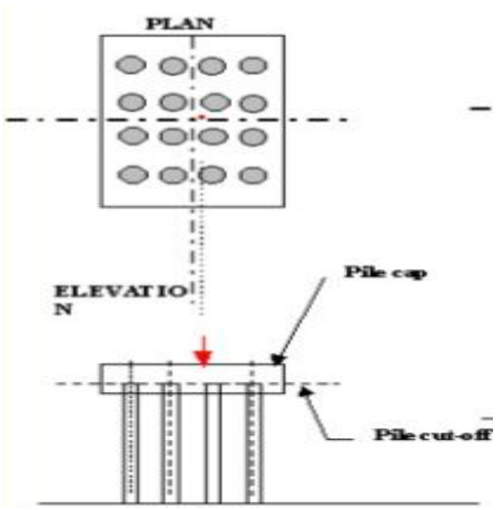


Figure 2.6: Plan and elevation of pile foundation

❖ **<u>Cassion Foundation</u>**: It is a type of deep foundation. These foundations are generally provided where there are more chance of scouring like, bridges. This type of foundation is used since Roman & Mughal periods. Sectional view of different types of cassion foundation is shown in figure 2.7.

Cassions foundations classification:

- Box cassions : this type of cassion foundations are closed at bottom and open at the top. It is generally made of reinforced concrete ,steel or timber.
- Open cassion (wells): this type of cassion foundation is opened at top and bottom both. These are also made of either reinforced concrete, steel or timber. It is commonly known as well foundation. In India, it is most common type of foundation for bridges.
- Pneumatic cassions: lower end of this type foundation is designed as working compartment/chamber. To prevent the entry of water, compressed air is forced into it, so that excavation can be done in dry conditions.

  The common types of shapes of well are:
  - Single circular
  - Twin circular
  - Dumb well
  - Double-D
  - Twin hexagonal
  - Twin octagonal
  - Rectangular.

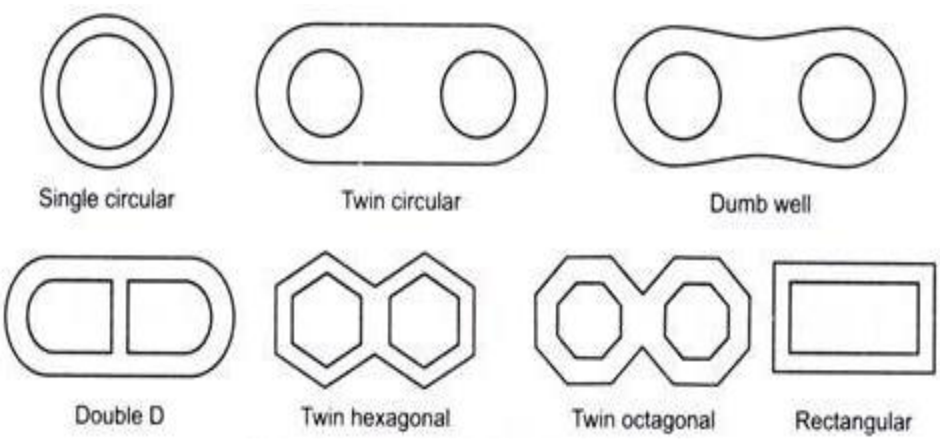


Figure 2.7: Sectional view of cassion foundation

Chapter 3
Raft Foundation

3.1 General

In the construction industry, various types of foundation are used. Mat foundation is considered as the most secure foundation, because there is no space left for differential settlements and the whole raft act as an inverted slab for the whole structure. Sometimes due to types of buildings, space limitations and economic reasons, it is not used and then substituted by other types of foundations.

Raft foundation is a special combined footing that may cover the entire area under a structure supporting several columns and walls. Mat foundations are sometimes preferred for soils that have low load-bearing capacities but that will have to support high column and/or wall loads. It is recommended to use under some conditions when, spread footings would have to cover more than half the building area, and mat foundations might be more economical.

3.2 Types of raft foundation

Some of common types of raft foundation include the following:

1) **Flat plate Raft:** This type of mat is having uniform thickness throughout its span. This raft is most suitable when column loads are relatively light and the spacing of column is relatively small and uniform. Plan and sectional view of Flat plate raft is shown in fig-3.1.

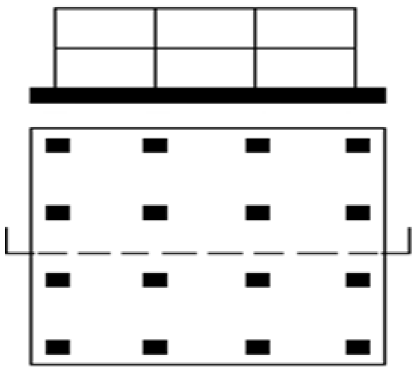


Fig-3.1: Flat Plate Raft

2) Flat plate raft thickened under columns: When the column loads are heavy, this type is more suitable than flat plate type of raft. A portion of slab under the columns is thickened to provide enough thickness for negative bending moment and to resist two way shear. Plan and sectional view of flat plate raft thickened under column is shown in fig-3.2.

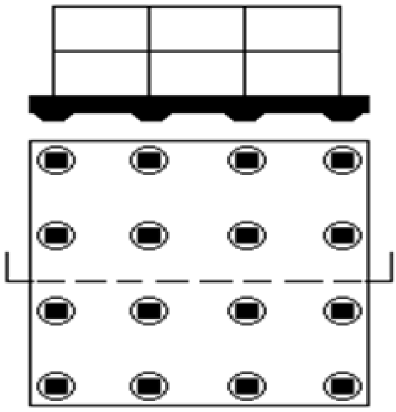


Fig-3.2: Flat Plate Raft Thickened Under Column

3) **Slab and Beams raft:** In this type of raft, beams run in two perpendicular directions along column to column line and a slab is provided beneath the beams and the columns are located at the intersection of the beams. Plan and sectional view of slab beam raft is shown in fig-3.3.

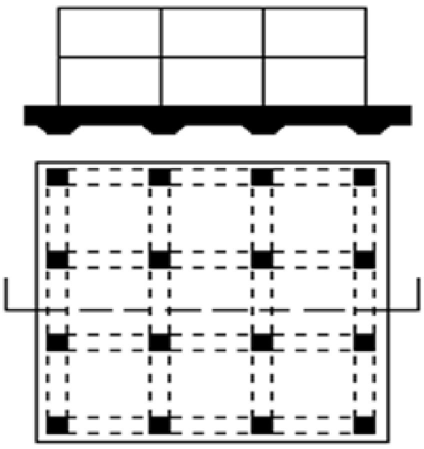


Fig-3.3: Slab and Beam Raft

4) **Flat plates with pedestals:** In this type of raft a pedestal is provided under each column above the slab to increase the depth of raft. It provides a better section below column to sustain two way or punching shear. Plan and sectional view of flat plates with pedestals raft is shown in fig-3.4.

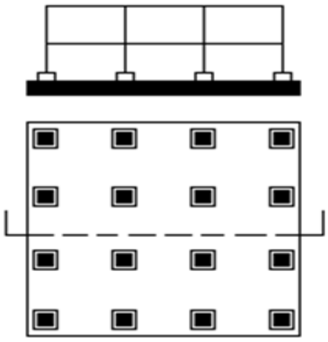


Fig-3.4: Flat Plates with Pedestals

5) **Box type Raft:** Slab with basement walls as a part of the mat, where the walls act as stiffeners for the mat. In this type of raft foundation a box structure is provided in which the basement walls act as stiffeners for the mat. Boxes may be made of cellular construction or rigid frames consisting of slabs and basement walls. This type of raft foundation can resist very high bending Stresses. Plan and sectional view of box type raft is shown in fig-3.5

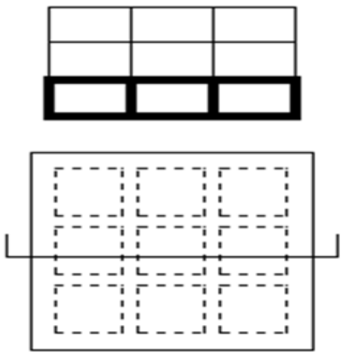


Fig-3.5: Box Type Raft

6) **Raft placed on piles:** Mats may be supported by piles. The piles help in reducing the settlement of a structure built over highly compressible soil. Where the water table is high, mats are often placed over piles to control buoyancy. Pile raft is shown in fig-3.6.

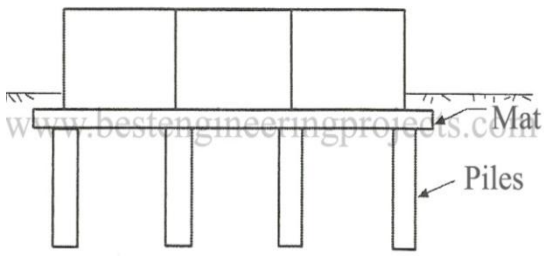


Fig-3.6: Pile Raft

3.3 Different Approaches for the Analysis and Design of Raft Foundations

1. **Conventional Approach**: it is further classified into two types:
   i. Conventional rigid approach
   ii. Approximate flexible approach
2. **Finite Difference Method**
3. **Finite Element Method**
4. **Finite Grid Method**

1(i) Conventional rigid approach: In this approach, it is presumed that rigidity of raft is infinite or so high to overcome non uniformities of soil structure. It is considered that the pressure distribution is uniform.

There are two methods suggested for the design and analysis of conventional rigid raft:

A) inverted floor system

B) combined footing method

This method can be used if either of these following condition is satisfied:

A) The column spacing is less than 1.75/λ.

B) Due to the combined action of foundation and the superstructure, the structure behaves as rigid with a relative stiffness factor 'k'>0.5

In case of rigid rafts, it is assumed that there is almost negligible chances of differential settlements. In this method mat is divided into strips both ways and each strip is analysed individually as an independent beam with a line of column loads and resisted by contact pressure. This method is not recommended now a days because of substantial amount of approximations in it.

1(ii)Approximate flexible approach:

ACI Committee 336(1988) suggested this method, in this approach it is assumed that the soil is equivalent to infinite number of independent elastic springs. The equivalent spring constant of these elastic springs is equal to the soil's coefficient of sub grade reaction(ks). It is also known as Winkler's foundation. At any point contact pressure is proportional to the settlement at that point.

Modulus of sub grade reaction(ks): Measure of stiffness of the sub-grade, it is defined as load per unit area causing unit deflection.

ks = q/ **D**H

where,

ks= Modulus of sub grade reaction (kN/ cm^3)

q = Base contact pressure.(kN/cm^2)

DH = Total estimated foundation settlement (cm)

Modulus of sub grade reaction is determined by plate load test and plotting a graph between soil pressure V/s deflection.

Factors influencing modulus of sub grade reaction are as follows:

- Size of Footing,
- Shape of footing and
- Depth of footing.

According to IS: 2950(part-I)-1981, suggested values of modulus of sub grade reaction are given in Tables 3.1 and 3.2.

Table-3.1: Modulus of sub grade reaction (ks) for cohesion less soils

CHARACTERISTIC OF SOIL		*MODULUS OF SUBGRADE REACTION (ks) in kg/cm^3	
Relative Density	Standard penetration Test (N)	For dry or moist soil	For submerged soil
Loose	<10	1.5	0.9
Medium	10 to 30	1.5 to 4.7	0.9 to 2.9
Dense	>30	4.7 to 18	2.9 to 10.8

(* The above values apply to square plate of 30 x 30 cm or to 30 cm wide beams.)

Table-3.2: Modulus of sub grade reaction (ks) for cohesive soils

CHARACTERSTIC OF SOIL		*MODULUS OF SUBGRADE REACTION (ks) in kg/cm^3
Consistency	Unconfined Compressive strength in kg/cm^3	For dry or moist soil
Stiff	1 to 2	2.7
Very stiff	2 to 4	2.7 to 5.4
Hard	>4	5.4 to 10.8

(*The values applies to square plate of 30 x 30 cm. The above value are based on assumption that the average loading intensity does not exceed half the ultimate bearing capacity.)

2. Finite difference method:

It is reliable and rapid method because input data are minimal as compared to any other discrete method. Computation of stiffness array is not so broad or extensive as other methods. But, it is difficult to model boundary conditions of fixity of column and application of concentrated moment from a column.

3. Finite Element Method(FEM):

Finite element method is a computer oriented method. It transforms the analysis of plates on elastic foundation into a matrix structural analysis. In this method, plate is idealized as a mesh of small finite elements inter-connected at the nodes/corners, and the soil is modeled as a set of isolated elastic springs. The element continuity is maintained via the use of displacement functions. This method can include the influence of the super-structure also. Therefore, the interaction between the super-structure, and the sub structure (i.e., foundation) and the soil may be accounted for. It is possible to apply different values of the sub-grade modulus in various zones below the raft foundation. It is considered that the raft is consist of beams in both perpendicular directions. Each element of these beams is supported on spring constant calculated using modulus of sub grade reaction and carrying column loads. Its methodology uses advanced mathematical concepts. Therefore, identification of incorrect output is somewhat difficult for structural engineers. It takes about 4 times as long to run a problem of reasonable length as the Finite Grid method(FGM).

4. Finite Grid Method(FGM):

Finite grid method is best well suited method for the analysis of plates and rafts/mats.

It is easy to get design shear at the elements end and the shear is the sum of end moments of the elements divided by the length of the elements. boundary cases can be easily modeled. We can easily input column moments directly. interpretation of output is easy because of the beam column type elements . the moment per unit width is nothing but the node moment.

Chapter 4
Analysis of Various Type of Rafts

4.1 General

This chapter covers the description and details of different types raft foundation to be analyzed for different soil conditions for a fifteen storey building loads. These different rafts are analysed and checked as per the IS 456:2000 specifications in SAFE-v12 software. It also covers the description and details of the superstructure i.e. fifteen storey RCC building, which is considered for loading on different types of rafts.

4.2Object of study

In this report, efforts have been made to explain the behavior of6 different types of raft foundation on six different soil conditions for a fifteen storied residential building. These foundations are analyzed by using SAFE-v12 Software. In the present work, analysis of six different types of raft foundations on six different soil types is carried out. A fifteen storied building of3bay in longitudinal direction and 3 bay in transverse direction is analysed to get base reactions and moments under columns in ETABS software. Limit state method is considered for the analysis of the super structure as well as for the analysis of the raft foundations. All six type of rafts are analysed for the support reactions and moments coming from superstructure, for all 6 different soil conditions. The results of deflections(overall settlement as well as differential settlement), punching shear(i.e. two way shear), shear force and bending moments obtained for these 6 types of rafts foundations on various soils are compared.

4.3 Building plan considered for loading on rafts

A typical fifteen storey building, in Delhi, Zone-IV, with 3 bay in the longitudinal direction and 3 bay in transverse direction has been considered in the present study. Centre-to-centre distance between columns is 7 m in both perpendicular directions. Cross-sectional dimension of columns are 600x 600mm. The dimensions of proposed building is21.6m x 21.6m in plan. The floor-to-floor height of the super structure is 3.0m each. Cross sectional dimension of the main beams are 450x600mm and secondary beams are of size 350 x 600mm. This building is having 16 R.C.C. columns and 0.23m thick external and internal walls of brick masonry. Thickness of RCC slabs are 125mm. Live load considered on each floor is 3 kN/m²and live load on terrace is 1.5 kN/m². The grade of concrete used is M25 and that of steel is Fe415.The building is modeled in ETABS software, for analysis, as shown in fig. 4.1(a) and its plan and 3-D view are shown in fig 4.1(b).

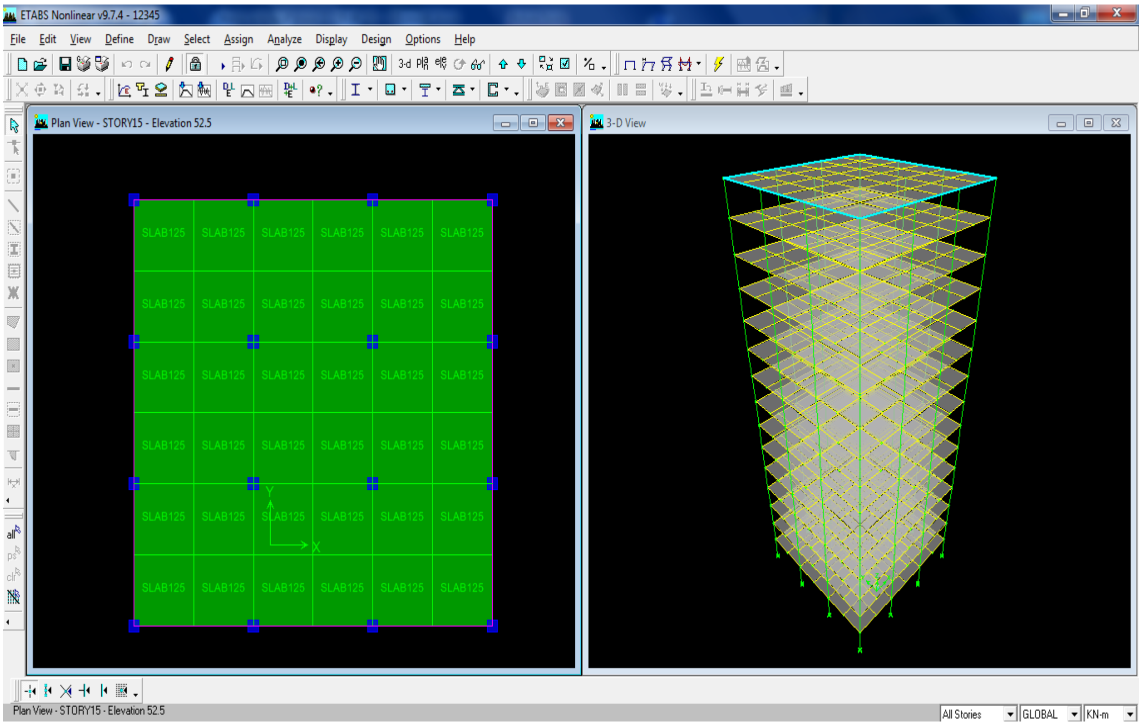


Fig-4.1(a): Modeling of 3 x 3 bay, 15Storied building in ETABS.

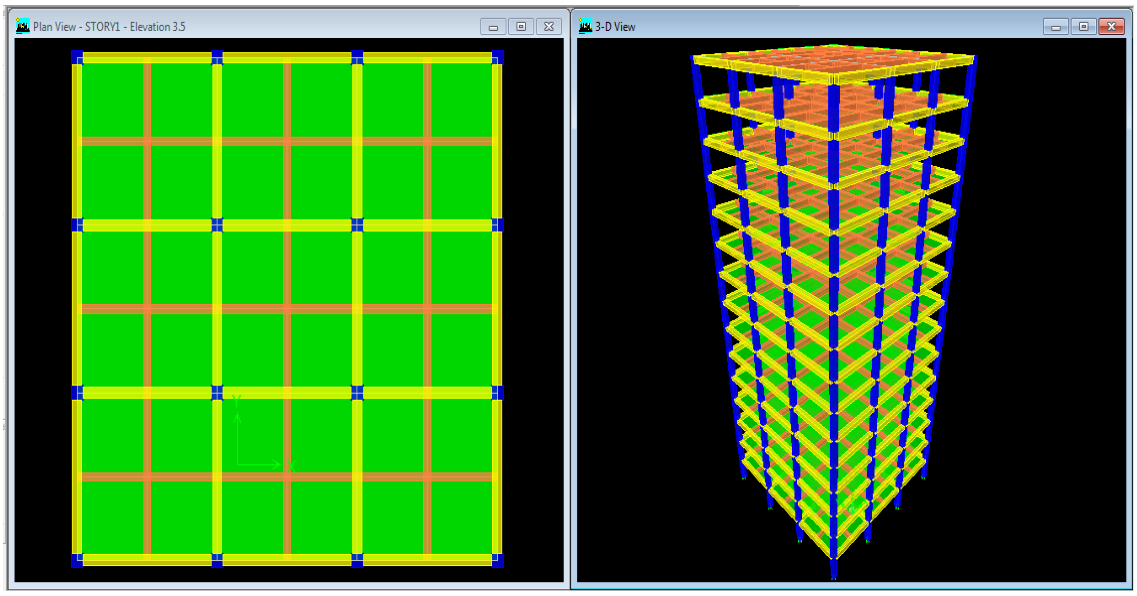


Fig-4.1(b): Plan view and 3-D view of 15 storied building

Node number of the base point of columns of the building model in ETABS software is shown in figure 4.2(a).

Figure 4.2(b) shows plan of the column positions on raft with column numbers(Cx), where x varies from 1 to 16. Centre-to-centre dimensions between the columns is also shown. All columns are of cross sectional dimension 0.6m x 0.6m.

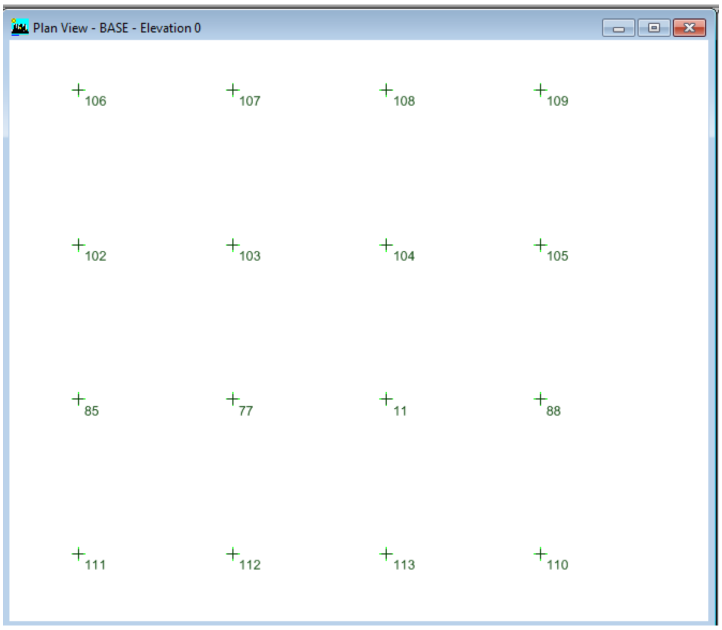


Fig-4.2(a):Planshowing node no. of base of columns of the superstructure in ETABS model.

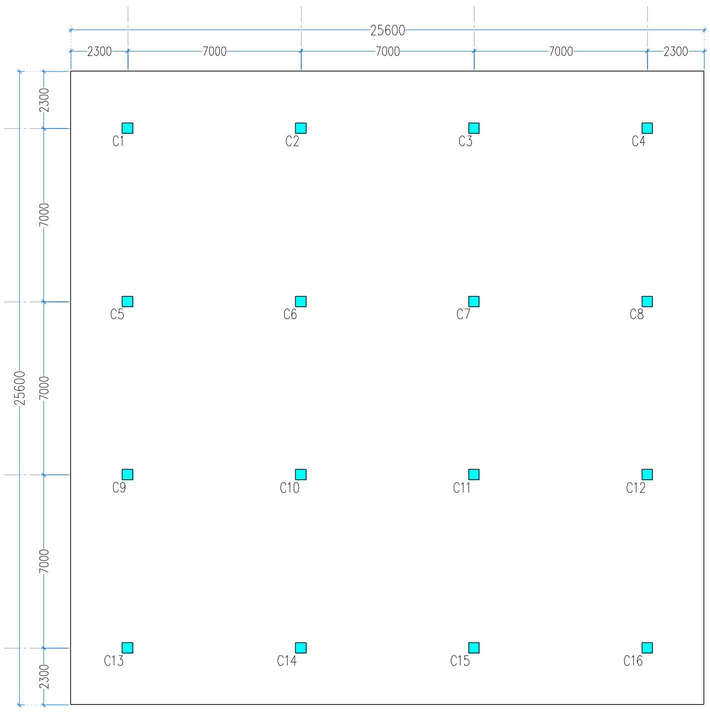


Fig-4.2(b):Plan showing column number and their position with c/c distance (in"mm") on raft.

4.4 Soil Data

Various type of soil considered along with their modulus of sub grade reactions(ks) and bearing pressures are given in Table 4.1.

Table-4.1 Data of Different types of Soil

S. No	Type of Soil below Raft	Modules of Sub grade reaction (kN/m^2/m)	Gross allowable bearing pressure (kN/m^2)
Soil-1	Sandy Clayey Silt	10000	195
Soil-2	Sandy soil with low percentage of Gravels	14000	205
Soil-3	Clayey Sandy Silt with Gravels predominantly	15000	235
Soil-4	Sandy Silt	16000	245
Soil-5	Sand-Silt mix with or without Gravel	20000	195
Soil-6	Hard Mooram with Kanker	25000	270

4.5 Load combinations for analysis

Limit state design method is used for the analysis and design of the building as well as raft. Due to symmetry of the structure, load combination is considered in only one direction. As per IS 875 (part-5), these load combinations have been considered:

Wind load combinations are:

1. Dead Load + Wind force in x-direction
2. Dead Load -Wind force in x-direction
3. Dead Load+ Live load + Wind force in x-direction
4. Dead Load+ Live load -Wind force in x-direction

Earthquake load combinations has been considered as per Clause-6.3.1.2 of IS 1893(part-1): 2002. These are as follows:

1. 1.0 (Dead Load) + (k) (Live load)
2. 1.5 (Dead Load + seismic force in x-direction)
3. 1.5 (Dead Load - seismic force in x-direction)
4. 1.2 (Dead Load+ (k)Live load + seismic force in x-direction)
5. 1.2 (Dead Load+ (k)Live load - seismic force in x-direction)
6. 0.9 (Dead Load) + 1.5 (seismic force in x-direction)
7. 0.9 (Dead Load) - 1.5 (seismic force in x-direction)

Note: Where, k = 0.25 (if live load $\leq$ 3 kN/m^2); k = 0.5 (if live load > 3 kN/m^2)

Comparative chart of base reactions due to earthquake forces and wind forces:

Comparison of base reactions of the super structure due to earthquake forces with the base reactions of the super structure due to wind forces is given below in Table 4.2.

Table 4.2 Comparison between base reactions due to wind and earthquake forces

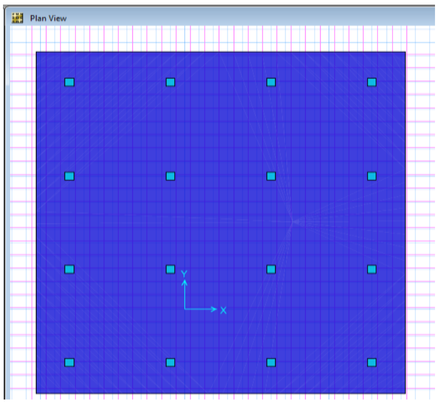
Story	BasePoint (refer fig. 4.2 (a)	Load	FX	FY	FZ	MX	MY	MZ
BASE	11	EQX	-185.18	0	-15.61	0.002	-438.691	0
BASE	11	WINDX	-101.67	0	-1.27	0.002	-239.261	0
BASE	77	EQX	-185.18	0	15.61	-0.002	-438.691	0
BASE	77	WINDX	-101.67	0	1.27	-0.002	-239.261	0
BASE	85	EQX	-141.73	0.19	-737.95	-0.21	-390.14	0
BASE	85	WINDX	-78.31	0.1	-438.93	-0.116	-213.158	0
BASE	88	EQX	-141.73	-0.19	737.95	0.21	-390.14	0
BASE	88	WINDX	-78.31	-0.1	438.93	0.116	-213.158	0
BASE	102	EQX	-141.73	-0.19	-737.95	0.21	-390.14	0
BASE	102	WINDX	-78.31	-0.1	-438.93	0.116	-213.158	0
BASE	103	EQX	-185.18	0	15.61	0.002	-438.691	0
BASE	103	WINDX	-101.67	0	1.27	0.002	-239.261	0
BASE	104	EQX	-185.18	0	-15.61	-0.002	-438.691	0
BASE	104	WINDX	-101.67	0	-1.27	-0.002	-239.261	0
BASE	105	EQX	-141.73	0.19	737.95	-0.21	-390.14	0
BASE	105	WINDX	-78.31	0.1	438.93	-0.116	-213.158	0
BASE	106	EQX	-135.43	1.61	-785.99	-1.799	-383.108	0
BASE	106	WINDX	-74.96	0.86	-467.23	-0.963	-209.414	0
BASE	107	EQX	-177.71	-0.63	-3.37	0.7	-430.343	0
BASE	107	WINDX	-97.71	-0.34	-9.57	0.376	-234.834	0
BASE	108	EQX	-177.71	0.63	3.37	-0.7	-430.343	0
BASE	108	WINDX	-97.71	0.34	9.57	-0.376	-234.834	0
BASE	109	EQX	-135.43	-1.61	785.99	1.799	-383.108	0
BASE	109	WINDX	-74.96	-0.86	467.23	0.963	-209.414	0
BASE	110	EQX	-135.43	1.61	785.99	-1.799	-383.108	0
BASE	110	WINDX	-74.96	0.86	467.23	-0.963	-209.414	0
BASE	111	EQX	-135.43	-1.61	-785.99	1.799	-383.108	0
BASE	111	WINDX	-74.96	-0.86	-467.23	0.963	-209.414	0
BASE	112	EQX	-177.71	0.63	-3.37	-0.7	-430.343	0
BASE	112	WINDX	-97.71	0.34	-9.57	-0.376	-234.834	0
BASE	113	EQX	-177.71	-0.63	3.37	0.7	-430.343	0
BASE	113	WINDX	-97.71	-0.34	9.57	0.376	-234.834	0

Discussion: After comparison of base reactions of the building due to wind forces with the base reaction of the building due to earthquake forces , it is concluded that the earthquake forces are governing.

4.6 General arrangement of Raft

1).Flat Plate Raft

Considering whole raft as a flat slab having dimensions 25.6m x 25.6m x 1.5m supporting columns of size 0.6 x 0.6mof a 3bay x 3 bay building with centre to centre distance between columns as 7m.The slab is modeled for analysis in SAFE-v12 software. General arrangement of flat plate raft is shown below in fig-4.3 and fig-4.4.



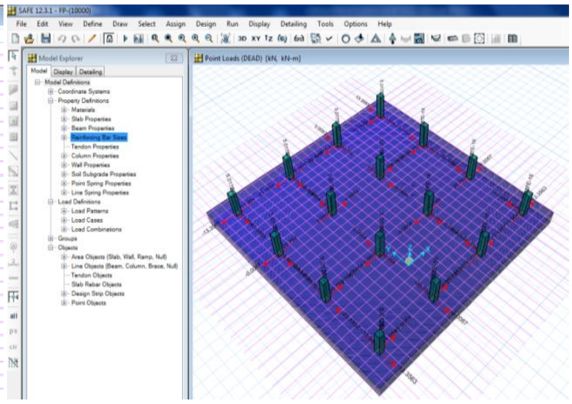
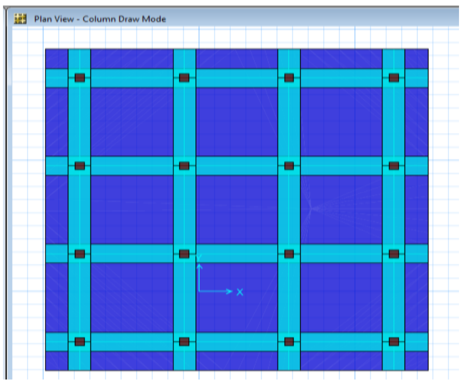


Fig-4.3: Plan view of flat plate Raft   Fig-4.4: 3-D view of flat plate Raft with loading

2).Slab Beam Raft

Raft of 25.6m x 25.6m x 0.6m is modeled as slab and beam arrangement having beam dimensions of 1.5m x 1.5m, supporting columns of size 600x600mm.Centre to centre distance between columns is 7m in both directions. The slab beam raft is modeled for analysis in SAFE-v12 software. General arrangement of slab beam raft is shown below in fig-4.5 and fig-4.6.



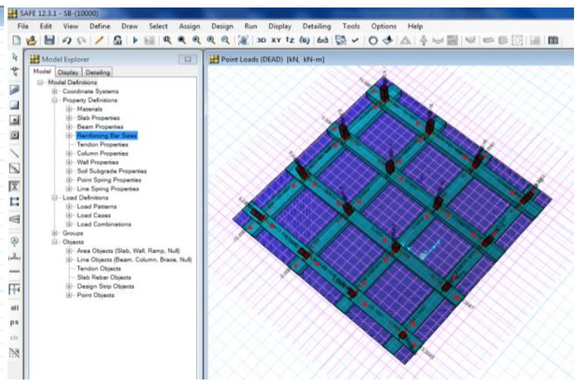
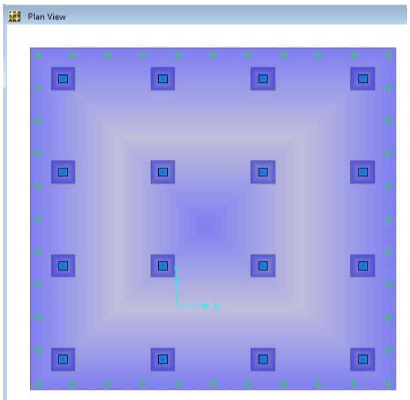


Fig4.5:Plan view of slab beam raft   Fig-4.6:3-D view of slab beam raft with loading

3). Flat plate raft thickened under column

Considering whole raft as an inverted flat slab having slab dimensions of 25.6m x 25.6m x 1.2m supporting columns of size 0.6 m x 0.6 m. These columns are 0.55m thickened below the raft. Centre to centre distance between columns is 7m in both directions. The flat plate raft thickened under column is modeled in for analysis of computer program SAFE-v12. General arrangement of flat raft thickened under column raft is shown belowin fig-4.7 and fig-4.8.



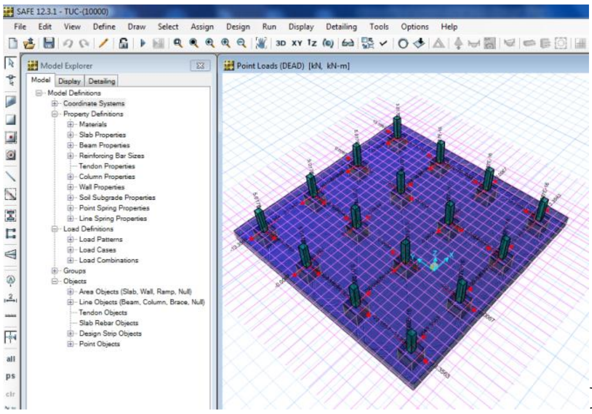
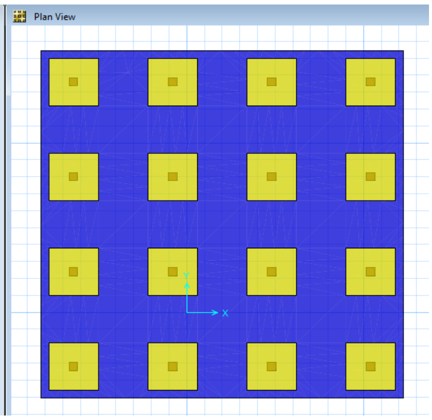


Fig-4.7:Plan view of raft thickened under column

Fig-4.8: 3-D view of flat raft thickened under column with loading

4). Flat plate raft with pedestal

Considering whole raft as an inverted flat Slab having slab dimensions of 25.6m x 25.6m x 0.7m with pedestal dimension of 3.5m x 3.5m x 0.7m, supporting columns of size 0.6 x 0.6m. Centre to centre distance between columns is 7m in both directions. The flat plate raft with pedestal is modeled in for analysis of computer program SAFE-v12. General arrangement of this raft is shown below in fig-4.9 and fig-4.10.



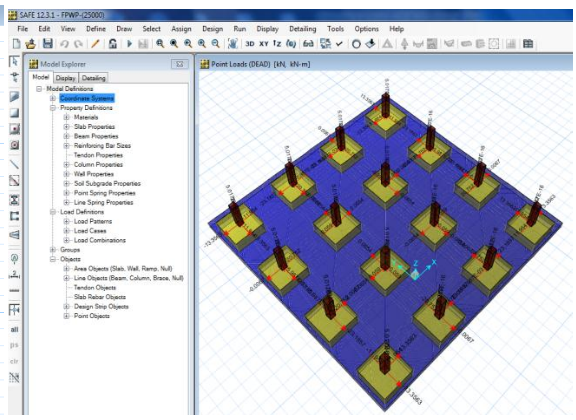
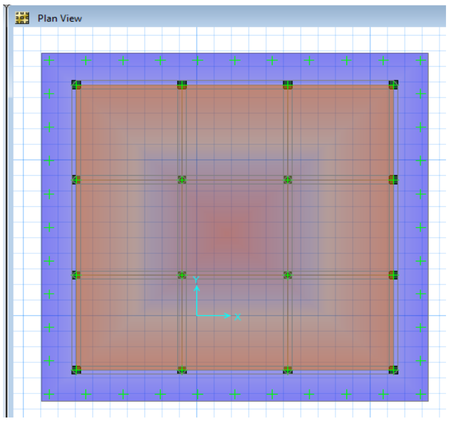


Fig-4.9:Plan view of flat plate raft with pedestal

Fig-4.10: 3-D view of flat plate raft with pedestal with loading

5). Box type raft

In this type of raft, two slabs are connected with walls, of thickness 0.6m and height 3m, along column to column in both longitudinal as well as transverse directions. Dimension of the base slab is25.6m x 25.6m x 0.8m and dimension of the above slab is 21.6m x 21.6m x 0.3m,supporting columns of size 600 x 600mm. Centre to centre distance between columns is 7m in both directions. This box type raft is modeled in for analysis of computer program SAFE-v12. General arrangement of box type raft is shown belowin fig-4.11 and fig-4.12.



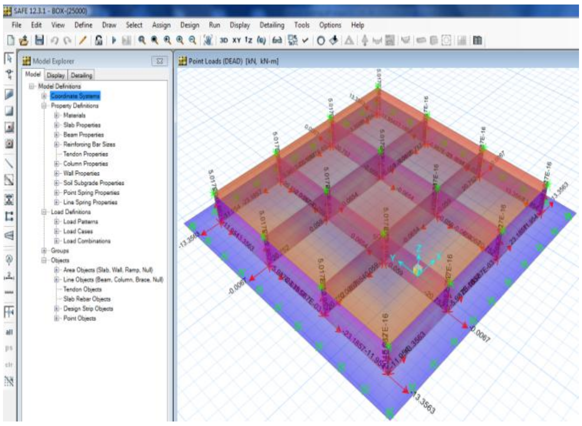
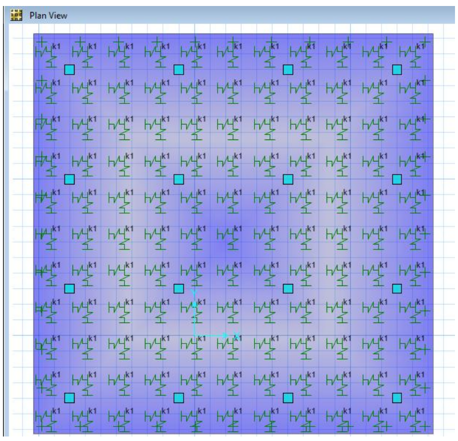


Fig4.11:Plan view of box type Raft   Fig4.12:3-D view of box Raft with loading

6). Pile raft

Considering a raft of plan dimensions 25.6m x 25.6m with a depth of1.5m supporting columns of size 0.6 x 0.6mof a 3 bay x 3 bay building with centre to centre distance between columns is 7m. There are 121 piles provided in the raft in the form of equivalent pile springs, of equivalent stiffness properties as the pile considered, at a spacing of 2.33m. The slab is modeled in for analysis of computer program SAFE-v12. General arrangement of pile raft is shown below in fig-4.13 and fig-4.14.



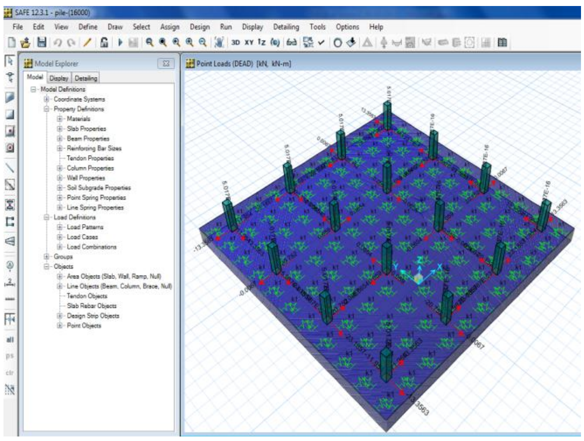


Fig-4.13: Plan View of Pile Raft   Fig-4.14: 3-D view of Pile Raft with loading

(Note: All these type of rafts are divided into strips of 1m along x-direction as well as in y- directions)

4.7Pile foundation

4.7.1 Pile capacity and spacing calculation

Sample calculations are being furnished as per empirical formula for calculation of pile capacity as per IS 2911(Part-1), (clause-5.3.1.1), Appendix-A :

Diameter of pile = 90 cms.

Effective length of the pile = 13 m

Following soil properties have been used for sample calculations :

Ap = Cross-Sectional area of pile stem at toe level

= 6361.72 cm^2

As = Surface area of the stem of pile = 367566 cm^2

r = Average effective unit weight of soil at pile toe level = 0.0010 kg. / cm^3

Nr = Bearing Capacity Factor = 22.40

Nq = Bearing Capacity Factor = 21.0

k = Earth pressure coefficient = 1.25

Ø = Angle of wall friction = 30 degrees

Pd'= Effective overburden pressure at pile toe = 0.9 kg. / cm^2

Pd = Effective overburden pressure at the layer centre = 0.6 kg./ cm^2

Empirical Formulae for calculation of pile capacity is as follows :

Qu = Ultimate bearing capacity of the pile

Qu = Ap.(1/2 D r Nr + Pd' Nq) + K Pd tan (Ø) As

= 285.81tones

= 2858.1kN

Safe pile capacity (F.O.S. = 3.0)

Safe pile capacity = 952.7kN

Optimum centre-to-centre spacing (s)between piles = 2.5 to 3.5D

Where, D = diameter of piles

Providing a centre-to-centre spacing(s) between piles = 2.33m

4.7.2Calculation of number of piles

Number of piles is calculated for the total vertical load of the super structure. Total loads and moments of the super structure is given in Table 4.3

Table 4.3 Total loads and moments of superstructure:

Column base Point (refer fig.4.2(a))	FX	FY	FZ	MX	MY	MZ
11	-0.42	0.42	10156.47	-0.472	-0.472	0
77	0.42	0.42	10156.47	-0.472	0.472	0
85	48.31	0.25	6847.37	-0.282	53.978	0
88	-48.31	0.25	6847.37	-0.282	-53.978	0
102	48.31	-0.25	6847.37	0.282	53.978	0
103	0.42	-0.42	10156.47	0.472	0.472	0
104	-0.42	-0.42	10156.47	0.472	-0.472	0
105	-48.31	-0.25	6847.37	0.282	-53.978	0
106	29.62	-29.62	4708.46	33.097	33.097	0
107	0.25	-48.31	6847.37	53.978	0.282	0
108	-0.25	-48.31	6847.37	53.978	-0.282	0
109	-29.62	-29.62	4708.46	33.097	-33.097	0
110	-29.62	29.62	4708.46	-33.097	-33.097	0
111	29.62	29.62	4708.46	-33.097	33.097	0
112	0.25	48.31	6847.37	-53.978	0.282	0

TOTAL VERTICAL LOAD(TOTAL FZ)= 114238.7 kN

Capacity of piles considered = 952.7kN

Number of piles required(n) = 119.91

Providing total no. of piles =121

Hence, providing 121 number of 0.9m diameter piles at a centre-to-centre spacing of 2.33m.

Chapter-5
Results and Discussion

5.1Introduction

This chapter covers the results of all six types of raft, (i)Flat plate raft, (ii)Slab beam raft, (iii)Flat plate raft thickened under column, (iv) Flat plate with pedestal raft, (v)box type raft, and (vi) pile raft, on six different soil types. The results of settlement, punching shear, maximum shear force and maximum bending moments values in all these rafts are reported for static load combination (i.e., Dead load + 0.25 Live load) in this chapter.

This chapter is divided in following five parts:

i. Results of deformations/settlements in six different types of rafts for three critical locations(i.e. centre, edges and corners) of rafts on six different soil types.
   A comparison chart of maximum overall settlement and differential settlement with their respective permissible values as per IS:1904-1986, are also shown.

ii. Results of punching shear values, below various columns on six different types of rafts for three critical locations(i.e. centre, edges and corners) of rafts on six different soil types.

iii. Results of maximum shear force in six different types of rafts for six different soil types.

iv. Results of maximum bending moment in six different types of rafts for six different soil types.

v. Comparative study of six different types of rafts on six different soil types on the basis of maximum settlement in raft, maximum punching shear below columns, maximum shear force and maximum bending moments in these rafts.

5.2Deformation/settlement in rafts

In this section, deformation graphs of all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are sequentially mentioned and discussed.

5.2.1: Deformation graphs of flat plate raft on different soil types

Deformation graphs of flat plate raft for the six different soil types are discussed in this section and a comparison for settlement of this type of raft for three critical locations (i.e. centre, edges and corners) is given in Table 5.2.1

5.2.1.1 Deformation(in mm) graph of flat plate raft on Sandy Clayey Silt

Deformation/ settlement graph of flat plate raft onsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.2.1.1. It can be seen that, maximum settlement is below the interior four columns. The magnitude of maximum settlement is 21.4mm.

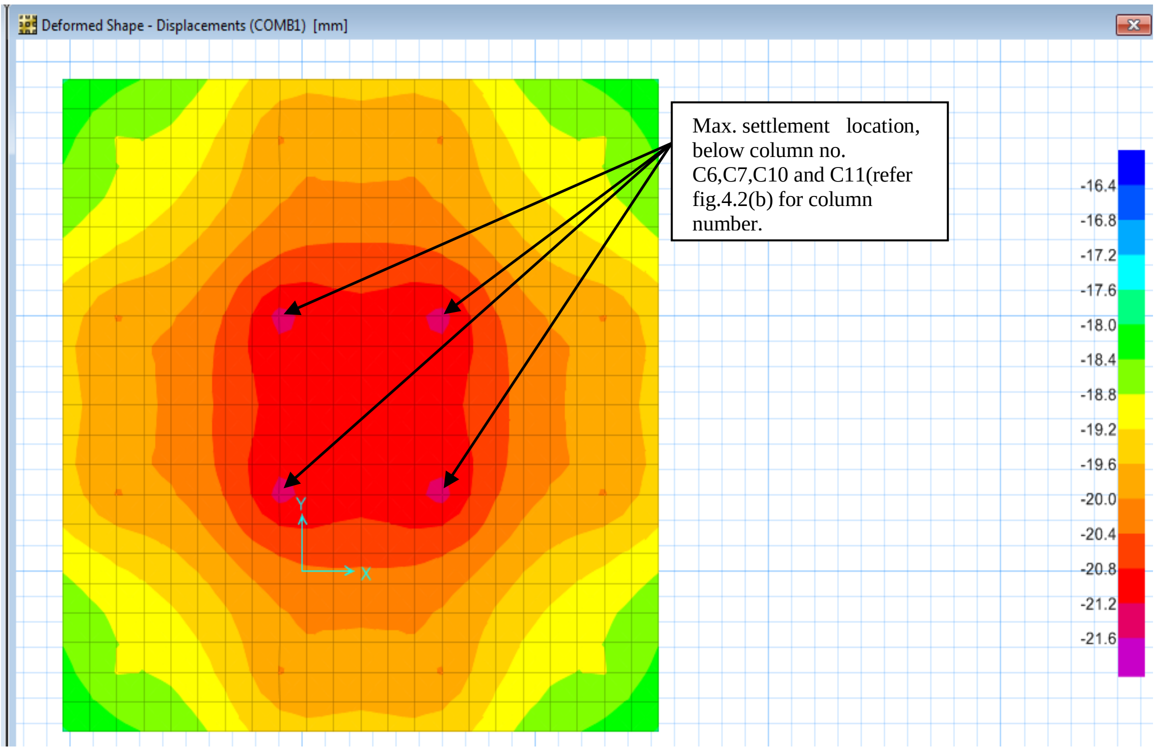


Fig-5.2.1.1: Deformation(in mm) graph of flat plate raft on soil-1 (i.e. Sandy Clayey Silt)

5.2.1.2 Deformation(in mm) graph of flat plate raft on Sandy soil with low percentage of gravel:

Deformation/ settlement graph of flat plate raft onsoil-2 (i.e. Sandy Soil with low percentage of gravel) is shown below in fig. 5.2.1.2. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 15.6mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

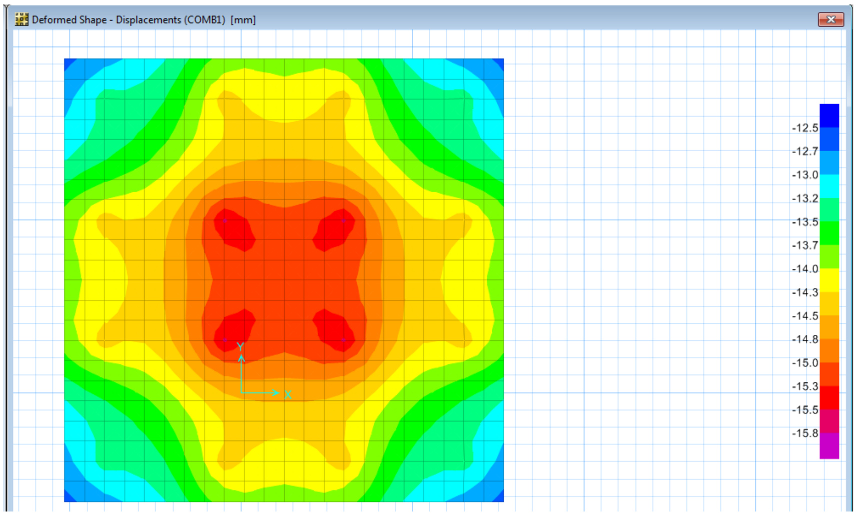


Fig-5.2.1.2: Deformation(in mm) graph of flat plate raft on soil-2 (i.e. Sandy soil with low percentage of Gravel)

5.2.1.3Deformation(in mm)graph of flat plate raft on Clayey Sand Silt with Gravels:

Deformation/ settlement graph of flat plate raft onsoil-3 (i.e. Clayey Sand Silt with Gravels) with Gravels is shown below in fig. 5.2.1.3. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 14.6 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

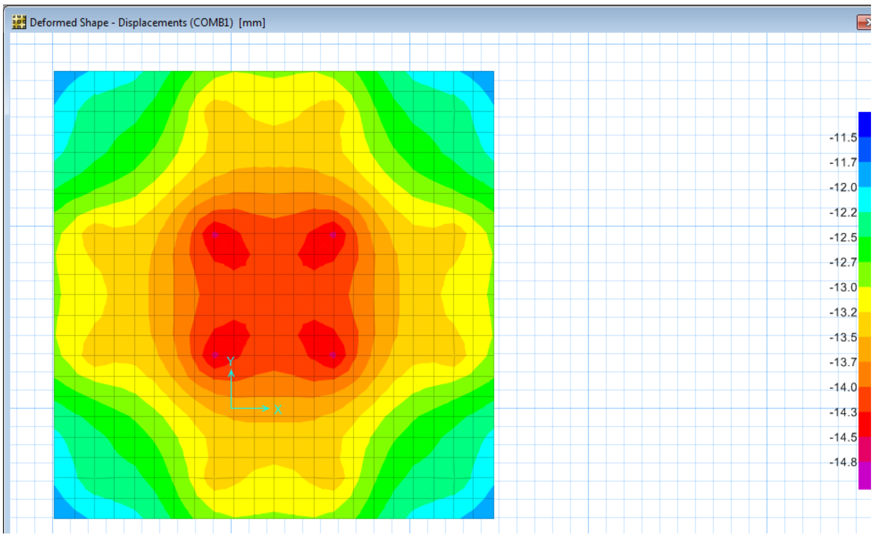


Fig-5.2.1.3: Deformation(in mm) graph of flat plate raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.2.1.4Deformation(in mm) graph of flat plate raft on Sandy Silt:

Deformation/ settlement graph of flat plate raft onsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.2.1.4. It can be seen that, maximum settlement is below the interior four columns. The magnitude of maximum settlement is 13.7 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

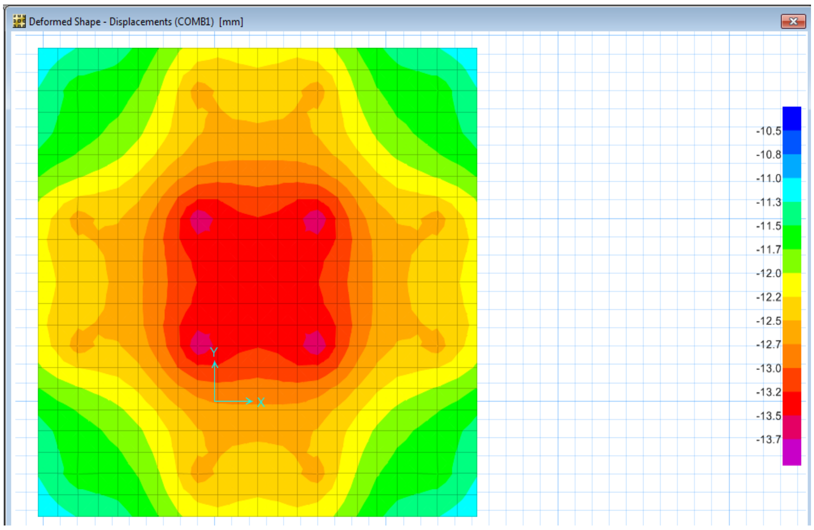


Fig-5.2.1.4: Deformation(in mm) graph of flat plate raft on soil-4 (i.e. Sandy Silt)

5.2.1.5Deformation(in mm)graph of flat plate raft on Sand-Silt mix with or without Gravel:

Deformation/ settlement graph of flat plate raft on soil-5 (i.e. Sand-Silt Mix with or without gravel) is shown below in fig. 5.2.1.5. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 11.2 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

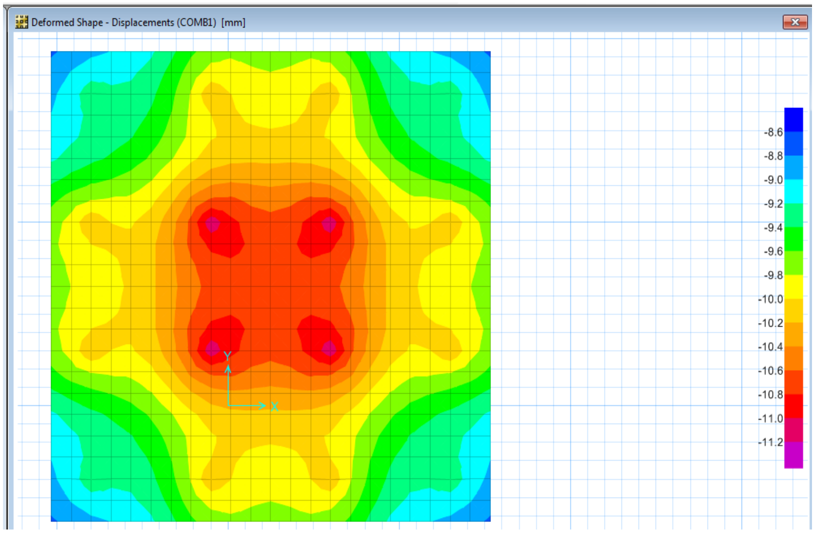


Fig-5.2.1.5: Deformation(in mm) graph of flat plate raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.2.1.6Deformation(in mm)graph of flat plate raft on hard Mooram with Kanker:

Deformation/ settlement graph of flat plate raft on soil-6 (i.e. Hard Mooram with Kanker) is shown below in fig. 5.2.1.6. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 9.1 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

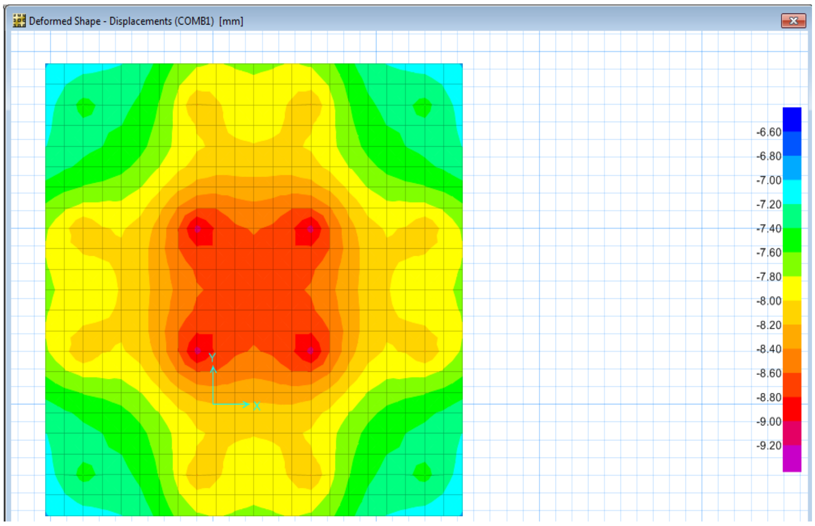


Fig-5.2.1.6: Deformation(in mm) graph of flat plate raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.2.1: Deformation(in mm) in flat plate raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Deformation(in mm)		
				At centre of raft	At edges of raft	At corners of raft
1	Sandy Clayey Silt	10000	195	-21.1	-19.5	-18.0
2	Sandy soil with low percentage of Gravel	14000	205	-15.2	-13.9	-12.7
3	Clayey Sand Silt with Gravels	15000	235	-14.2	-12.9	-11.8
4	Sandy Silt	16000	245	-13.4	-12.2	-11.0
5	Sand-Silt mix with or without Gravel	20000	195	-10.7	-9.7	-8.8
6	Hard Mooram with Kanker	25000	270	-8.6	-7.8	-7.0

Note: As per IS:1904-1986Clause-16.3.4 ,Permissible max. settlement for reinforced concrete raft foundations is 75mm.

5.2.2: Deformation graphs of Slab Beam Raft on different Soil types

Deformation graphs of slab beam raft for the six different soil types are discussed in this section and a comparison for settlement of this type of raft for three critical locations(i.e. centre, edges and corners) is given in Table 5.2.2.

5.2.2.1 Deformation(in mm)graph of slab beam raft on Sandy Clayey Silt:

Deformation/ settlement graph of slab beam raft onsoil-1(i.e. Sandy Clayey Silt) is shown below in fig. 5.2.2.1. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 21.13 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

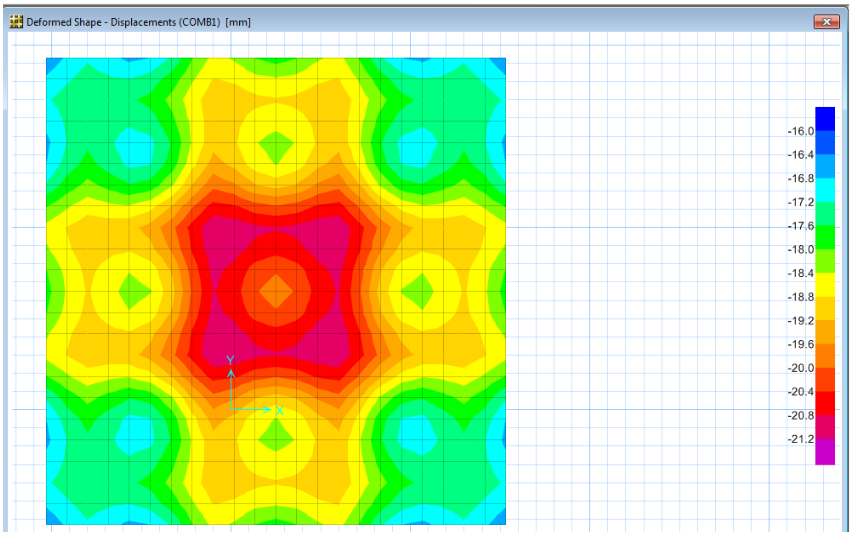


Fig-5.2.2.1: Deformation(in mm) graph of slab beam raft on soil-1(i.e. Sandy Clayey Silt)

5.2.2.2 Deformation(in mm)graph of slab beam raft on Sandy Soil with low percentage of gravel:

Deformation/ settlement graph of slab beam raft onsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.2.2.2. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 15.5 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

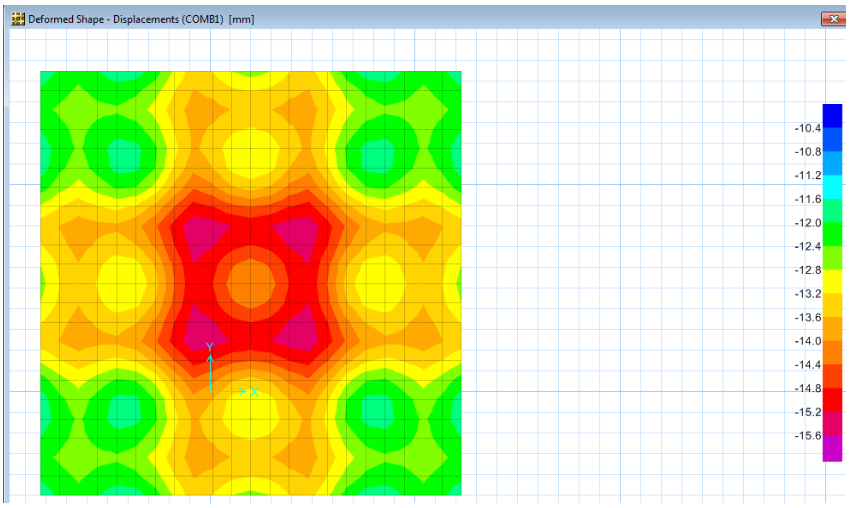


Fig-5.2.2.2: Deformation(in mm) graph of slab beam raft on soil-2 (i.e. Sandy Soil with low percentage of gravel)

5.2.2.3 Deformation(in mm)graph of slab beam raft on Clayey Sand Silt with Gravels:

Deformation/ settlement graph of slab beam raft onsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.2.2.3. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 14.5 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

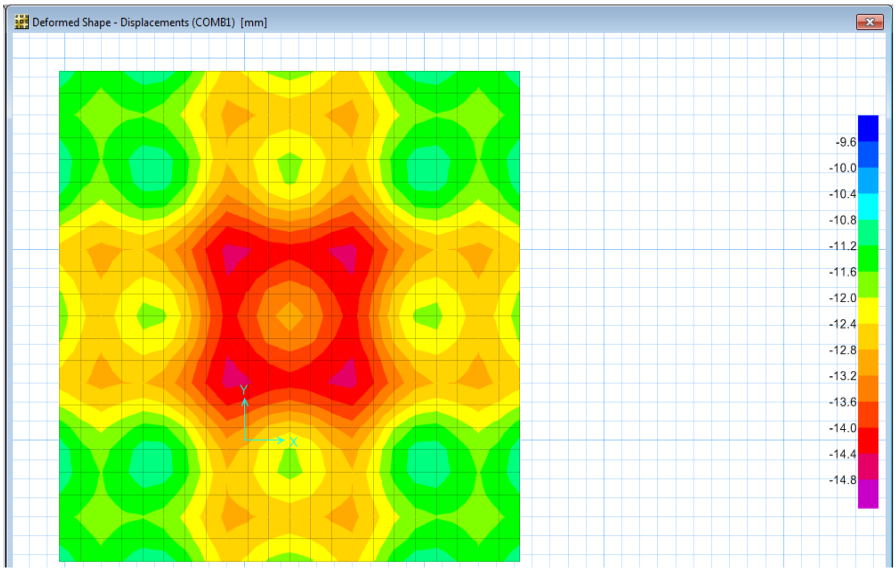


Fig-5.2.2.3: Deformation(in mm) graph of slab beam raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.2.2.4Deformation(in mm)graph of slab beam raft on Sandy Silt:

Deformation/ settlement graph of slab beam raft onsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.2.2.4. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 13.6 mm

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

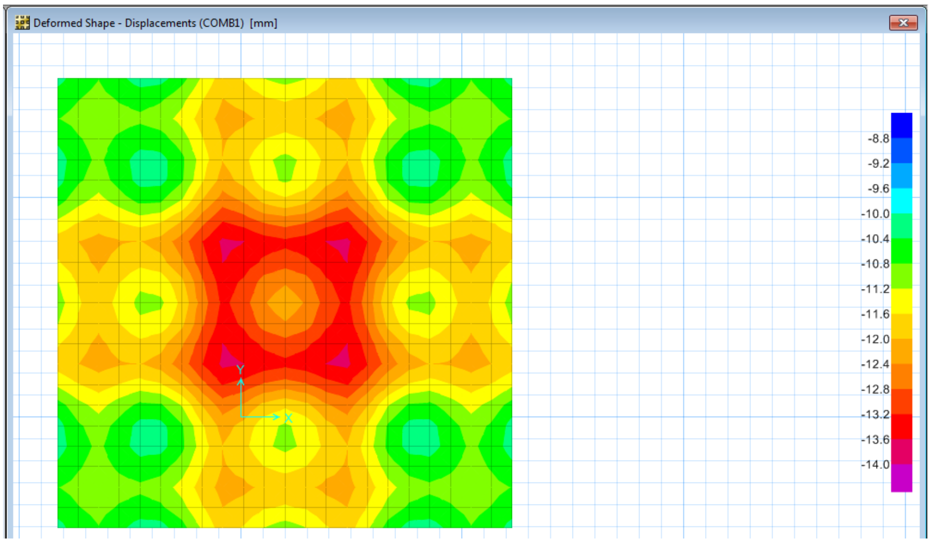


Fig-5.2.2.4: Deformation(in mm) graph of slab beam raft on soil-4 (i.e. Sandy Silt)

5.2.2.5 Deformation(in mm)graph of slab beam raft on Sand-Silt mix with or without Gravel:

Deformation/ settlement graph of slab beam raft onsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.2.2.5. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 11.2 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

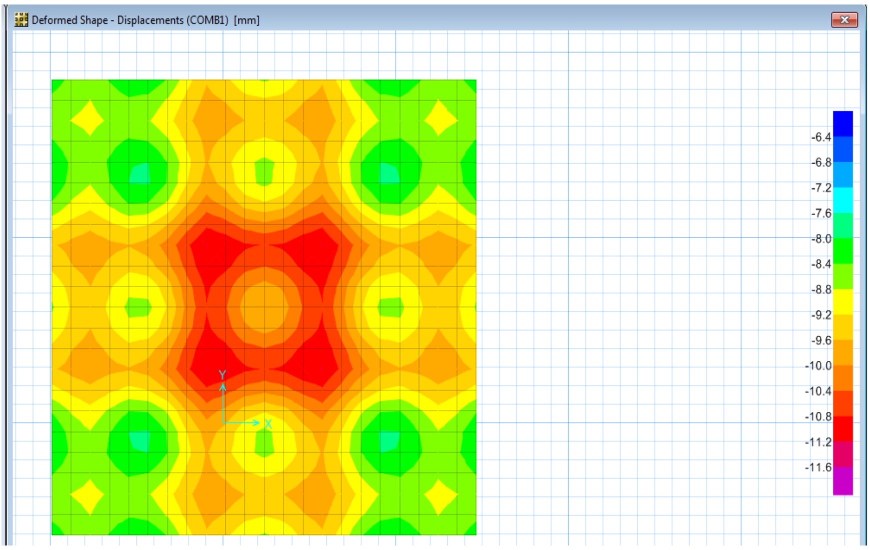


Fig-5.2.2.5: Deformation(in mm) graph of slab beam raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.2.2.6 Deformation(in mm)graph of slab beam raft on Hard Mooram with Kanker:

Deformation/ settlement graph of slab beam raft onsoil-6 (i.e. Hard Mooram with Kanker) is shown below in fig. 5.2.2.6. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 9.2 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

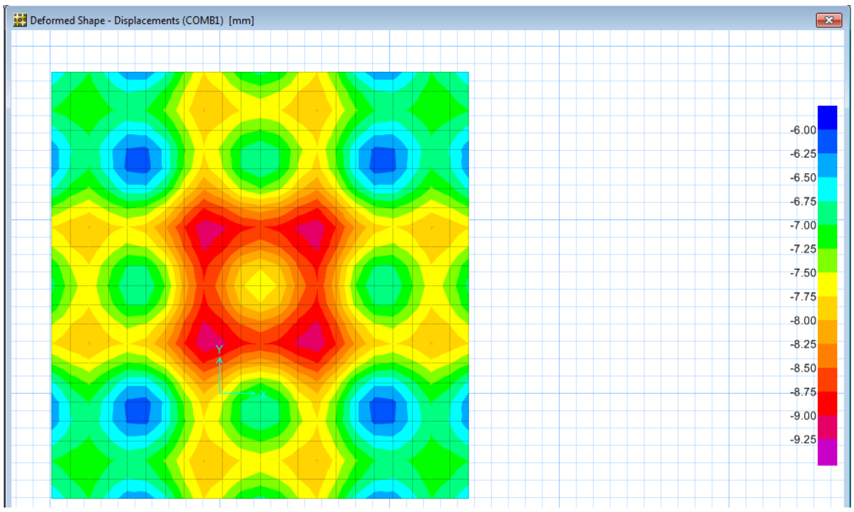


Fig-5.2.2.6: Deformation(in mm) graph of slab beam raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.2.2: Deformation(in mm) in slab beam raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Deformation(in mm)		
				At centre of raft	At edges of raft	At corners of raft
1	Sandy Clayey Silt	10000	195	-19.8	-17.9	-16.5
2	Sandy Soil with low percentage of gravel	14000	205	-14.0	-12.7	-11.8
3	Clayey Sand Silt with Gravels	15000	235	-13.0	-11.8	-11.0
4	Sandy Silt	16000	245	-12.2	-11.1	-10.3
5	Sand-Silt mix with or without Gravel	20000	195	-9.6	-8.8	-8.2
6	Hard Mooram with Kanker	25000	270	-7.6	-7.0	-6.6

Note: As per IS:1904-1986Clause-16.3.4 ,Permissible max. settlement for reinforced concrete raft foundations is 75mm.

5.2.3: Deformation graphs of flat plate thickened under column Raft on Different Soil types

Deformation graphs of flat plate thickened under column raft for the six different soil types are discussed in this section and a comparison for settlement of this type of raft for three critical locations(i.e. centre, edges and corners) is given in Table 5.2.3

5.2.3.1 Deformation(in mm) graph of flat plate raft thickened under column on Sandy Clayey Silt:

Deformation/ settlement graph of flat plate raft thickened under column onsoil-1 (i.e. Sandy Clayey Silt) is shown below in fig. 5.2.3.1. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 21.0mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

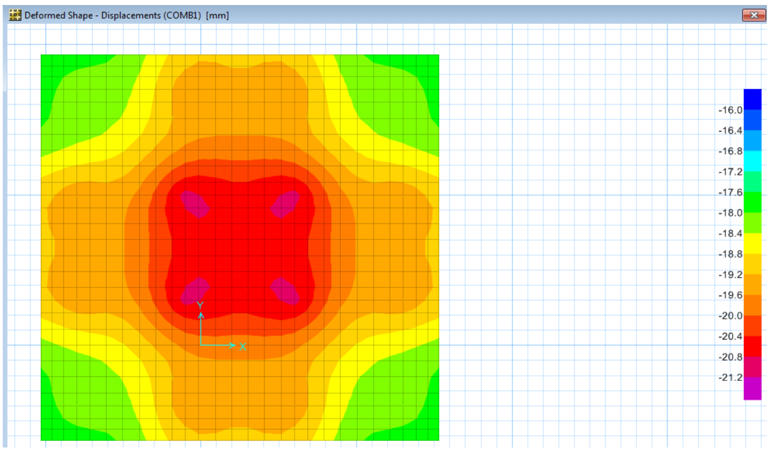


Fig-5.2.3.1:Deformation(in mm) graph of flat plate raft thickened under column on soil-1 (i.e. Sandy Clayey Silt)

5.2.3.2Deformation(in mm) graph of flat plate raft thickened under column on Sandy Soil with low percentage of gravel:

Deformation/ settlement graph of flat plate raft thickened under column for soil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.2.3.2. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 15.3 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

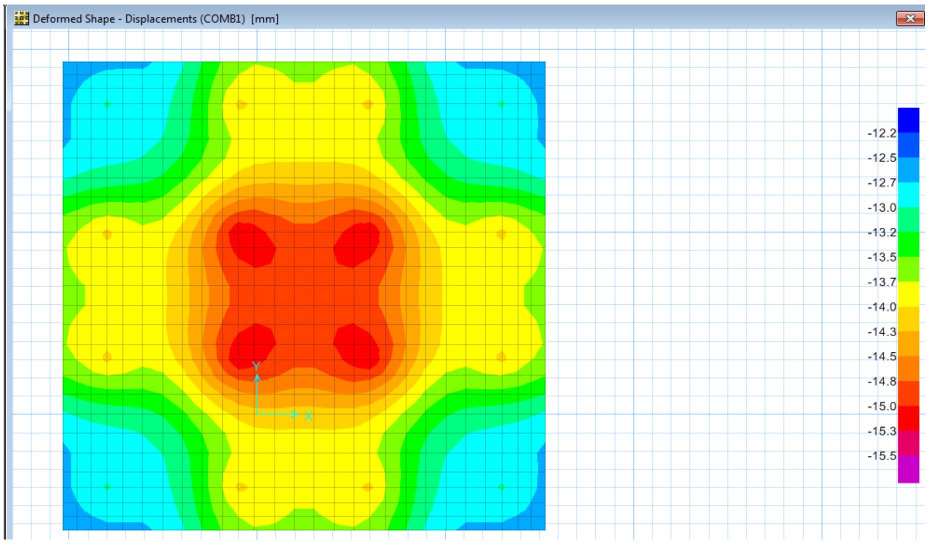


Fig-5.2.3.2:Deformation(in mm) graph of flat plate thickened under column raft on soil-2 (i.e. Sandy Soil with low percentage of gravel)

5.2.3.3Deformation(in mm) graph of flat plate raft thickened under column on Clayey Sand Silt with Gravels:

Deformation/ settlement graph of flat plate raft thickened under column onsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.2.3.3. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 14.3 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

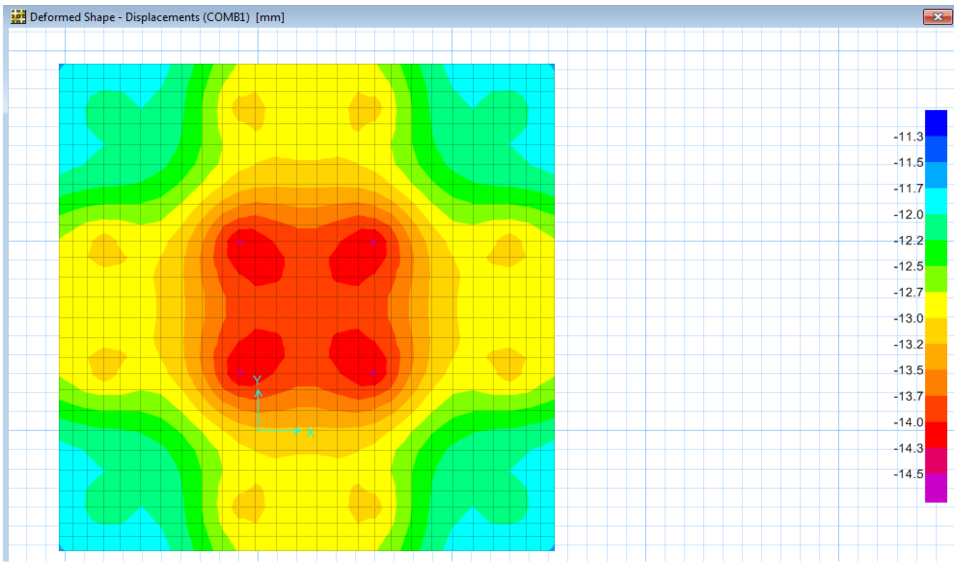


Fig-5.2.3.3:Deformation(in mm) graph of flat plate raft thickened under column on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.2.3.4Deformation(in mm) graph of flat plate raft thickened under column on Sandy Silt:

Deformation/ settlement graph of flat plate raft thickened under column onsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.2.3.4. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 13.5 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

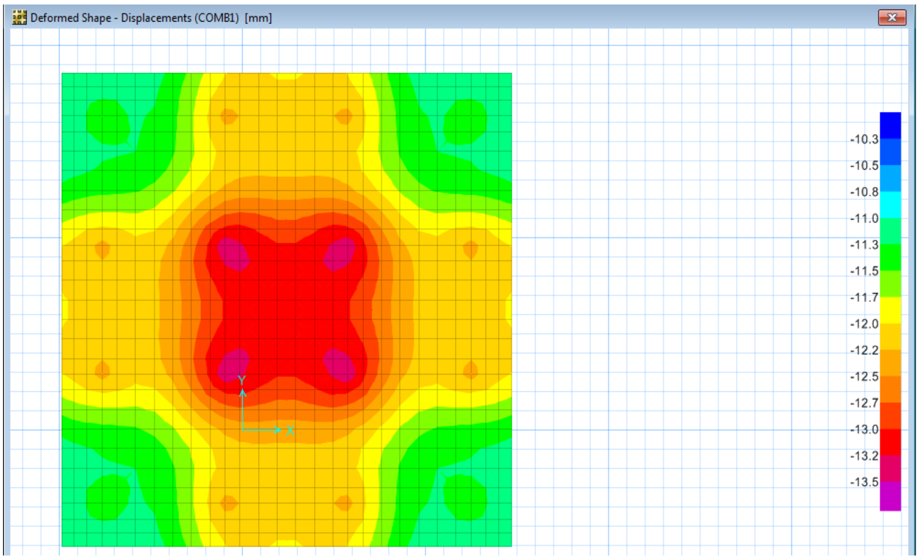


Fig-5.2.3.4:Deformation(in mm) graph of flat plate raft thickened under column on soil-4 (i.e. Sandy Silt)

5.2.3.5Deformation(in mm) graph of flat plate raft thickened under column on Sand-Silt mix with or without Gravel:

Deformation/ settlement graph of flat plate raft thickened under column raft onsoil-5 (i.e. Sand-Silt Mix with or without gravel)is shown below in fig. 5.2.3.5. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 11.0 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

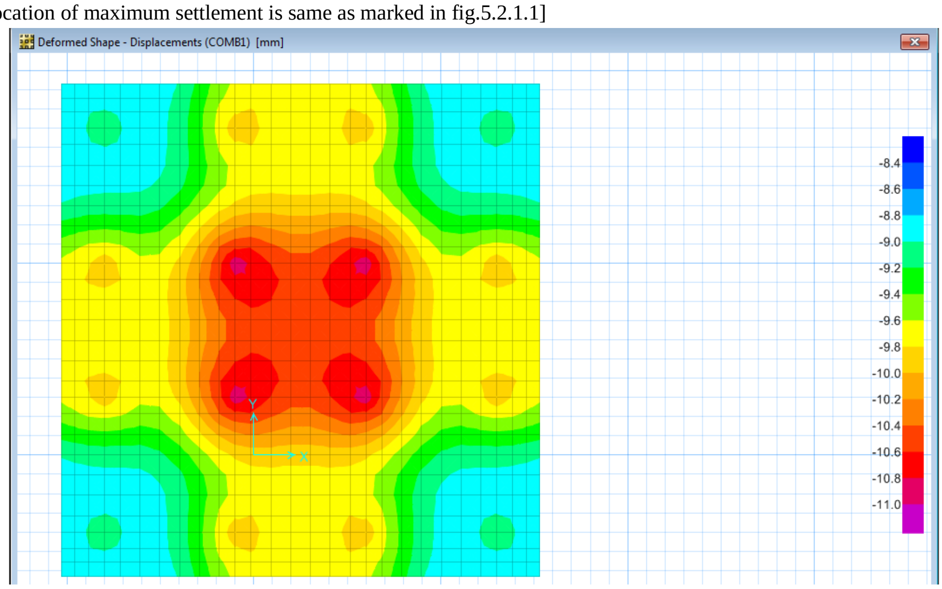


Fig-5.2.3.5:Deformation(in mm) graph of flat plate raft thickened under column on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.2.3.6Deformation(in mm) graph of flat plate thickened under column raft on Hard Mooram with Kanker:

Deformation/ settlement graph of flat plate raft thickened under column onsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.2.3.6. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 9.0 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

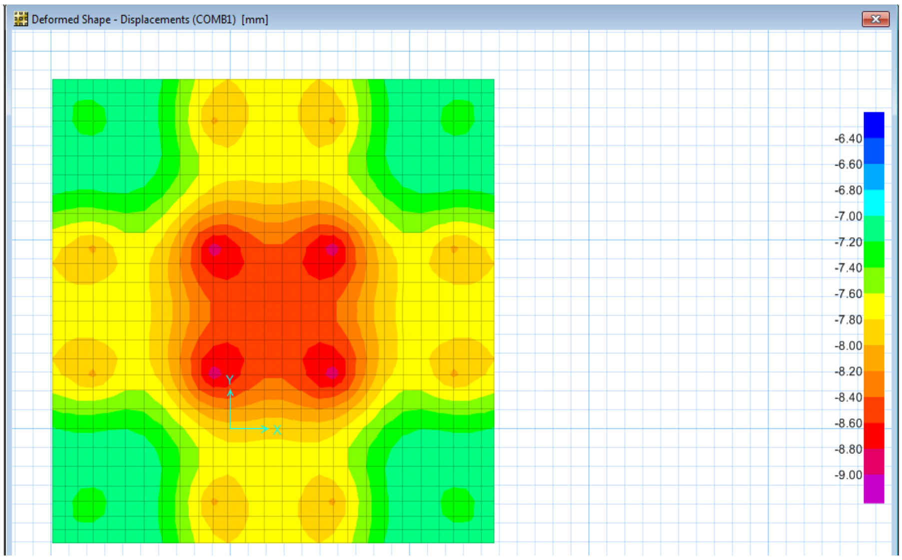


Fig-5.2.3.6:Deformation(in mm) graph of flat plate raft thickened under column on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.2.3: Deformation(in mm) in flat plate raft thickened under column on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Deformation(in mm)		
				At centre of raft	At edges of raft	At corners of raft
1	Sandy Clayey Silt	10000	195	-20.7	-19.1	-17.6
2	Sandy Soil with low % of gravel	14000	205	-14.9	-13.7	-12.6
3	Clayey Sand Silt with Gravels	15000	235	-14.0	-12.8	-11.7
4	Sandy Silt	16000	245	-13.1	-12.0	-11.0
5	Sand-Silt mix with or without Gravel	20000	195	-10.5	-9.6	-8.8
6	Hard Mooram with Kanker	25000	270	-8.5	-7.7	-7.1

Note: As per IS:1904-1986Clause-16.3.4 ,Permissible max. settlement for reinforced concrete raft foundations is 75mm.

5.2.4 Deformation graphs of flat plate with pedestal Raft on Different Soil types

Deformation graphs of flat plate with pedestal raft for the six different soil types are discussed in this section and a comparison for settlement of this type of raft for three critical locations(i.e. centre, edges and corners) is given in Table 5.2.4

5.2.4.1Deformation(in mm) graph of flat plate with pedestal raft on Sandy Clayey Silt:

Deformation/ settlement graph of flat plate with pedestal raft on soil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.2.4.1. Maximum settlement is in the innermost panel of raft. The magnitude of maximum settlement is 20.5mm.

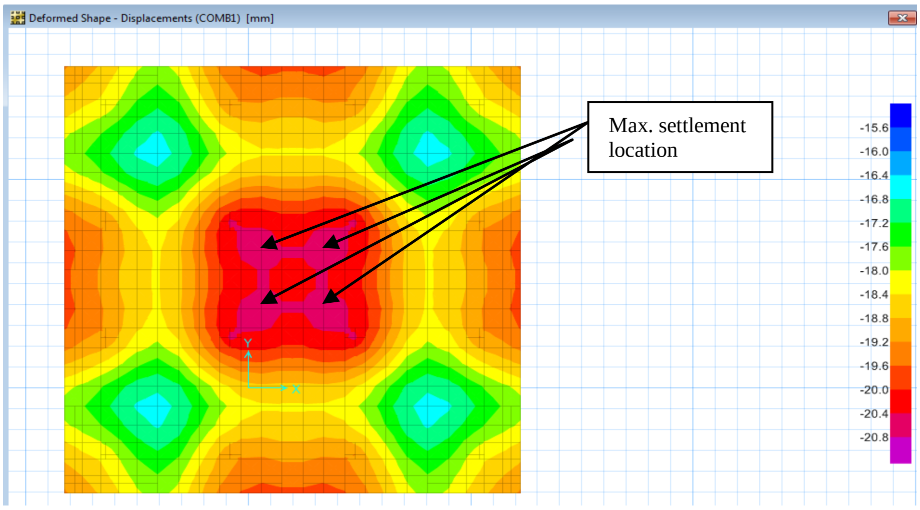


Fig5.2.4.1:Deformation(in mm) graph of flat plate with pedestal raft on soil-1 (i.e. Sandy Clayey Silt)

5.2.4.2Deformation(in mm) graph of flat plate with pedestal raft on Sandy Soil with low percentage of gravel:

Deformation/ settlement graph of flat plate with pedestal raft onsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.2.4.2. Maximum settlement is in the innermost panel of raft. The magnitude of maximum settlement is 15.1 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.4.1]

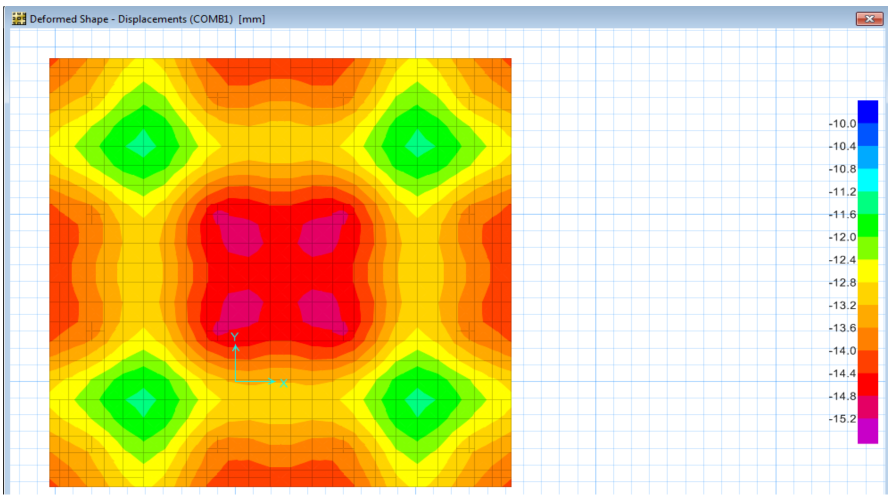


Fig-5.2.4.2:Deformation(in mm) graph of flat plate with pedestal raft on soil-2 (i.e.Sandy Soil with low percentage of gravel).

5.2.4.3Deformation(in mm) graph of flat plate with pedestal raft on Clayey Sand Silt with Gravels:

Deformation/ settlement graph of flat plate with pedestal raft onsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.2.4.3. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 14.1 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

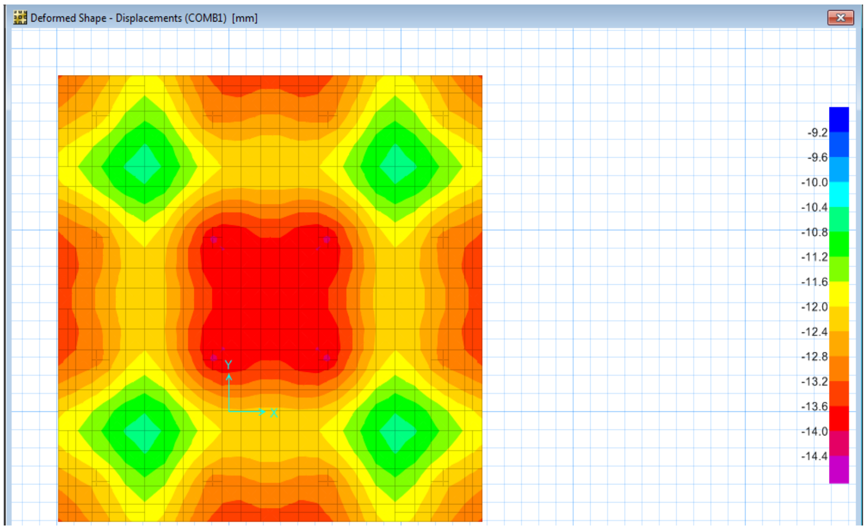


Fig-5.2.4.3:Deformation(in mm) graph of flat plate with pedestal raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.2.4.4Deformation(in mm) graph of flat plate with pedestal raft on Sandy Silt:

Deformation/ settlement graph of flat plate with pedestal raft onsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.2.4.4. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 13.3 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

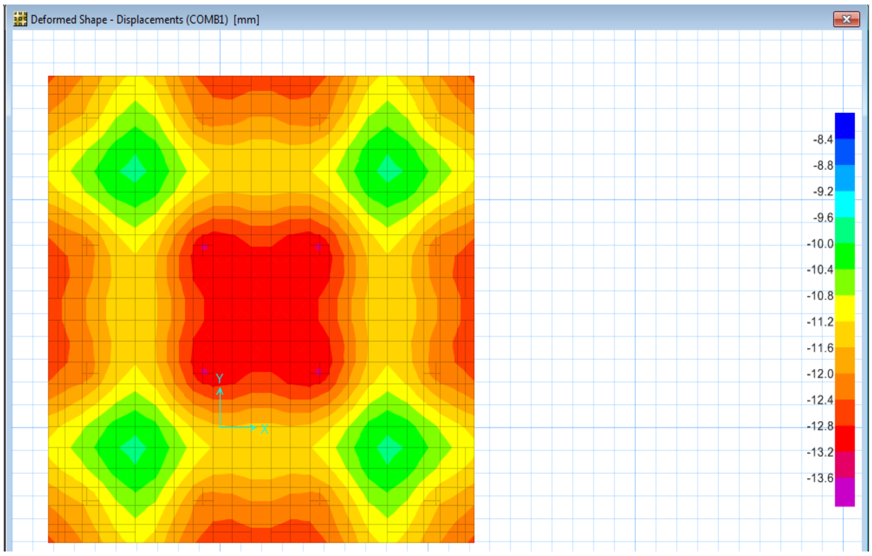


Fig-5.2.4.4:Deformation(in mm) graph of flat plate with pedestal raft on soil-4 (i.e. Sandy Silt)

5.2.4.5Deformation(in mm) graph of flat plate with pedestal raft on Sand-Silt mix with or without Gravel:

Deformation/ settlement graph of flat plate with pedestal raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.2.4.5. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 10.9mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

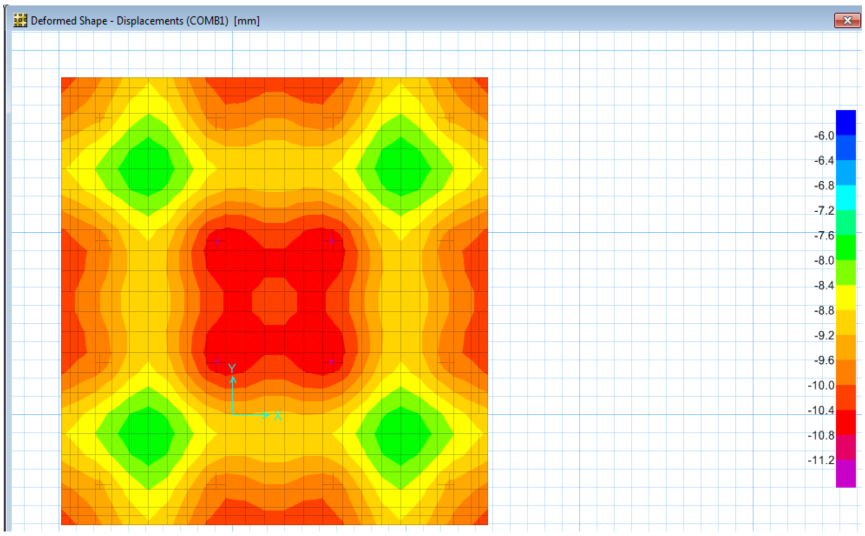


Fig-5.2.4.5:Deformation(in mm) graph of flat plate with pedestal raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.2.4.6Deformation(in mm) graph of flat plate with pedestal raft on Hard Mooram with Kanker:

Deformation/ settlement graph of flat plate with pedestal raft onsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.2.4.6. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 9.0 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

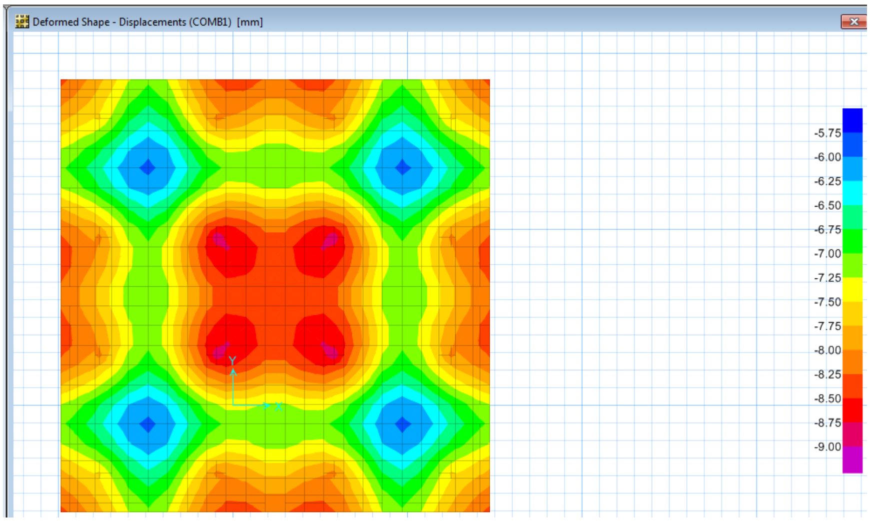


Fig-5.2.4.6:Deformation(in mm) graph of flat plate with pedestal raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.2.4: Deformation(in mm) in flat plate with pedestal raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Deformation(in mm)		
				At centre of raft	At edges of raft	At corners of raft
1	Sandy Clayey Silt	10000	195	-20.4	-19.7	-19.3
2	Sandy Soil with low percentage of gravel	14000	205	-14.7	-14.3	-14.1
3	Clayey Sand Silt with Gravels	15000	235	-13.7	-13.4	-13.3
4	Sandy Silt	16000	245	-12.9	-12.6	-12.5
5	Sand-Silt mix with or without Gravel	20000	195	-10.3	-10.2	-10.1
6	Hard Mooram with Kanker	25000	270	-8.3	-8.1	-8.0

Note: As per IS:1904-1986Clause-16.3.4 ,Permissible max. settlement for reinforced concrete raft foundations is 75mm.

5.2.5 Deformation graphs of box type raft on different soil types

Deformation graphs of box type raft for the six different soil types are discussed in this section and a comparison for settlement of this type of raft for three critical locations(i.e. centre, edges and corners) is given in Table 5.2.5

5.2.5.1 Deformation(in mm) graph of box type raft on Sandy Clayey Silt:

Deformation/ settlement graph of box type raft onsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.2.5.1. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 19.6 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

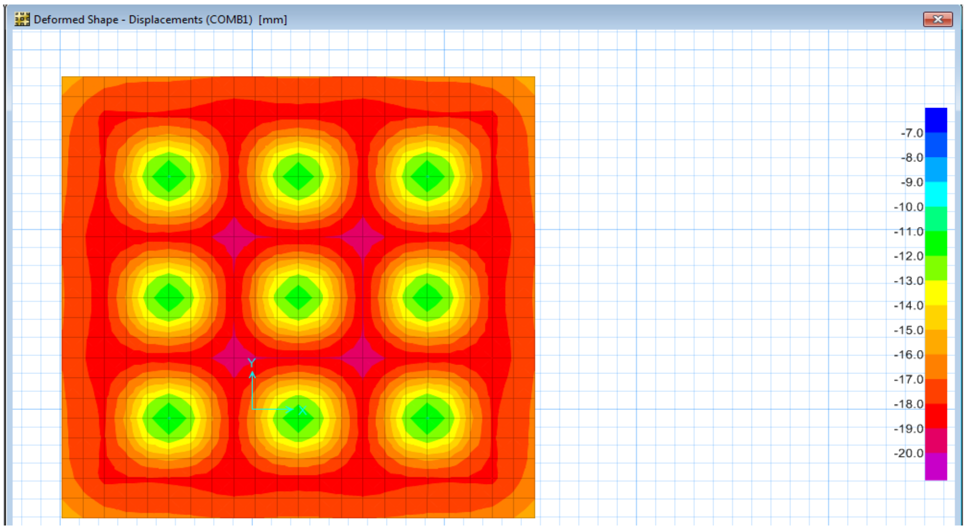


Fig-5.2.5.1:Deformation(in mm) graph of box type raft on soil-1(i.e. Sandy Clayey Silt)

5.2.5.2 Deformation(in mm) graph of box type raft on Sandy Soil with low percentage of gravel:

Deformation/ settlement graph of box type raft onsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.2.5.2. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 14.7 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

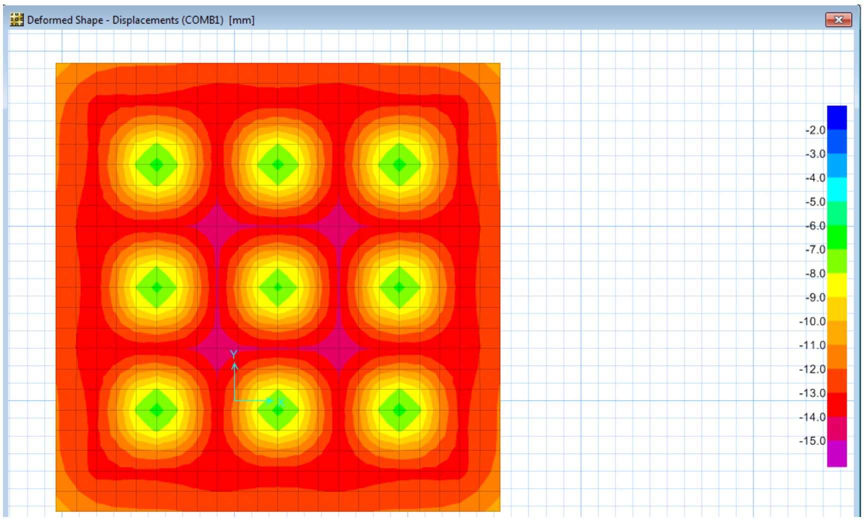


Fig-5.2.5.2:Deformation(in mm) graph of box type raft on soil-2 (i.e. Sandy Soil with low percentage of gravel)

5.2.5.3 Deformation(in mm) graph of box type raft on Clayey Sand Silt with Gravels:

Deformation/ settlement graph of box type raft onsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.2.5.3. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 13.9 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

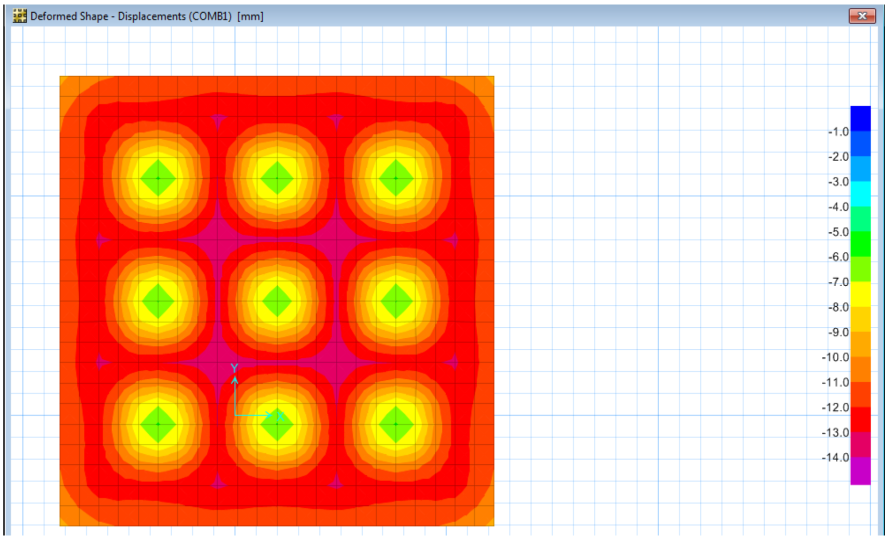


Fig-5.2.5.3:Deformation(in mm) graph of box type raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.2.5.4Deformation(in mm) graph of box type raft onSandy Silt:

Deformation/ settlement graph of box typeraft onsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.2.5.4. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 13.2 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

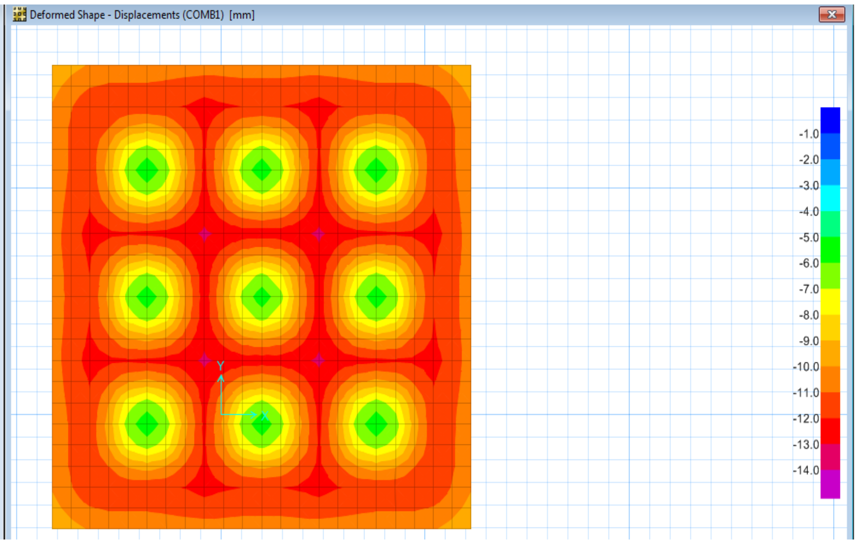


Fig-5.2.5.4:Deformation(in mm) graph of box type raft on soil-4 (i.e. Sandy Silt)

5.2.5.5 Deformation(in mm) graph of box type raft onSand-Silt mix with or without Gravel:

Deformation/ settlement graph of box typeraft onsoil-5 (i.e. Sand-Silt Mix with or without gravel)is shown below in fig. 5.2.5.5. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 11.1 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

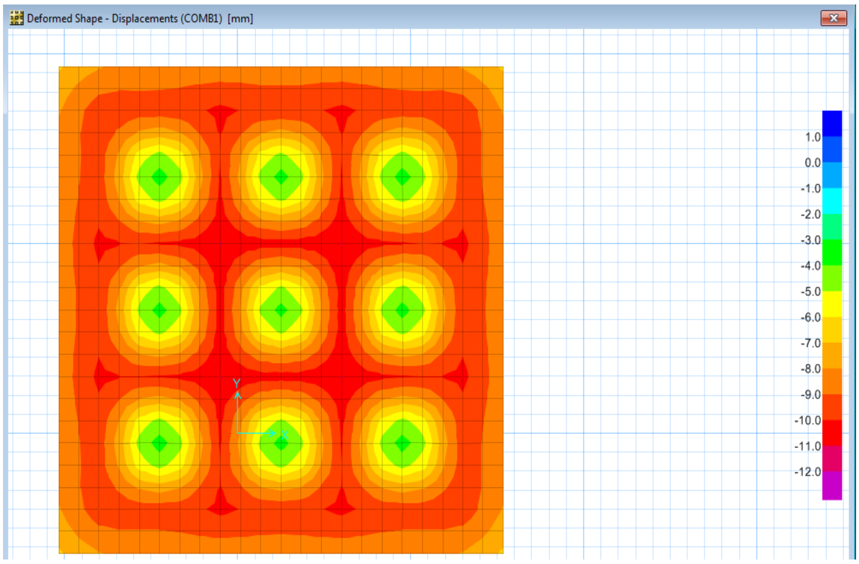


Fig-5.2.5.5:Deformation(in mm) graph of box type raft on soil-5 (i.e., Sand-Silt mix with or without Gravel)

5.2.5.6 Deformation(in mm) graph of box type raft on Hard Mooram with Kanker:

Deformation/ settlement graph of box type raft onsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.2.5.6. Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 9.3 mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

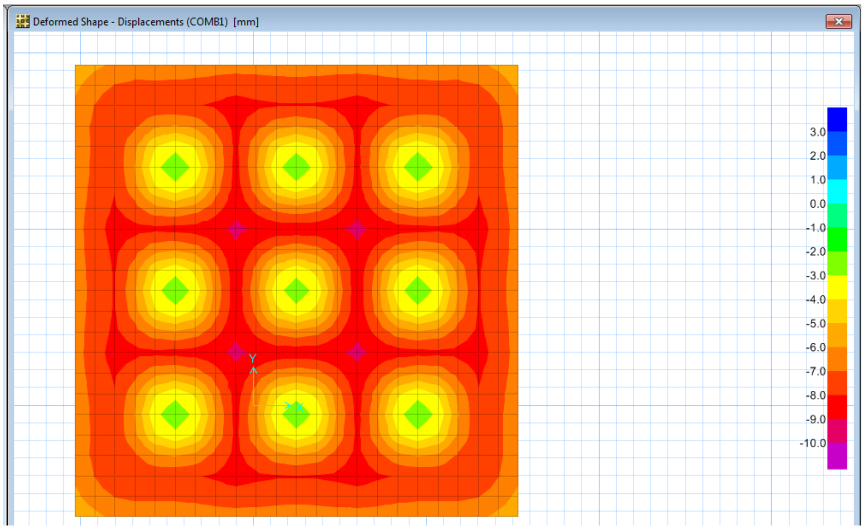


Fig-5.2.5.6:Deformation(in mm) graph of box type raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.2.5: Deformation(in mm) in box type raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Deformation(in mm)		
				At centre of raft	At edges of raft	At corners of raft
1	Sandy Clayey Silt	10000	195	-11.1	-17.0	-15.4
2	Sandy Soil with low percentage of gravel	14000	205	-6.8	-12.0	-10.6
3	Clayey Sand Silt with Gravels	15000	235	-6.0	-11.2	-9.7
4	Sandy Silt	16000	245	-5.4	-10.5	-9.0
5	Sand-Silt mix with or without Gravel	20000	195	-3.7	-8.3	-6.9
6	Hard Mooram with Kanker	25000	270	-2.3	-6.5	-5.2

Note: As per IS:1904-1986Clause-16.3.4 ,Permissible max. settlement for reinforced concrete raft foundations is 75mm.

5.2.6 Deformation graphs of pile raft on different soil types

Deformation graphs of pile raft for the six different soil types are discussed in this section and a comparison for settlement of this type of raft for three critical locations(i.e. centre, edges and corners) is given in Table 5.2.6

5.2.6.1 Deformation(in mm) graph of pile raft on Sandy Clayey Silt:

Deformation/ settlement graph of pile raft onsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.2.6.1.Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 4.1mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

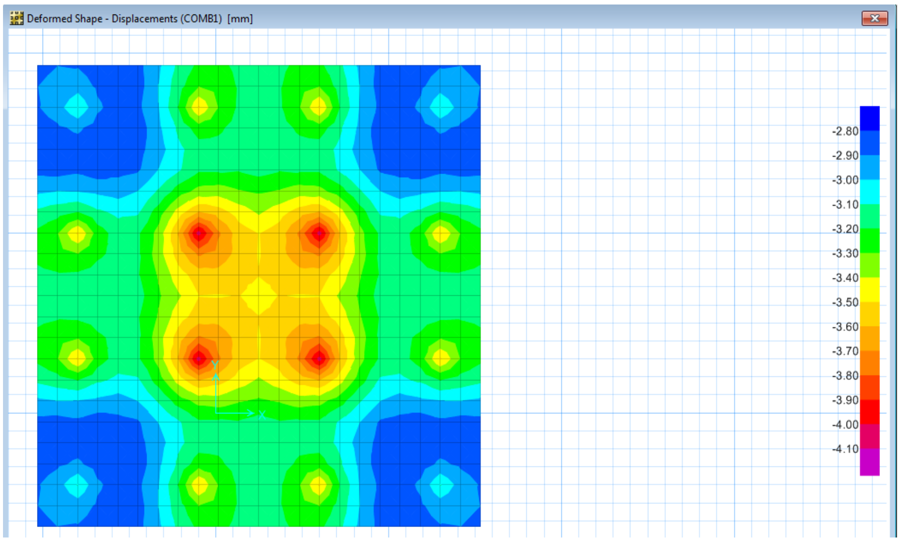


Fig-5.2.6.1: Deformation(in mm) graph of pile raft on soil-1 (i.e. Sandy Clayey Silt)

5.2.6.2 Deformation(in mm) graph of pile raft on Sandy Soil with low percentage of gravel:

Deformation/ settlement graph of pile raft onsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.2.6.2.Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 3.9mm

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

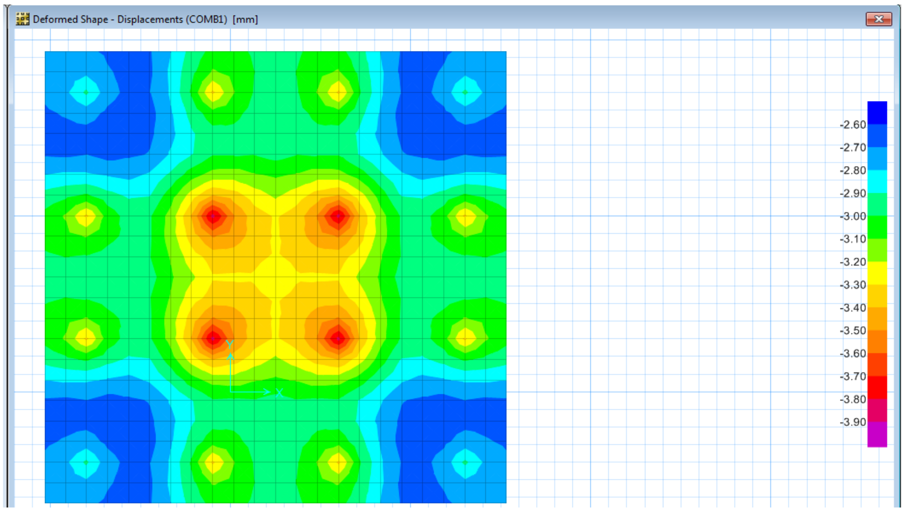


Fig-5.2.6.2: Deformation(in mm) graph of pile raft on soil-2 (i.e. Sandy Soil with low percentage of gravel)

5.2.6.3 Deformation(in mm) graph of pile raft on Clayey Sand Silt with Gravels:

Deformation/ settlement graph of pile raft onsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.2.6.3.Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 3.8mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

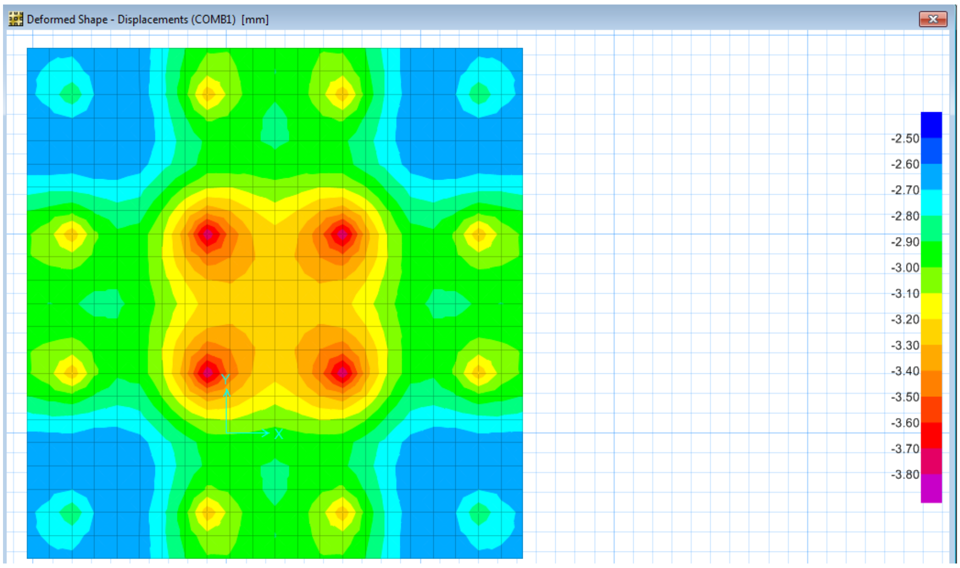


Fig-5.2.6.3: Deformation(in mm) graph of pile raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.2.6.4 Deformation(in mm) graph of pile raft on Sandy Silt:

Deformation/ settlement graph of pile raft onsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.2.6.4.Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 3.7mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

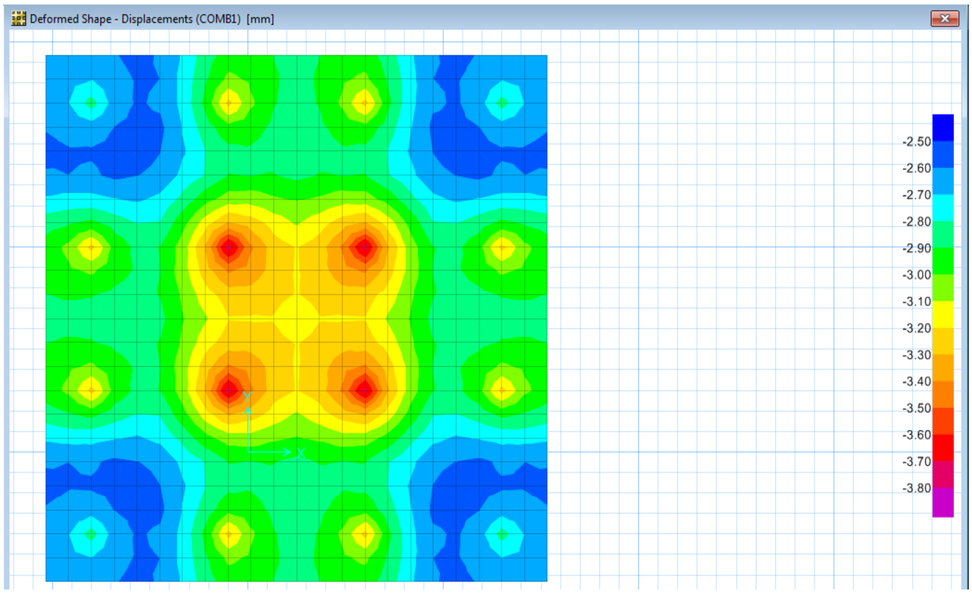


Fig-5.2.6.4: Deformation(in mm) graph of pile raft on soil-4 (i.e. Sandy Silt)

5.2.6.5 Deformation(in mm) graph of pile raft on Sand-Silt mix with or without Gravel:

Deformation/ settlement graph of pile raft onsoil-5 (i.e. Sand-Silt Mix with or without gravel)is shown below in fig. 5.2.6.5.Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 3.6mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

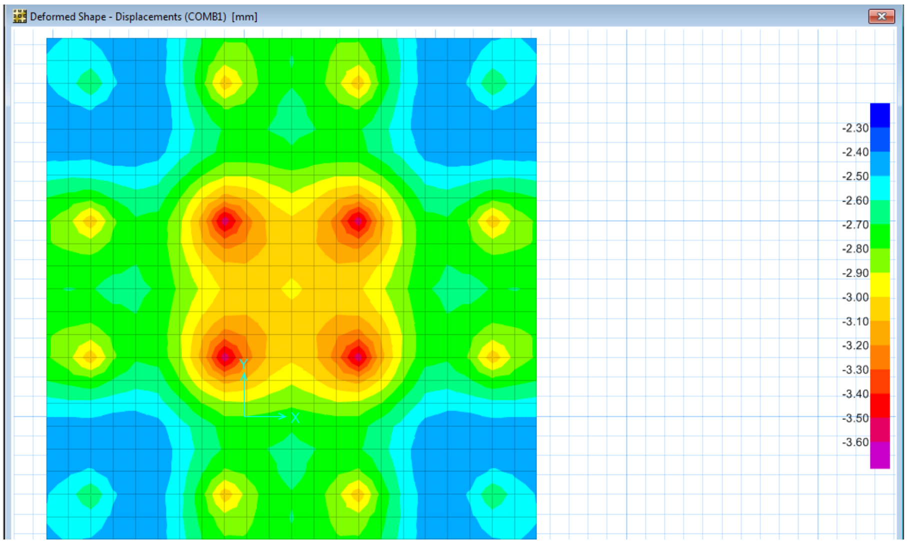


Fig-5.2.6.5: Deformation(in mm) graph of pile raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.2.6.6 Deformation(in mm) graph of pile raft on Hard Mooram with Kanker:

Deformation/ settlement graph of pile raft onsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.2.6.6.Maximum settlement is below the interior four columns. The magnitude of maximum settlement is 3.4mm.

[Note: Location of maximum settlement is same as marked in fig.5.2.1.1]

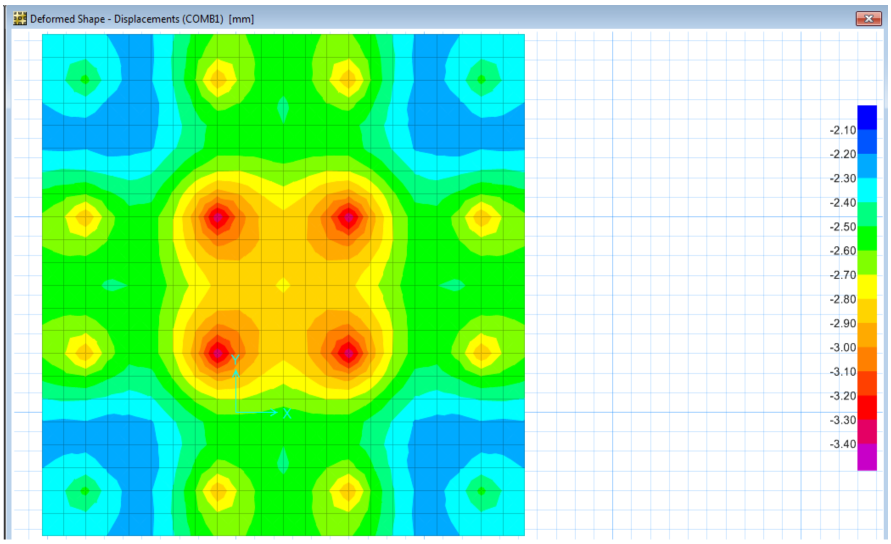


Fig-5.2.6.6: Deformation(in mm) graph of pile raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.2.6: Deformation(in mm) in pile raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Deformation(in mm)		
				At centre of raft	At edges of raft	At corners of raft
1	Sandy Clayey Silt	10000	195	3.5	3.2	2.9
2	Sandy Soil with low percentage of gravel	14000	205	3.3	3.0	2.7
3	Clayey Sand Silt with Gravels	15000	235	3.2	2.9	2.7
4	Sandy Silt	16000	245	3.2	2.9	2.6
5	Sand-Silt mix with or without Gravel	20000	195	3.0	2.7	2.5
6	Hard Mooram with Kanker	25000	270	2.8	2.5	2.3

Note: As per IS:1904-1986Clause-16.3.4 ,Permissible max. settlement for reinforced concrete raft foundations is 75mm.

5.2.7 Maximum overall settlement and maximum differential settlement in rafts for different soils

Maximum value of overall settlement and maximum value of differential settlement in all six rafts for various soils considered is given below in table no. 5.2.7 with their permissible values as per IS : 1904-1986, clause 16.3.4(table-1).

Table-5.2.7: Max. settlement/differential settlement(in mm) in different rafts for different soil:

S. No.	Foundation system type	Permissible max. settlement (as per IS:1904-1986 Clause-16.3.4 Table-1) (mm)	Actual max. settlement in raft (mm)	Permissible max. Differential settlement (as per IS:1904-1986Clause -16.3.4 Table-1) (0.0021L) (mm)	Actual max. Differential settlement in raft (mm)	
					On a single strip in a 7m span (mm)	Max. settlement - min. settlement (mm)
1	Flat Plate raft on soil-1	75	21.4	14.7	1.9	3.4
2	Flat Plate raft on soil-2	75	15.6	14.7	1.7	2.9

3	Flat Plate raft on soil-3	75	14.6	14.7	1.6	2.8
4	Flat Plate raft on soil-4	75	13.7	14.7	1.6	2.7
5	Flat Plate rafton soil-5	75	11.2	14.7	1.4	2.4
6	Flat Plate raft on soil-6	75	9.1	14.7	1.3	2.1
7	Slab beamraft on soil-1	75	21.1	14.7	2.6	4.6
8	Slab beamrafton soil-2	75	15.5	14.7	2.1	3.7
9	Slab beam raft on soil-3	75	14.5	14.7	2.0	3.6
10	Slab beam raft on soil-4	75	13.6	14.7	1.9	3.5
11	Slab beamrafton soil-5	75	11.2	14.7	1.7	3.2
12	Slab beamrafton soil-6	75	9.2	14.7	1.4	3.1
13	Flat plate raft thickened under column on soil-1	75	21.0	14.7	1.9	3.3
14	Flat plate raft thickened under column on soil-2	75	15.3	14.7	1.6	2.7
15	Flat plate raft thickened under column on soil-3	75	14.3	14.7	1.5	2.6
16	Flat plate raft thickened under column on soil-4	75	13.5	14.7	1.5	2.5
17	Flat plate raft thickened under column on soil-5	75	11.0	14.7	1.3	2.1
18	Flat plate raft thickened under column on soil-6	75	9.0	14.7	1.2	1.9
19	Flat plate with pedestal on soil-1	75	20.5	14.7	1.9	3.9
20	Flat plate with pedestal on soil-2	75	15.1	14.7	1.3	3.6
21	Flat plate with pedestal on soil-3	75	14.1	14.7	1.3	3.5
22	Flat plate with pedestal on soil-4	75	13.3	14.7	1.2	3.4
23	Flat plate with pedestalon soil-5	75	10.9	14.7	0.9	3.2

24	Flat plate with pedestal on soil-6	75	9.0	14.7	0.8	3.0
25	Box raft on soil-1	75	19.6	14.7	1.6	8.7
26	Box raft on soil-2	75	14.7	14.7	1.6	8.1
27	Box raft on soil-3	75	13.9	14.7	1.6	8.0
28	Box raft on soil-4	75	13.2	14.7	1.6	7.9
29	Box raft on soil-5	75	11.1	14.7	1.5	7.5
30	Box raft on soil-6	75	9.3	14.7	1.8	7.0
31	Pile raft on soil-1	75	4.1	14.7	0.5	1.2
32	Pile raft on soil-2	75	3.9	14.7	0.5	1.2
33	Pile raft on soil-3	75	3.8	14.7	0.5	1.2
34	Pile raft on soil-4	75	3.7	14.7	0.5	1.2
35	Pile raft on soil-5	75	3.6	14.7	0.5	1.2
36	Pile raft on soil-6	75	3.4	14.7	0.5	1.2

5.3 Punching Shear behavior in rafts

In this section, Punching shear values for various columns of all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are sequentially mentioned and discussed.

5.3.1 Punching shear values for various columns of flat plate raft on different Soil types

Punching shear values for various columns of flat plate raft for the six different soil types are discussed in this section and a comparison for punching shear values of this raft for various columns at three critical locations (i.e. centre, edges and corners) is given in Table 5.3.1

5.3.1.1: Punching shear values for various columns of flat plate raft on Sandy Clayey Silt:

Punching shear values for various columns of flat plate raft on soil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.3.1.1.It is observed that punching shear is maximum of 1.1012 N/mm^2 at central columns and minimum of 0.5275 N/mm^2 at corner columns.

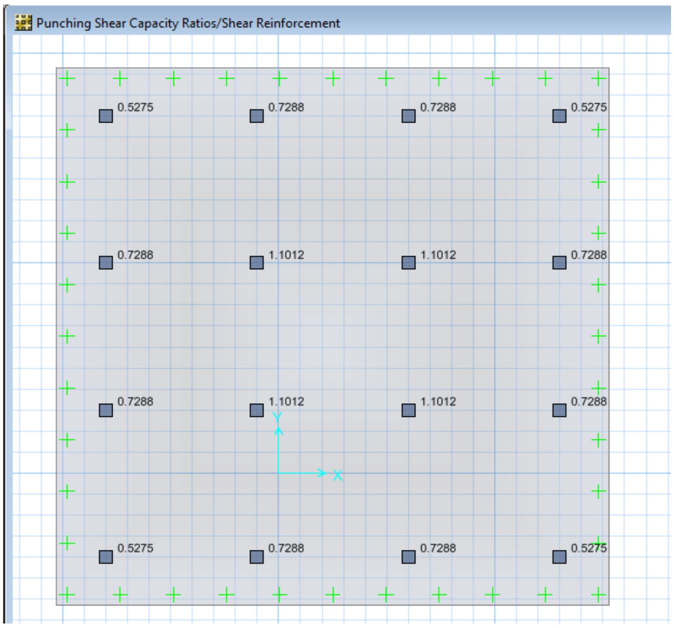


Fig-5.3.1.1: Punching shear values for various columns of flat plate raft on soil-1 (i.e. Sandy Clayey Silt)

5.3.1.2: Punching shear values for various columns of flat plate raft on Sandy Soil with low percentage of gravel:

Punching shear values for various columns of flat plate raft on soil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.3.1.2.It is observed that punching shear is maximum of 1.1005 N/mm² at central columns and minimum of 0.5262 N/mm² at corner columns.

Fig-5.3.1.2: Punching shear values for various columns of flat plate raft on soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.3.1.3: Punching shear values for various columns of flat plate raft on Clayey Sand Silt with Gravels:

Punching shear values for various columns of flat plate raft on soil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.3.1.3.It is observed that punching shear is maximum of 1.1004 N/mm² at central columns and minimum of 0.526 N/mm² at corner columns.

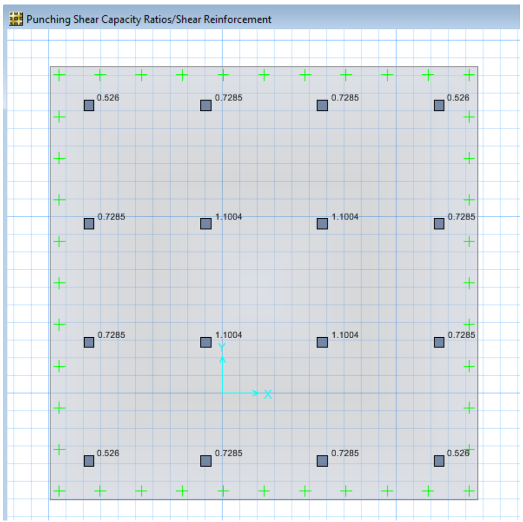


Fig-5.3.1.3: Punching shear values for various columns of flat plate raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.3.1.4: Punching shear values for various columns of flat plate raft on Sandy Silt:

Punching shear values for various columns of flat plate raft on soil-4 (i.e. Sandy Silt)is shown below in fig. 5.3.1.4.It is observed that punching shear is maximum of 1.1002 N/mm² at central columns and minimum of 0.5258 N/mm² at corner columns.

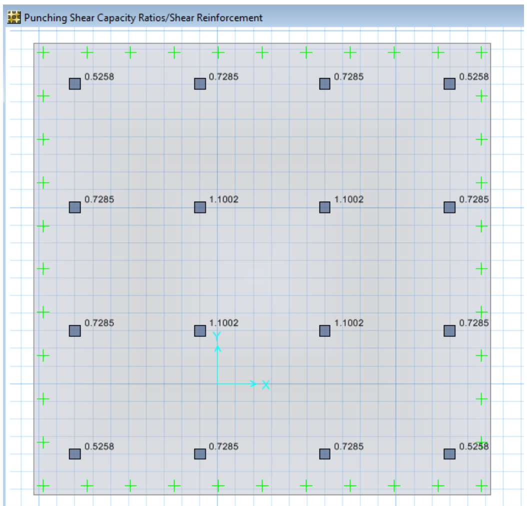


Fig-5.3.1.4: Punching shear values for various columns of flat plate raft on soil-4 (i.e. Sandy Silt)

5.3.1.5: Punching shear values for various columns of flat plate raft on Sand-Silt mix with or without Gravel:

Punching shear values for various columns of flat plate raft on soil-5 (i.e., Sand-Silt Mix with or without gravel)is shown below in fig. 5.3.1.5.It is observed that punching shear is maximum of 1.0996 N/mm² at central columns and minimum of 0.5252 N/mm² at corner columns.

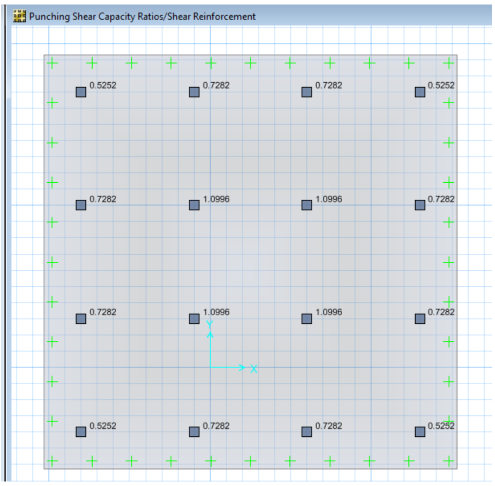


Fig-5.3.1.5: Punching shear values for various columns of flat plate raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.3.1.6: Punching shear values for various columns of flat plate raft on Hard Mooram with Kanker:

Punching shear values for various columns of flat plate raft on soil-6 (i.e., Hard Mooram with Kanker)is shown below in fig. 5.3.1.6.It is observed that punching shear is maximum of 1.099 N/mm² at central columns and minimum of 0.5247 N/mm² at corner columns.

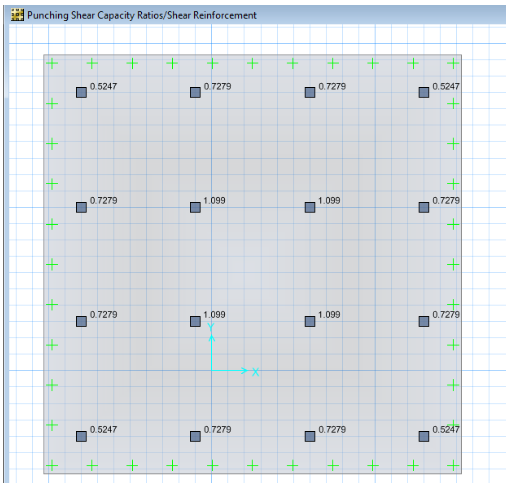


Fig-5.3.1.6: Punching shear values for various columns of flat plate raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.3.1:Punching shear in flat plate raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Punching shear (N/mm²)		
				below central columns of raft	below columns on edge of raft	Below columns on corner of raft
1	Sandy Clayey Silt	10000	195	1.10	0.73	0.53
2	Sandy Soil with low % of gravel	14000	205	1.10	0.73	0.53
3	Clayey Sand Silt with Gravels	15000	235	1.10	0.73	0.53
4	Sandy Silt	16000	245	1.10	0.73	0.53
5	Sand-Silt mix with or without Gravel	20000	195	1.10	0.73	0.53
6	Hard Mooram with Kanker	25000	270	1.10	0.73	0.53

5.3.2 Punching shear values for various columns of slab beam raft on different Soil types

Punching shear values for various columnsof slab beam raft for the six different soil types are discussed in this section. As two way shear is countered by the shear reinforcement in beams, so it is not calculated here.

5.3.3 Punching shear values for various columns of flat plate thickened under columnraft on different soiltypes

Punching shear values of plate thickened under column raft for the six different soil types are discussed in this section and a comparison for punching shear of this raft for various columns at threecritical locations(i.e.centre, edges and corners) is given in Table 5.3.3

5.3.3.1: Punching shear values for various columns of flat plate thickened under columnraft on Sandy Clayey Silt:

Punching shear values for various columns of flat plate thickened under column raft on soil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.3.3.1.It is observed that punching shear is maximum of 0.8753 N/mm² at central columns and minimum of 0.4223 N/mm² at corner columns.

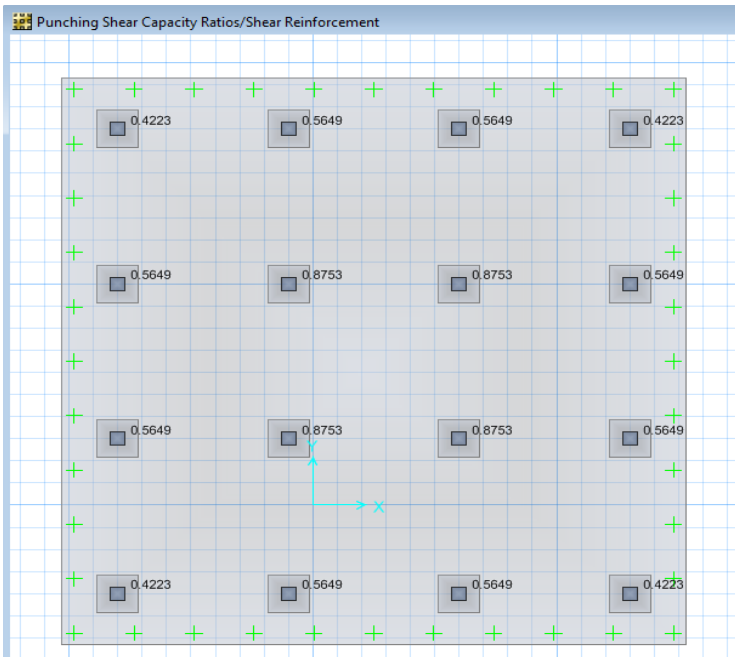


Fig-5.3.3.1: Punching shear values for various columns of flat plate thickened under column raft on soil-1 (i.e. Sandy Clayey Silt)

5.3.3.2: Punching shear values for various columns of flat plate thickened under columnraft on Sandy Soil with low percentage of gravel:

Punching shear values for various columns of flat plate thickened under column raft on soil-2 (i.e., Sandy Soil with low percentage of gravel)is shown below in fig. 5.3.3.2. It is observed that punching shear is maximum of 0.873 N/mm² at central columns and minimum of 0.4188 N/mm² at corner columns.

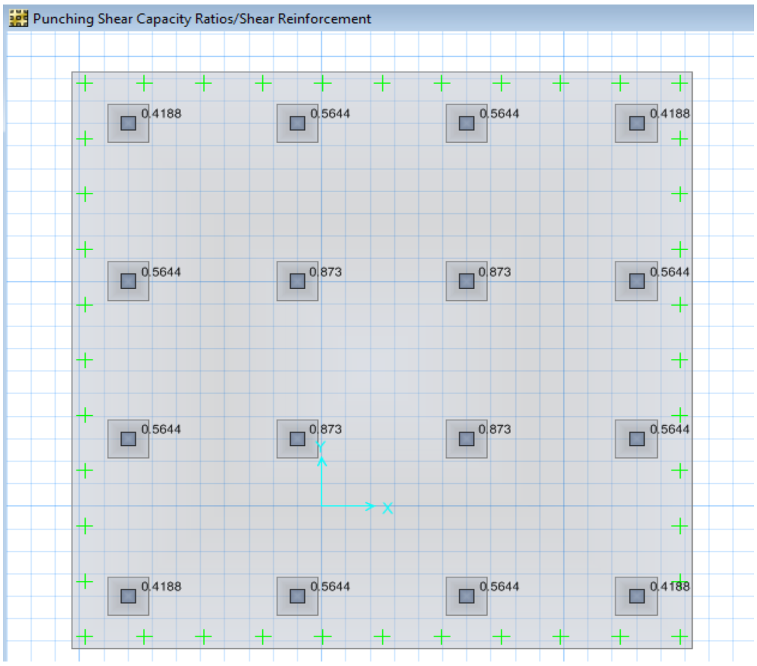


Fig-5.3.3.2: Punching shear values for various columns of flat plate thickened under column raft on soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.3.3.3: Punching shear values for various columns of flat plate thickened under columnraft onClayey Sand Silt with Gravels:

Punching shear values for various columns of flat plate thickened under column raft on soil-3 (i.e., Clayey Sand Silt with Gravels)is shown below in fig. 5.3.3.3. It is observed that punching shear is maximum of 0.8725 N/mm² at central columns and minimum of 0.4179 N/mm² at corner columns.

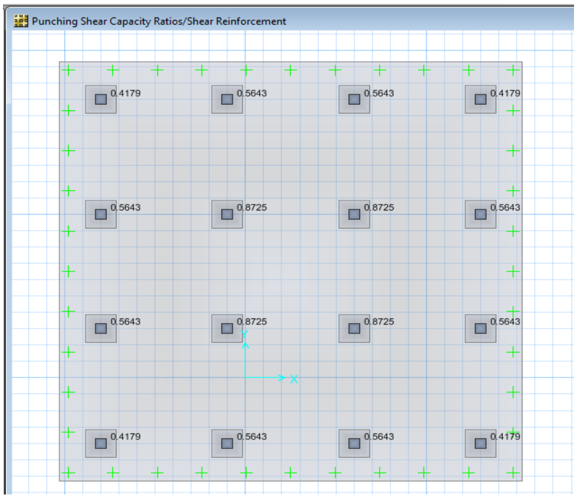


Fig-5.3.3.3: Punching shear values for various columns of flat plate thickened under column raft on soil-3 (i.e. Clayey Sand Silt with Gravels)

5.3.3.4: Punching shear values for various columns of flat plate thickened under columnraft onSandy Silt:

Punching shear values for various columns of flat plate thickened under column raft on soil-4 (i.e., Sandy Silt) is shown below in fig. 5.3.3.4. It is observed that punching shear is maximum of 0.872 N/mm² at central columns and minimum of 0.4169 N/mm² at corner columns.

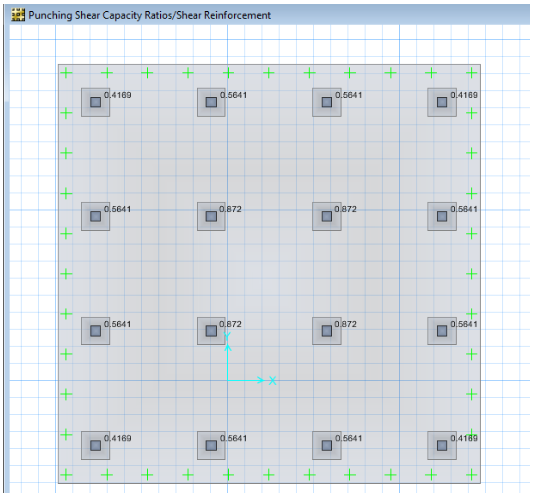


Fig-5.3.3.4: Punching shear values for various columns of flat plate thickened under column raft on soil-4 (i.e. Sandy Silt)

5.3.3.5: Punching shear values for various columns of flat plate thickened under columnraft onSand-Silt mix with or without Gravel:

Punching shear values for various columns of flat plate thickened under column raft on soil-5 (i.e., Sand-Silt Mix with or without gravel) is shown below in fig. 5.3.3.5. It is observed that punching shear is maximum of 0.8701 N/mm² at central columns and minimum of 0.4127 N/mm² at corner columns.

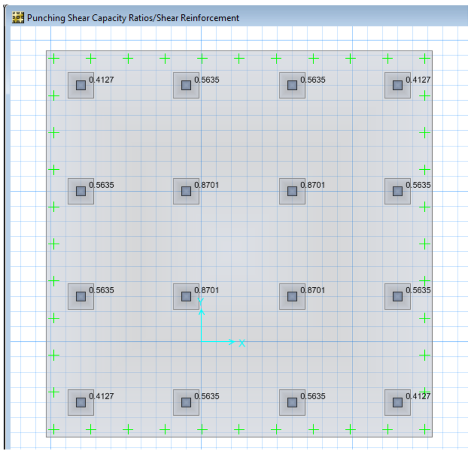


Fig-5.3.3.5: Punching shear values for various columns of flat plate thickened under column raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.3.3.6: Punching shear values for various columns of flat plate thickened under columnraft onHard Mooram with Kanker:

Punching shear values for various columns of flat plate thickened under column raft on soil-6 (i.e., Hard Mooram with Kanker)is shown below in fig. 5.3.3.6. It is observed that punching shear is maximum of 0.868 N/mm² at central columns and minimum of 0.4075 N/mm² at corner columns.

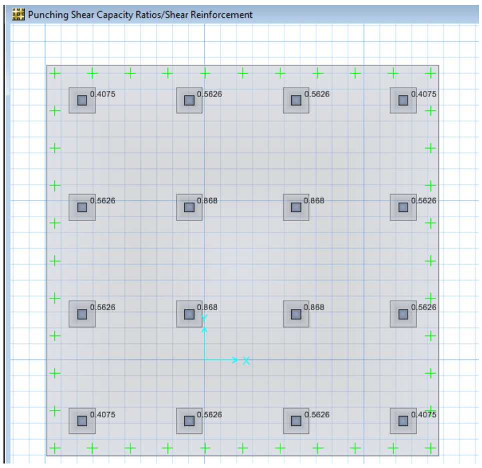


Fig-5.3.3.6: Punching shear values for various columns of flat plate thickened under column raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.3.3:Punching inflat plate thickened under column raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Punching shear (N/mm²)		
				below central column s of raft	below columns on edge of raft	Below column s on corner of raft
1	Sandy Clayey Silt	10000	195	0.88	0.57	0.42
2	Sandy Soil with low percentage of gravel	14000	205	0.87	0.56	0.42
3	Clayey Sand Silt with Gravels	15000	235	0.87	0.56	0.42
4	Sandy Silt	16000	245	0.87	0.56	0.42
5	Sand-Silt mix with or without Gravel	20000	195	0.87	0.56	0.41
6	Hard Mooram with Kanker	25000	270	0.87	0.56	0.41

5.3.4 Punching shear values for various columns of flat plate with pedestal raft on different soiltypes

Punching shear values for various columnsof flat plate with pedestal raft for the six different soil types are discussed in this section and a comparison for punching shear values of this raft for various columns at three critical locations(i.e.centre, edges and corners) is given in Table 5.3.4

5.3.4.1: Punching shear values for various columns of flat platewith pedestalraft on Sandy Clayey Silt:

Punching shear values for various columns of flat plate with pedestal raft on soil-1 (i.e. Sandy Clayey Silt) is shown below in fig. 5.3.4.1. It is observed that punching shear is maximum of 1.1422 N/mm² at central columns and minimum of 0.5659 N/mm² at corner columns.

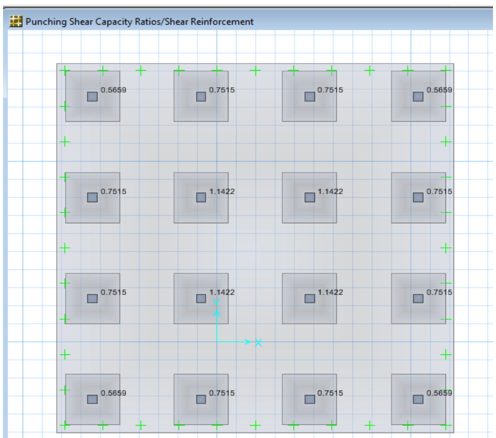


Fig-5.3.4.1: Punching shear values for various columns of flat plate with pedestal raft on soil-1 (i.e. Sandy Clayey Silt)

5.3.4.2: Punching shear values for various columns of flat platewith pedestalraft onSandy Soil with low percentage of gravel:

Punching shear values for various columns of flat plate with pedestal raft on soil-2 (i.e. Sandy Soil with low percentage of gravel) is shown below in fig. 5.3.4.2. It is observed that punching shear is maximum of 1.1395 N/mm² at central columns and minimum of 0.5389 N/mm² at corner columns.

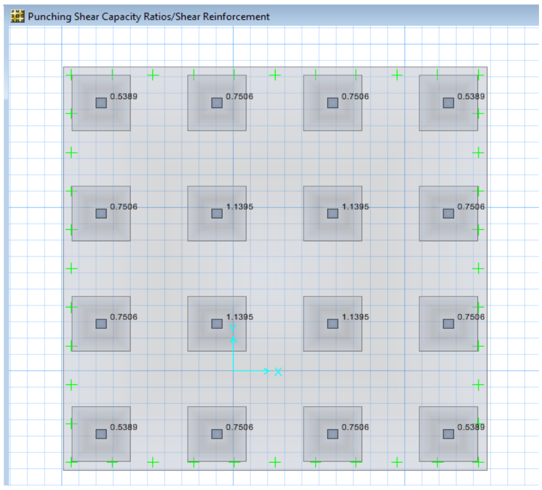


Fig-5.3.4.2: Punching shear values for various columns of flat plate with pedestal raft for soil-2 (i.e., Sandy Soil with low percentage of gravel)

5.3.4.3: Punching shear values for various columns of flat platewith pedestalraft onClayey Sand Silt with Gravels:

Punching shear values for various columns of flat plate with pedestal raft on soil-3 (i.e., Clayey Sand Silt with Gravels) is shown below in fig. 5.3.4.3. It is observed that punching shear is maximum of 1.1389 N/mm² at central columns and minimum of 0.5331 N/mm² at corner columns.

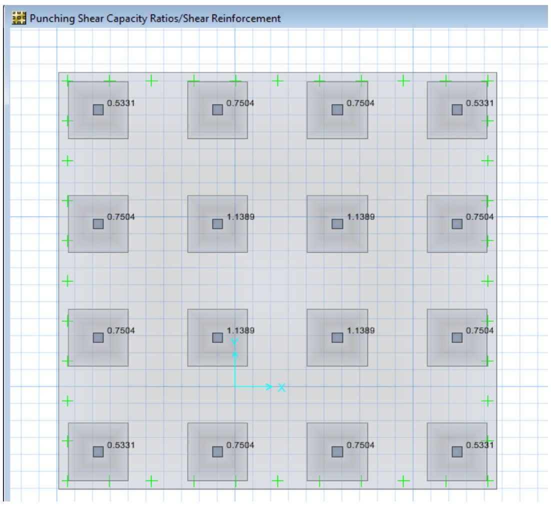


Fig-5.3.4.3: Punching shear values for various columns of flat plate with pedestal raft for soil-3 (i.e., Clayey Sand Silt with Gravels)

5.3.4.4: Punching shear values for various columns of flat platewith pedestalraft onSandy Silt:

Punching shear values for various columns of flat plate with pedestal raft on soil-4 (i.e., Sandy Silt) is shown below in fig. 5.3.4.4. It is observed that punching shear is maximum of 1.1382 N/mm² at central columns and minimum of 0.5275 N/mm² at corner columns.

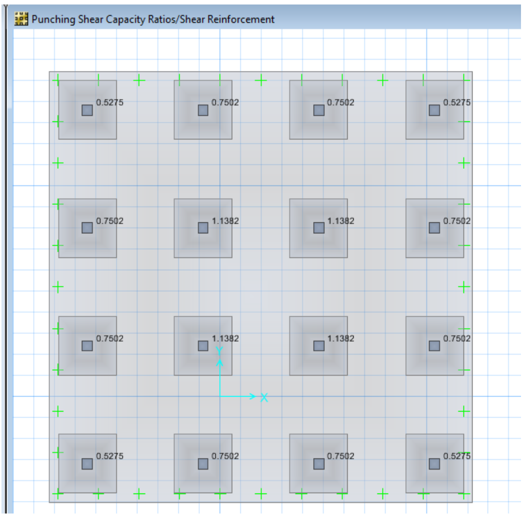


Fig-5.3.4.4: Punching shear values for various columns of flat plate with pedestal raft for soil-4 (i.e., Sandy Silt)

5.3.4.5: Punching shear values for various columns of flat platewith pedestalraft onSand-Silt mix with or without Gravel:

Punching shear values for various columns of flat plate with pedestal raft on soil-5 (i.e. Sand-Silt Mix with or without gravel) is shown below in fig. 5.3.4.5. It is observed that punching shear is maximum of 1.1358 N/mm² at central columns and minimum of 0.5149 N/mm² at corner columns.

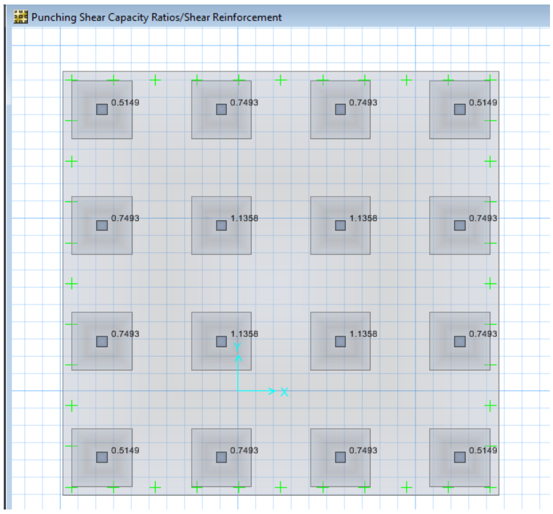


Fig-5.3.4.5: Punching shear values for various columns of flat plate with pedestal raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.3.4.6: Punching shear values for various columns of flat platewith pedestalraft onHard Mooram with Kanker:

Punching shear values for various columns of flat plate with pedestal raft on soil-6 (i.e. Hard Mooram with Kanker) is shown below in fig. 5.3.4.6. It is observed that punching shear is maximum of 1.1328 N/mm² at central columns and minimum of 0.5166 N/mm² at corner columns.

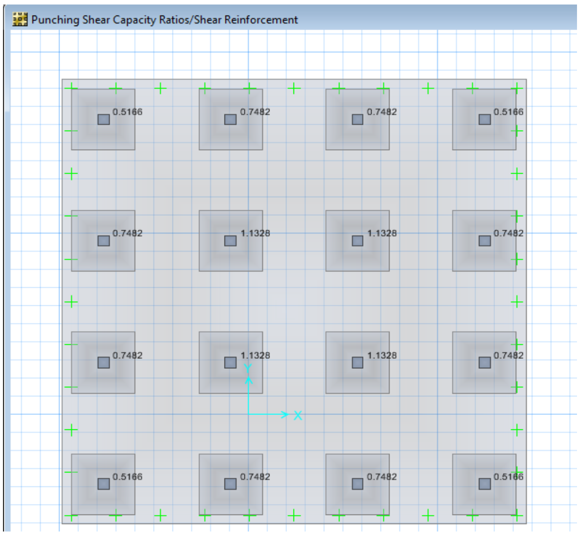


Fig-5.3.4.6: Punching shear values for various columns of flat plate with pedestal raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.3.4:Punching inflat plate with pedestal raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Punching		
				below central columns of raft	below columns on edge of raft	Below columns on corner of raft
1	Sandy Clayey Silt	10000	195	1.14	0.75	0.57
2	Sandy Soil with low percentage of gravel	14000	205	1.14	0.75	0.54
3	Clayey Sand Silt with Gravels	15000	235	1.14	0.75	0.53
4	Sandy Silt	16000	245	1.14	0.75	0.53
5	Sand-Silt mix with or without Gravel	20000	195	1.14	0.75	0.52
6	Hard Mooram with Kanker	25000	270	1.13	0.75	0.52

5.3.5 Punching shear values for various columns of box typeraft on different soil types

Punching shear values for various columnsof box typeraft for the six different soil types are discussed in this section. Punching shear is not calculated under the columns as the RCC walls connecting columns provide rigidity against two way shear.

5.3.6 Punching shear values for various columns and piles of pileraft on different soil types

Punching shear values for various columnsof pile raftfor the six different soil types are discussed in this section and a comparison for punching shear values of this raft for various columns at three critical locations(i.e.centre, edges and corners) is given in Table 5.3.6

5.3.6.1: Punching shear values for various columns of pile raft on Sandy Clayey Silt:

Punching shear values for various columns and piles of pile raft on soil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.3.6.1.It is observed that punching shear is maximum of 1.1275 N/mm² at central columns and minimum of 0.5427 N/mm² at corner columns.

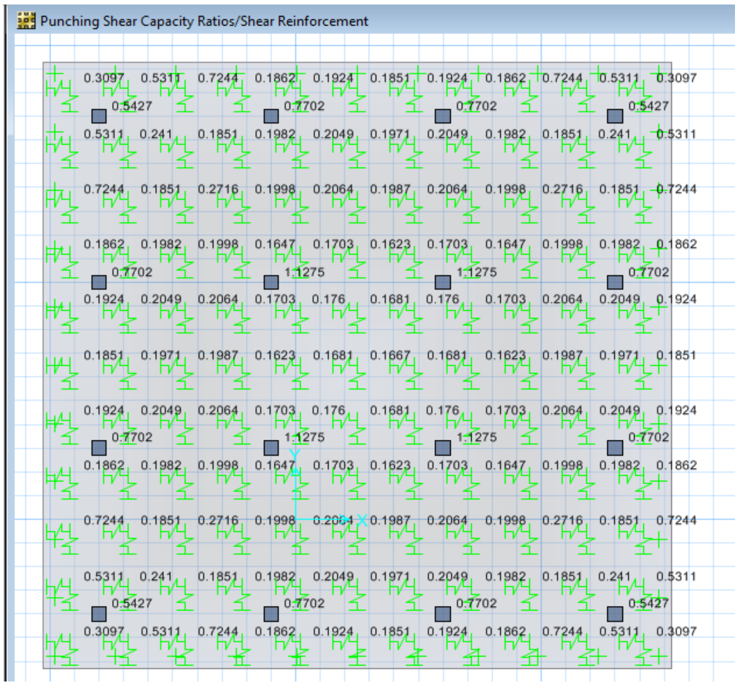


Fig-5.3.6.1: Punching shear values for various columns of pile raft on soil-1 (i.e. Sandy Clayey Silt)

5.3.6.2: Punching shear values for various columns of pile raft onSandy Soil with low percentage of gravel:

Punching shear values for various columns and piles of pile raft on soil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.3.6.2.It is observed that punching shear is maximum of 1.1255 N/mm² at central columns and minimum of 0.5418 N/mm² at corner columns.

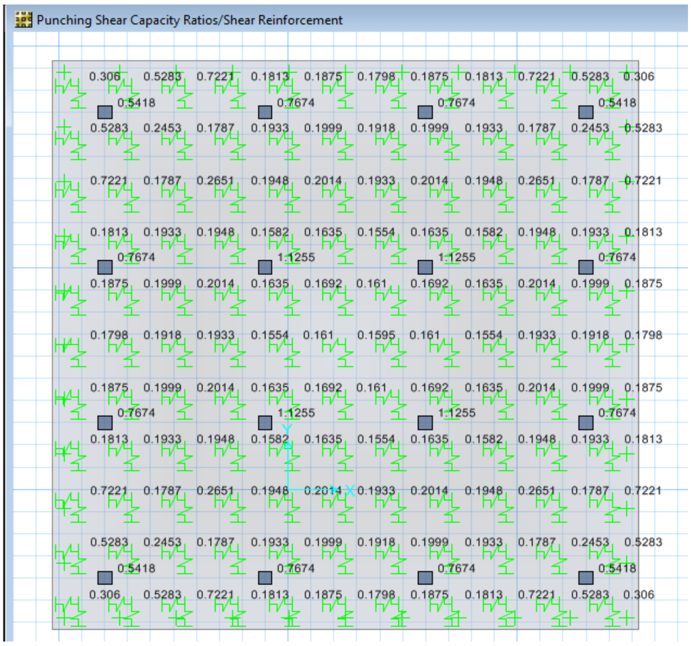


Fig-5.3.6.2: Punching shear values for various columns of pile raft for soil-2 (i.e. Sandy soil with low percentage of gravel)

5.3.6.3: Punching shear values for various columns of pile raft onClayey Sand Silt with Gravels:

Punching shear values for various columns and piles of pile raft on soil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.3.6.3.It is observed that punching shear is maximum of 1.1250 N/mm² at central columns and minimum of 0.5416 N/mm² at corner columns.

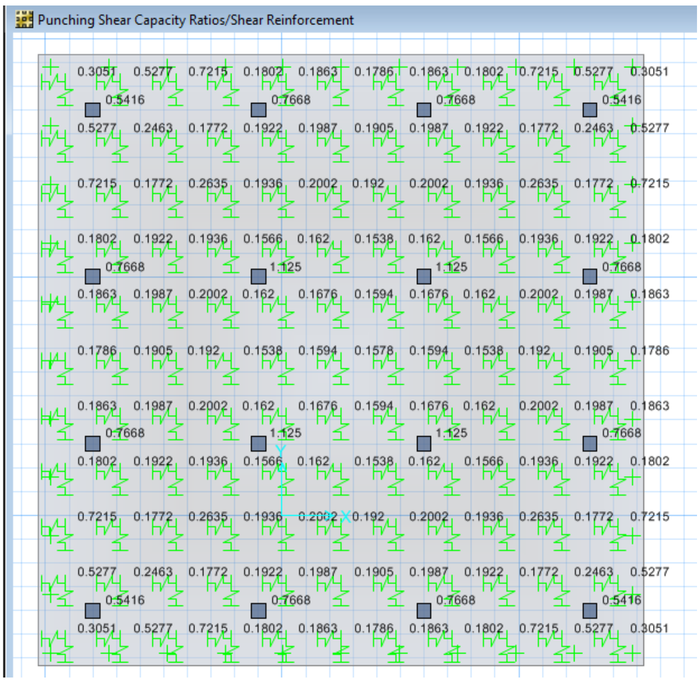


Fig-5.3.6.3: Punching shear values for various columns of pile raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.3.6.4: Punching shear values for various columns of pile raft onSandy Silt:

Punching shear values for various columns and piles of pile raft on soil-4 (i.e. Sandy Silt)is shown below in fig. 5.3.6.4.It is observed that punching shear is maximum of 1.1245 N/mm² at central columns and minimum of 0.5415 N/mm² at corner columns.

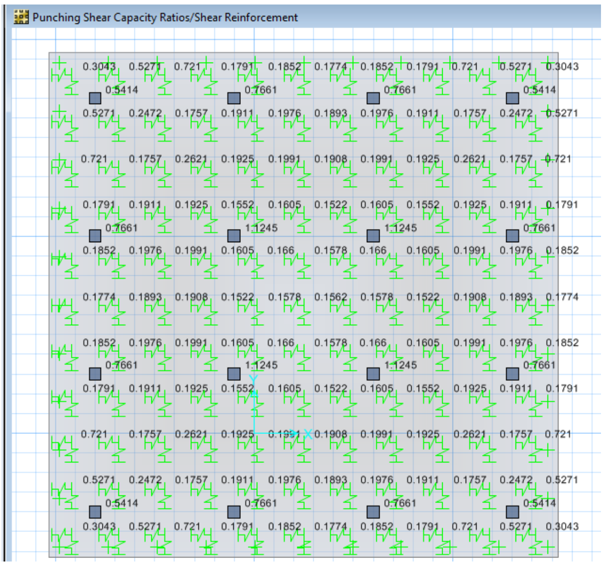


Fig-5.3.6.4: Punching shear values for various columns of pile raft for soil-4 (i.e. Sandy Silt)

5.3.6.5: Punching shear values for various columns of pile raft onSand-Silt mix with or without Gravel:

Punching shear values for various columns and piles of pile raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.3.6.5.It is observed that punching shear is maximum of 1.1227 N/mm² at central columns and minimum of 0.5407 N/mm² at corner columns.

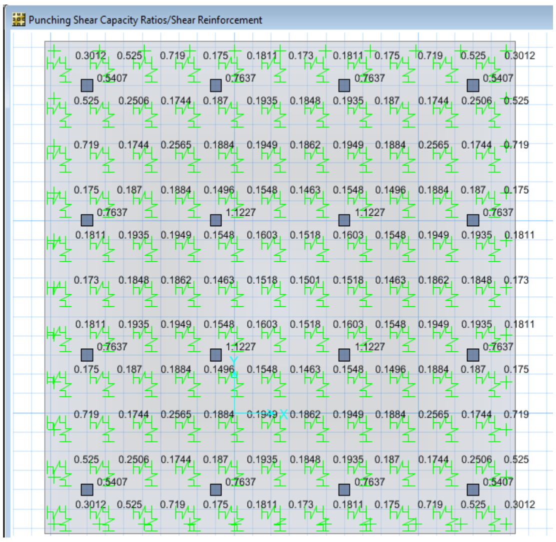


Fig-5.3.6.5: Punching shear values for various columns of pile raft on soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.3.6.6: Punching shear values for various columns of pile raft onHard Mooram with Kanker:

Punching shear values for various columns and piles of pile raft on soil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.3.6.6.It is observed that punching shear is maximum of 1.1206 N/mm² atcentral columns and minimum of 0.5399 N/mm² at corner columns.

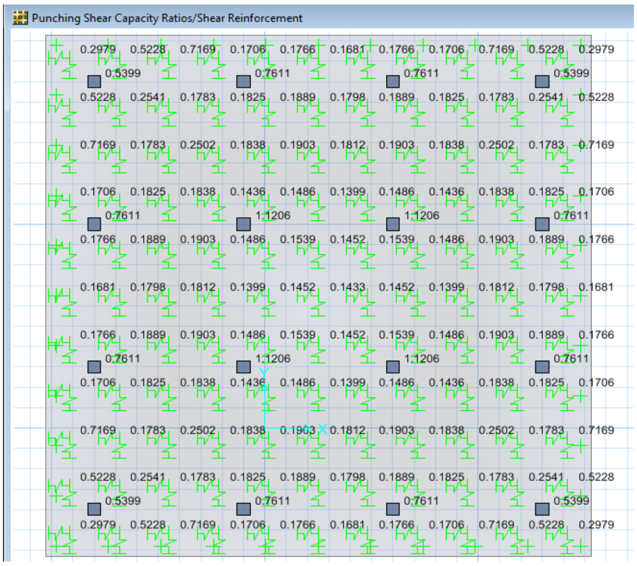


Fig-5.3.6.6: Punching shear values for various columns of pile raft on soil-6 (i.e. Hard Mooram with Kanker)

Table-5.3.6:Punching in pile raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Punching Shear (N/mm²)		
				below central columns of raft	below columns on edge of raft	Below columns on corner of raft
1	Sandy Clayey Silt	10000	195	1.13	0.77	0.54
2	Sandy Soil with low percentage of gravel	14000	205	1.13	0.77	0.54
3	Clayey Sand Silt with Gravels	15000	235	1.13	0.77	0.54
4	Sandy Silt	16000	245	1.13	0.77	0.54
5	Sand-Silt mix with or without Gravel	20000	195	1.12	0.76	0.54
6	Hard Mooram with Kanker	25000	270	1.12	0.76	0.54

5.4 Shear Force Diagrams of Rafts:

In this section, shear force diagram along interior and exterior strip of columns,of all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are sequentially mentioned and discussed.

5.4.1Shear force diagramof flat plate raft on different soiltypes

Shear force diagram along interior and exterior strip of columns,of flat plate raft for the six different soil types are discussed in this section and a comparison for maximum shear force values of this type of rafton all six types of soilis given in Table 5.4.1.

5.4.1.1: Shear force diagram of flat plate raft on Sandy Clayey Silt:

Variation of shear force along interior and exterior strip of columns,of flat plate raft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.4.1.1. It is showing the maximum positive(i.e. on interior strip 1565.97kN; on exterior strip 1073.77kN) and maximum negative (i.e. on interior strip -644.33kN; on exterior strip -459.12kN) shear force values for the two strips.

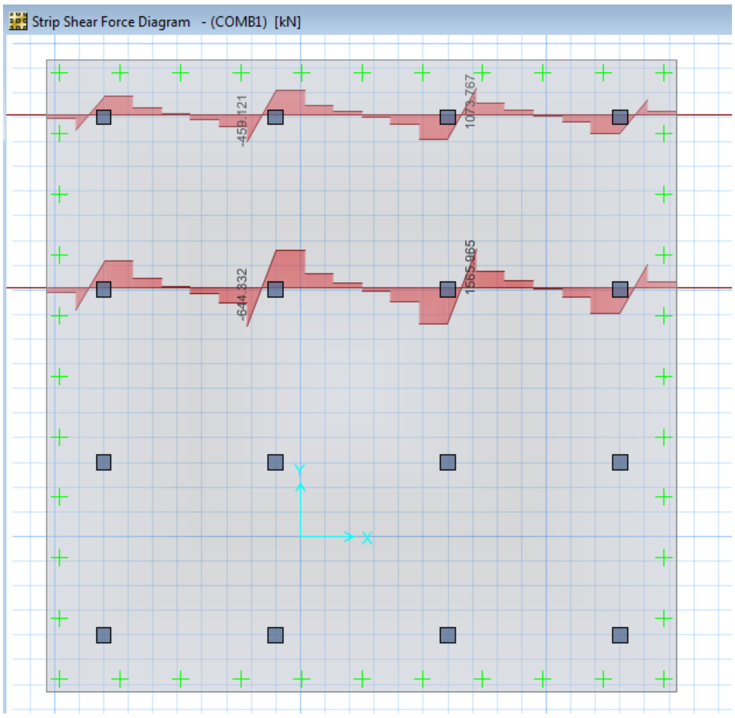


Fig-5.4.1.1: Shear force diagram of flat plate raft for soil-1 (i.e. Sandy Clayey Silt)

5.4.1.2: Shear Force Diagramof flat plate raft onSandy Soil with low percentage of Gravel:

Variation of shear force along interior and exterior strip of columns,of flat plate raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.4.1.2. It is showing the maximum positive(i.e. on interior strip 1560.84 kN; on exterior strip 1069.08 kN) and maximum negative(i.e. on interior strip -638.36 kN; on exterior strip -453.68 kN) shear force values for the two strips.

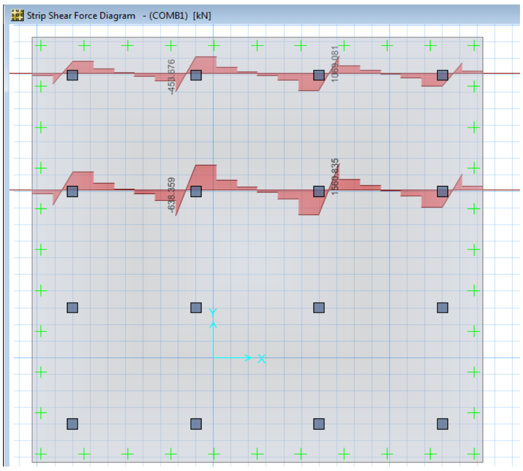


Fig-5.4.1.2: Shear force diagramof flat plate raft for soil-2 (i.e.Sandy Soil with low percentage of Gravel)

5.4.1.3: Shear Force Diagramof flat plate raft onClayey Sand Silt with Gravels:

Variation of shear force along interior and exterior strip of columnsof flat plate raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.4.1.3. It is showing the maximum positive(i.e. on interior strip 1559.75 kN; on exterior strip 1068.10 kN) and maximum negative(i.e. on interior strip -637.10 kN; on exterior strip -452.54 kN) shear force values for the two strips.

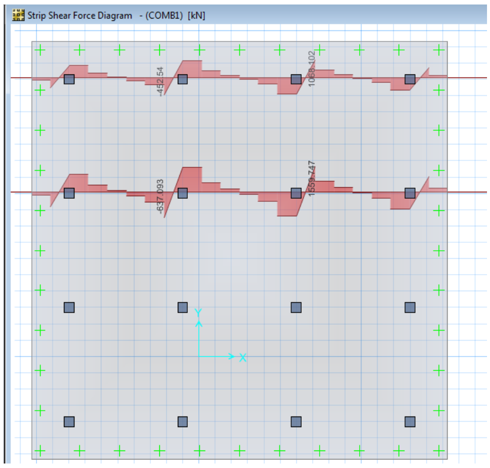


Fig-5.4.1.3: Shear force diagramof flat plate raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.4.1.4: Shear Force Diagramof flat plate raft onSandy Silt:

Variation of shear force along interior and exterior strip of columnsof flat plate raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.4.1.4. It is showing the maximum positive(i.e. on interior strip 1558.72 kN; on exterior strip 1067.18 kN) and maximum negative(i.e. on interior strip -635.90 kN; on exterior strip -451.47 kN) shear force values for the two strips.

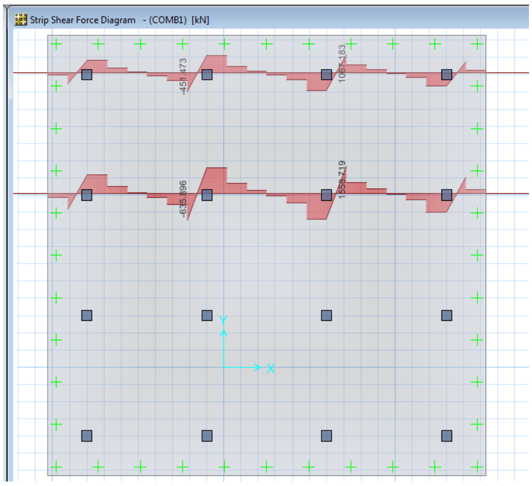


Fig-5.4.1.4: Shear force diagramof flat plate raft for soil-4 (i.e. Sandy Silt)

5.4.1.5: Shear Force Diagramof flat plate raft onSand-Silt mix with or without Gravel:

Variation of shear force along along interior and exterior strip of columnsof flat plate raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.4.1.5. It is showing the maximum positive(i.e. on interior strip 1555.09 kN; on exterior strip 1063.98 kN) and maximum negative(i.e. on interior strip -631.67 kN; on exterior strip -447.75 kN) shear force values for the two strips.

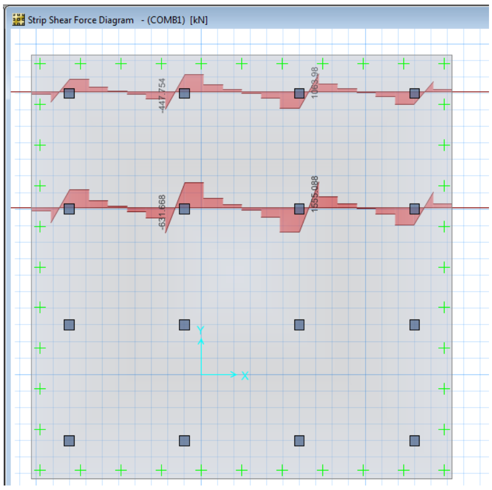


Fig-5.4.1.5: Shear force diagramof flat plate raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.4.1.6: Shear Force Diagramof flat plate raft onHard Mooram with Kanker:

Variation of shear force along interior and exterior strip of columnsof flat plate raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.4.1.6. It is showing the maximum positive(i.e. on interior strip 1551.33 kN; on exterior strip 1060.74 kN) and maximum negative (i.e. on interior strip -627.29 kN; on exterior strip -443.99 kN) shear force values for the two strips.

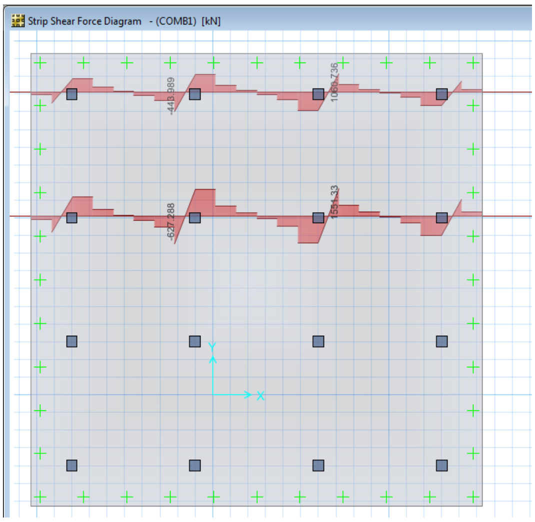


Fig-5.4.1.6: Shear force diagramof flat plate raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.4.1: Max. Shear Force in flat plate raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Max. Shear Force (kN)
1	Sandy Clayey Silt	10000	195	1566
2	Sandy Soil with low percentage of gravel	14000	205	1561
3	Clayey Sand Silt with Gravels	15000	235	1560
4	Sandy Silt	16000	245	1559
5	Sand-Silt Mix with or without gravel	20000	195	1555
6	Hard Mooram with Kanker	25000	270	1551

5.4.2 Shear force diagramof slab beam raft on different soils

Shear force diagram along interior and exterior strip of columns,of slab beam raft for the six different soil types are discussed in this section and a comparison for maximum shear force values of this type of rafton all six types of soilis given in Table no. 5.4.2.

5.4.2.1: Shear Force Diagramof slab beam raft on Sandy Clayey Silt:

Variation of shear force along along interior and exterior strip of columns,of slab beamraft forsoil-1(i.e. Sandy Clayey Silt)is shown below in fig. 5.4.2.1. It is showing the maximum positive(i.e. on interior strip 284.84 kN; on exterior strip 224.98 kN) and maximum negative (i.e. on interior strip -284.84 kN; on exterior strip -224.98 kN) shear force values for the two strips.

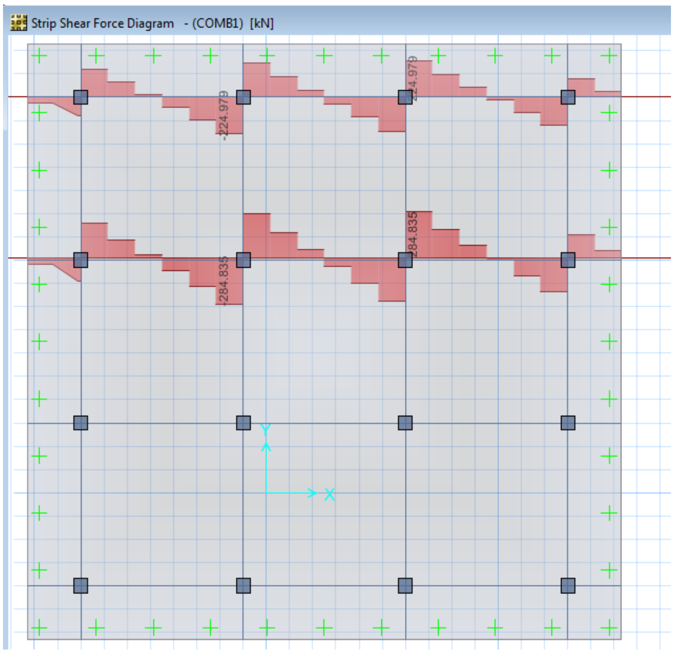


Fig-5.4.2.1: Shear force diagramof slab beam raft for soil-1 (i.e. Sandy Clayey Silt)

5.4.2.2: Shear Force Diagramof slab beam raft onSandy Soil with low percentage of gravel:

Variation of shear force along interior and exterior strip of columns,of slab beam raft forsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.4.2.2. It is showing the maximum positive(i.e. on interior strip 282.85 kN; on exterior strip 222.79 kN) and maximum negative(i.e. on interior strip -282.85 kN; on exterior strip -222.79 kN) shear force values for the two strips.

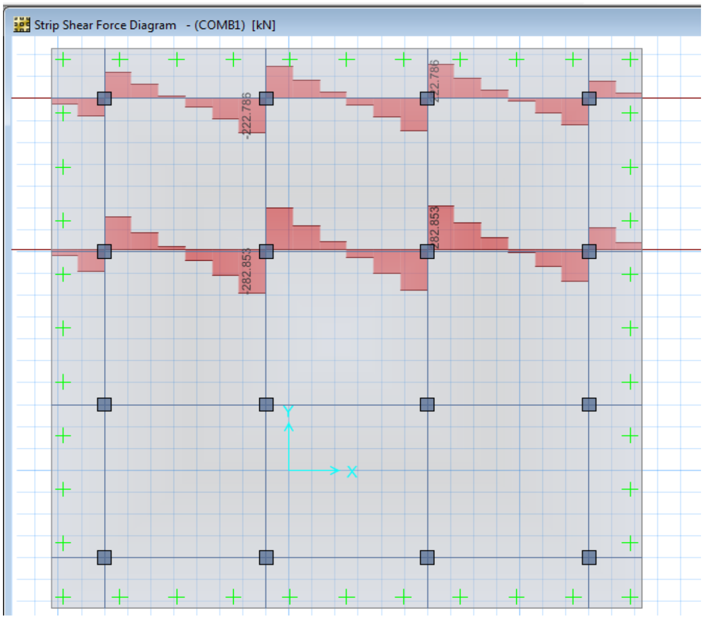


Fig-5.4.2.2: Shear force diagramof slab beam raft for soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.4.2.3: Shear Force Diagramof slab beam raft onClayey Sand Silt with Gravels:

Variation of shear force along interior and exterior strip of columns,of slab beam raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.4.2.3. It is showing the maximum positive(i.e. on interior strip 282.43 kN; on exterior strip 222.33 kN) and maximum negative (i.e. on interior strip -282.43 kN; on exterior strip -222.33 kN) shear force values for the two strips.

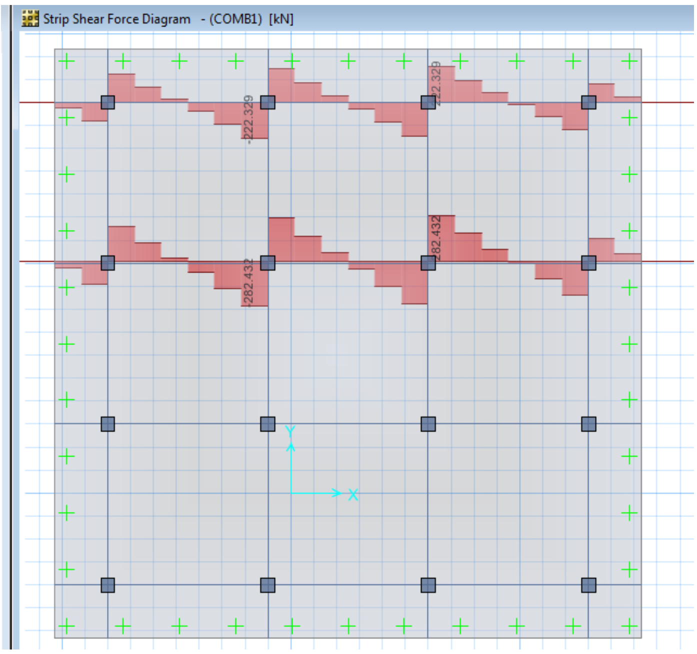


Fig-5.4.2.3: Shear force diagramof slab beam raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.4.2.4: Shear Force Diagramof slab beam raft onSandy Silt:

Variation of shear force along interior and exterior strip of columns,of slab beam raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.4.2.4. It is showing the maximum positive(i.e. on interior strip 282.03 kN; on exterior strip 221.90 kN) and maximum negative(i.e. on interior strip -282.03 kN; on exterior strip -221.90 kN) shear force values for the two strips.

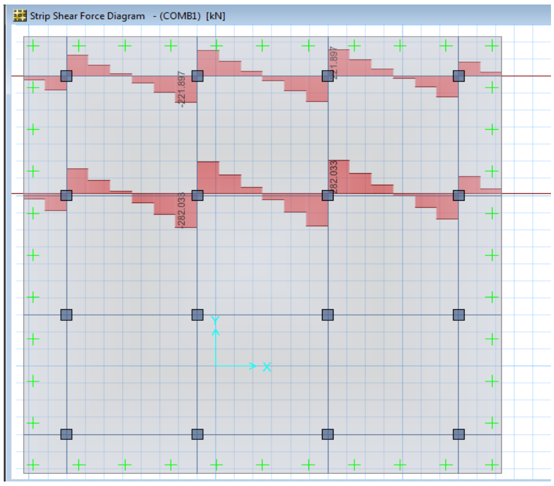


Fig-5.4.2.4: Shear force diagramof slab beam raft for soil-4 (i.e. Sandy Silt)

5.4.2.5: Shear Force Diagramof slab beam raft onSand-Silt mix with or without Gravel:

Variation of shear force along interior and exterior strip of columns,of slab beam raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig.5.4.2.5. It is showing the maximum positive(i.e. on interior strip 280.61 kN; on exterior strip 220.37 kN) and maximum negative (i.e. on interior strip -280.61 kN; on exterior strip -220.37 kN) shear force values for the two strips.

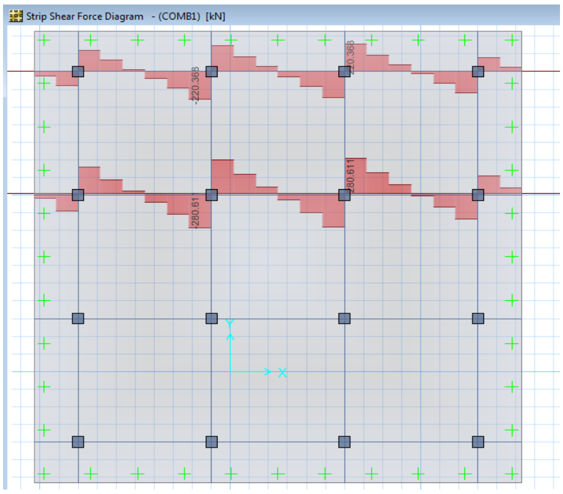


Fig-5.4.2.5: Shear force diagram of slab beam raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.4.2.6: Shear Force Diagramof slab beam raft onHard Mooram with Kanker:

Variation of shear force along interior and exterior strip of columns,of slab beam raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.4.2.6. It is showing the maximum positive(i.e. on interior strip 279.12kN; on exterior strip 218.77kN) and maximum negative (i.e. on interior strip -279.12kN; on exterior strip -218.77kN) shear force values for the two strips.

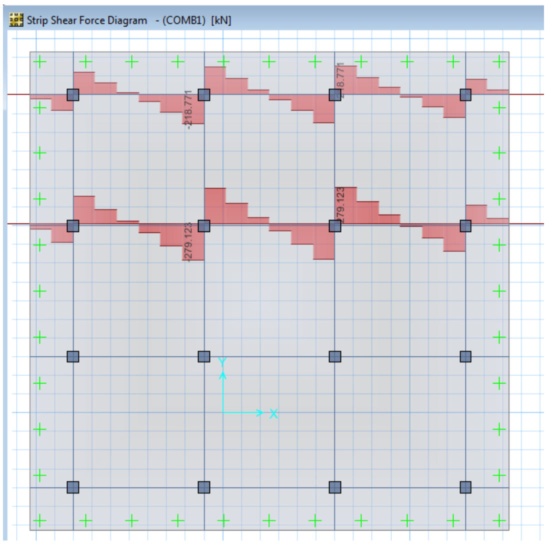


Fig-5.4.2.6: Shear force diagramof slab beam raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.4.2:Max. Shear Force inslab beam raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Max. Shear Force (kN)
1	Sandy Clayey Silt	10000	195	285
2	Sandy Soil with low percentage of gravel	14000	205	283
3	Clayey Sand Silt with Gravels	15000	235	282
4	Sandy Silt	16000	245	282
5	Sand-Silt Mix with or without gravel	20000	195	281
6	Hard Mooram with Kanker	25000	270	279

5.4.3 Shear force diagramof flat plate raft thickened under column on Different Soils

Shear force diagram along interior and exterior strip of columns,of flat plate raft thickened under column for the six different soil types are discussed in this section and a comparison for maximum shear force values of this type of rafton all six types of soilis given in Table no. 5.4.3.

5.4.3.1: Shear Force Diagramof flat plate raft thickened under columnon Sandy Clayey Silt:

Variation of shear force along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.4.3.1. It is showing the maximum positive(i.e. on interior strip 2224.50 kN; on exterior strip 1512.30 kN) and maximum negative(i.e. on interior strip -2224.50 kN; on exterior strip -1512.30 kN) shear force values for the two strips.

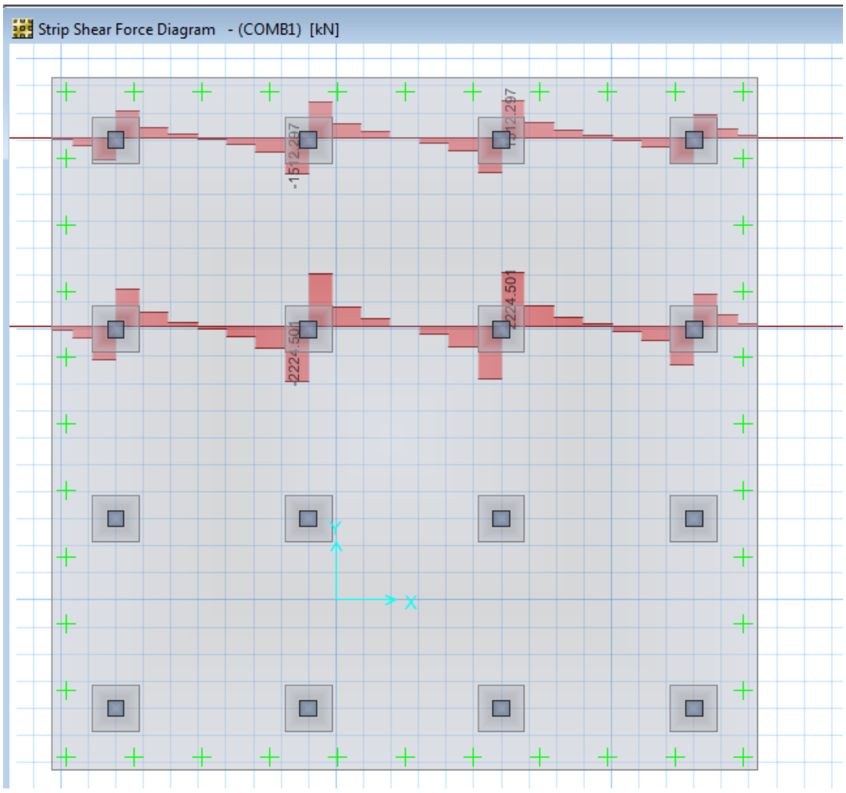


Fig-5.4.3.1: Shear force diagramof flat plate raft thickened under column for soil-1 (i.e. Sandy Clayey Silt)

5.4.3.2: Shear Force diagramof flat plate raft thickened under columnonSandy Soil with low percentage of gravel:

Variation of shear force along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.4.3.2. It is showing the maximum positive(i.e. on interior strip 2218.89 kN; on exterior strip 1507.32 kN) and maximum negative (i.e. on interior strip -2218.89 kN; on exterior strip -1507.32 kN) shear force values for the two strips.

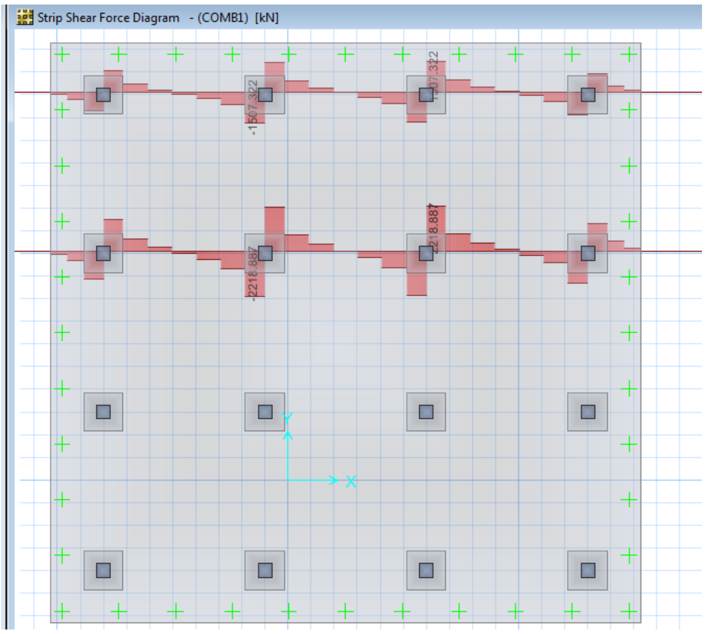


Fig-5.4.3.2: Shear force diagramof flat plate raft thickened under column for soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.4.3.3: Shear Force diagramof flat plate raft thickened under columnonClayey Sand Silt with Gravels:

Variation of shear force along interior and exterior strip of columns,of flat plate raft thickened under columnforsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.4.3.3. It is showing the maximum positive (i.e. on interior strip 2217.70 kN; on exterior strip 1506.29 kN) and maximum negative(i.e. on interior strip -2217.70 kN; on exterior strip -1506.29 kN) shear force values for the two strips.

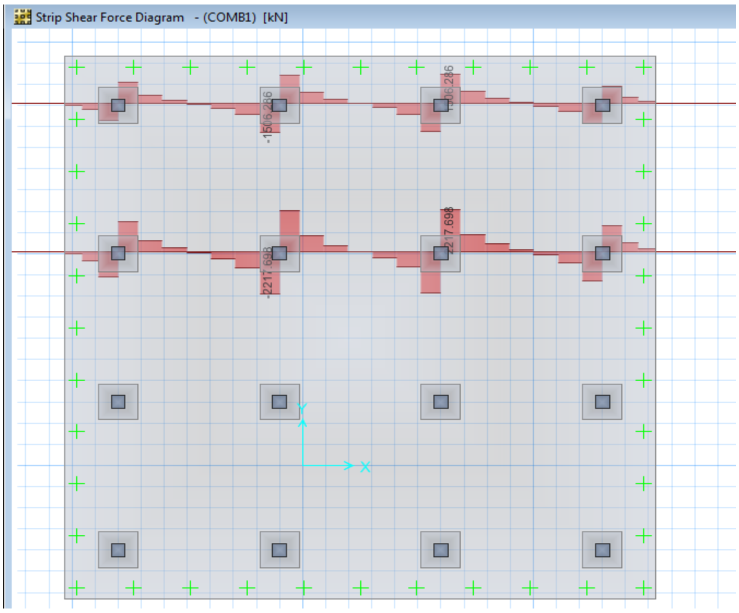


Fig-5.4.3.3: Shear force diagramof flat plate raft thickened under column for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.4.3.4: Shear Force Diagramof flat plate raft thickened under columnonSandy Silt:

Variation of shear force along interior and exterior strip of columns,of flat plate raft thickened under columnforsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.4.3.4. It is showing the maximum positive(i.e. on interior strip 2216.57 kN; on exterior strip 1505.31 kN) and maximum negative(i.e. on interior strip -2216.57 kN; on exterior strip -1505.31 kN) shear force values for the two strips.

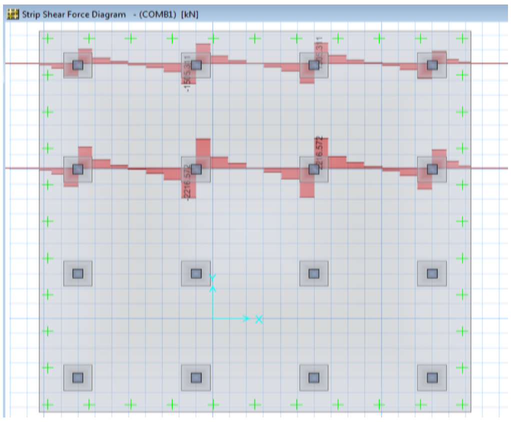


Fig-5.4.3.4: Shear force diagramof flat plate raft thickened under column for soil-4 (i.e. Sandy Silt)

5.4.3.5: Shear Force Diagramof flat plate raft thickened under columnon Sand-Silt mix with or without Gravel:

Variation of shear force along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.4.3.5. It is showing the maximum positive(i.e. on interior strip 2212.57 kN; on exterior strip 1501.89 kN) and maximum negative(i.e. on interior strip -2212.57 kN; on exterior strip -1501.89 kN) shear force values for the two strips.

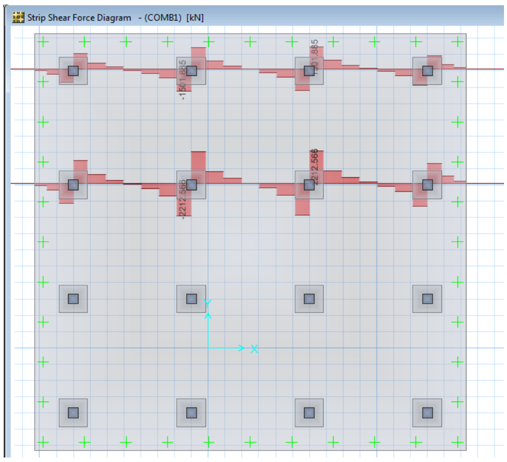


Fig-5.4.3.5: Shear force diagramof flat plate raft thickened under column for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.4.3.6: Shear Force Diagramof flat plate raftthickened under columnon Hard Mooram with Kanker:

Variation of shear force along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.4.3.6. It is showing the maximum positive(i.e. on interior strip 2208.36kN; on exterior strip 1498.35kN) and maximum negative(i.e. on interior strip -2208.36kN; on exterior strip -1498.35kN) shear force values for the two strips.

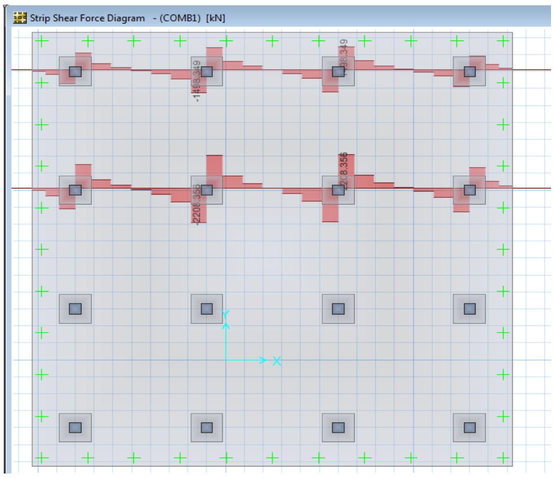


Fig-5.4.3.6: Shear force diagramof flat plate raft thickened under column for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.4.3: Max. Shear Force in flat plate raft thickened under column on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Max. Shear Force (kN)
1	Sandy Clayey Silt	10000	195	2225
2	Sandy Soil with low percentage of gravel	14000	205	2219
3	Clayey Sand Silt with Gravels	15000	235	2218
4	Sandy Silt	16000	245	2217
5	Sand-Silt Mix with or without gravel	20000	195	2213
6	Hard Mooram with Kanker	25000	270	2208

5.4.4Shear force diagramof flat plate with pedestal raft on different soiltypes

Shear force diagram along interior and exterior strip of columns,of flat plate with pedestal raft for the six different soil types are discussed in this section and a comparison for maximum shear force values of this type of rafton all six types of soilis given in Table no. 5.4.4.

5.4.4.1: Shear Force Diagramof flat plate with pedestal raft on Sandy Clayey Silt:

Variation of shear force along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-1(i.e. Sandy Clayey Silt)is shown below in fig. 5.4.4.1. It is showing the maximum positive (i.e. on interior strip 3027.12 kN; on exterior strip 1185.13 kN) and maximum negative (i.e. on interior strip -1063.81 kN; on exterior strip -739.01 kN) shear force values for the two strips.

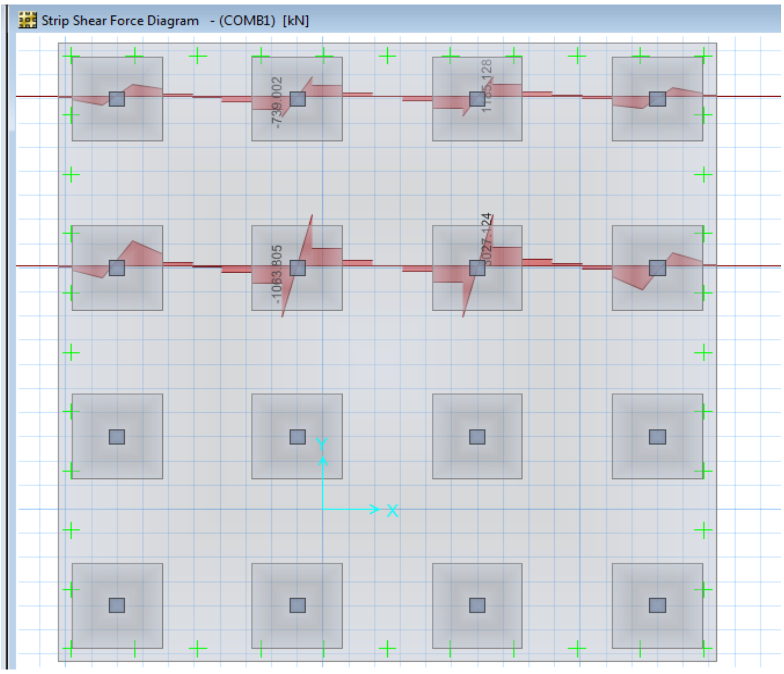


Fig-5.4.4.1:Shear force diagramof flat plate with pedestal raft for soil-1 (i.e. Sandy Clayey Silt)

5.4.4.2: Shear Force Diagramof flat plate with pedestal raft on Sandy Soil with low percentage of gravel:

Variation of shear force along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.4.4.2. It is showing the maximum positive (i.e. on interior strip 3025.45 kN; on exterior strip 1183.23 kN) and maximum negative (i.e. on interior strip -1055.19 kN; on exterior strip -732.23 kN) shear force values for the two strips.

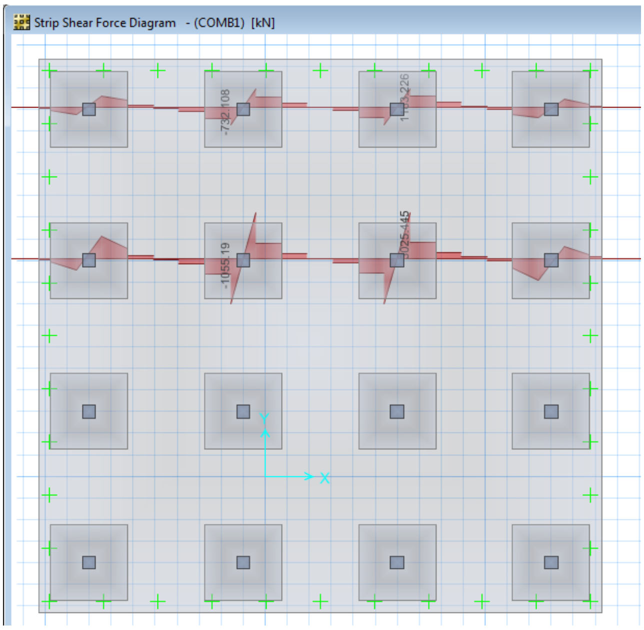


Fig-5.4.4.2: Shear Force diagramof flat plate with pedestal raft for soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.4.4.3: Shear Force Diagramof flat plate with pedestal raft onClayey Sand Silt with Gravels:

Variation of shear force along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.4.4.3. It is showing the maximum positive(i.e. on interior strip 3025.07 kN; on exterior strip 1182.82 kN) and maximum negative (i.e. on interior strip -1053.29 kN; on exterior strip -730.59 kN)shear force values for the two strips.

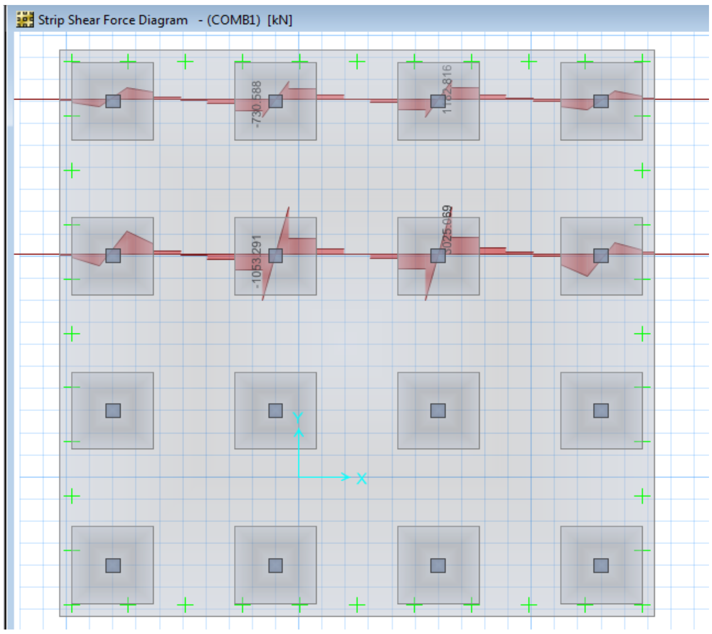


Fig-5.4.4.3: Shear force diagramof flat plate with pedestal raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.4.4.4: Shear Force Diagramof flat plate with pedestal raft onSandy Silt:

Variation of shear force along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.4.4.4. It is showing the maximum positive(i.e. on interior strip 3024.71 kN; on exterior strip 1182.43 kN) and maximum negative (i.e. on interior strip -1051.47 kN; on exterior strip -729.13 kN) shear force values for the two strips.

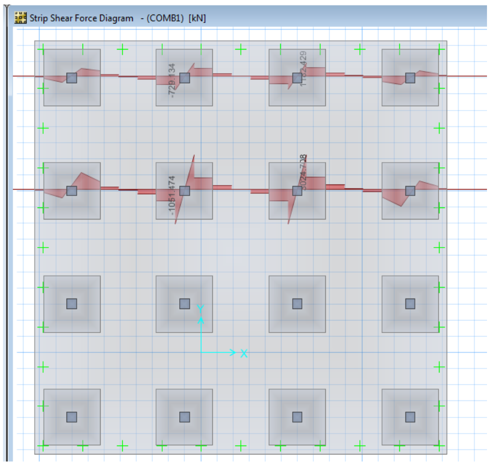


Fig-5.4.4.4: Shear force diagramof flat plate with pedestal raft for soil-4 (i.e. Sandy Silt)

5.4.4.5: Shear Force Diagramof flat plate with pedestal raft onSand-Silt mix with or without Gravel:

Variation of shear force along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.4.4.5. It is showing the maximum positive(i.e. on interior strip 3023.39 kN; on exterior strip 1181.06 kN) and maximum negative(i.e. on interior strip -1044.91 kN; on exterior strip -723.87 kN) shear force values for the two strips.

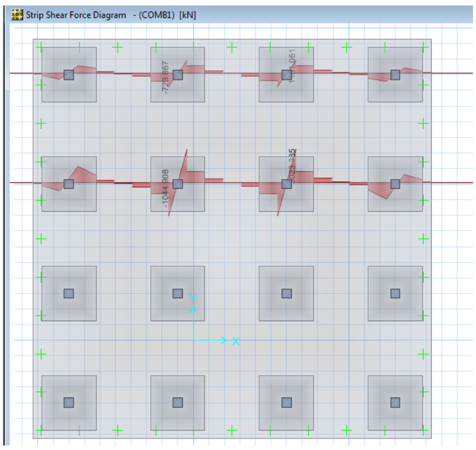


Fig-5.4.4.5:Shear force diagramof flat plate with pedestal raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.4.4.6: Shear Force Diagramof flat plate with pedestal raft onHard Mooram with Kanker:

Variation of shear force along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.4.4.6. It is showing the maximum positive(i.e. on interior strip 3021.95kN; on exterior strip 1179.67kN) and maximum negative (i.e. on interior strip -1087.93kN; on exterior strip -718.25kN) shear force values for the two strips.

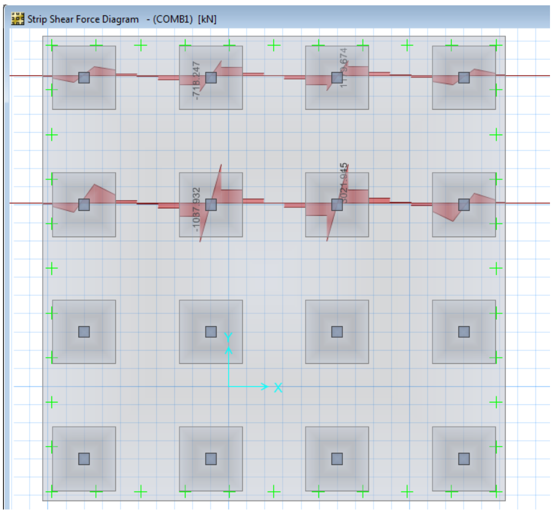


Fig-5.4.4.6: Shear force diagramof flat plate with pedestal raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.4.4: Max. Shear Force in flat plate with pedestal raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Max. Shear Force (kN)
1	Sandy Clayey Silt	10000	195	3027
2	Sandy Soil with low percentage of gravel	14000	205	3026
3	Clayey Sand Silt with Gravels	15000	235	3025
4	Sandy Silt	16000	245	3024
5	Sand-Silt Mix with or without gravel	20000	195	3023
6	Hard Mooram with Kanker	25000	270	3022

5.4.5 Shear force diagramof Box type raft on Different Soiltypes

Shear force diagram along interior and exterior strip of columns,of box type raft for the six different soil types are discussed in this section and a comparison for maximum shear force values of this type of rafton all six types of soilis given in Table no. 5.4.5.

5.4.5.1: Shear Force Diagramof box type raft on Sandy Clayey Silt:

Variation of shear force along interior and exterior strip of columns,of box type raft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.4.5.1. It is showing the maximum positive(i.e. on interior strip 431.54 kN; on exterior strip 515.23 kN) and maximum negative(i.e. on interior strip -431.54 kN; on exterior strip -515.23 kN) shear force values for the two strips.

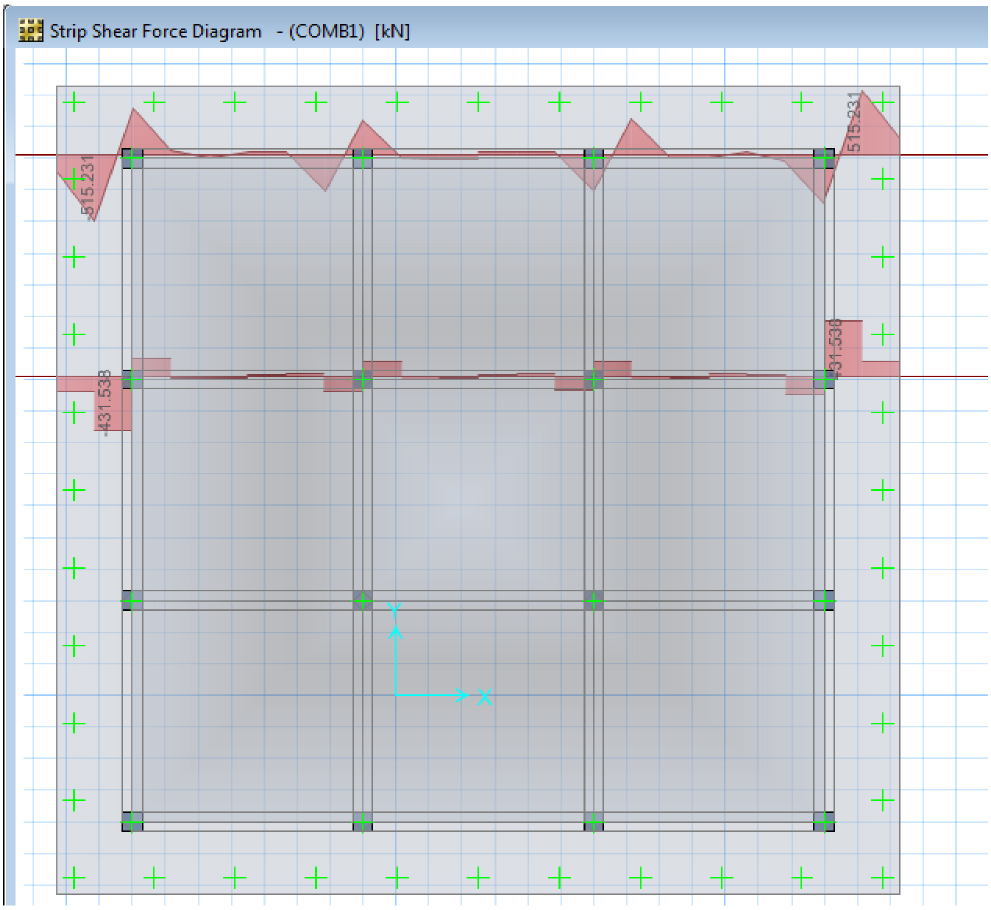


Fig-5.4.5.1: Shear force diagramof box type raft for soil-1 (i.e. Sandy Clayey Silt)

5.4.5.2: Shear Force Diagramof box type raft onSandy Soil with low percentage of Gravel:

Variation of shear force along interior and exterior strip of columns,of box type raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.4.5.2. It is showing the maximum positive(i.e. on interior strip 436.32 kN; on exterior strip 514.51 kN) and maximum negative(i.e. on interior strip -436.32 kN; on exterior strip -514.51 kN) shear force values for the two strips.

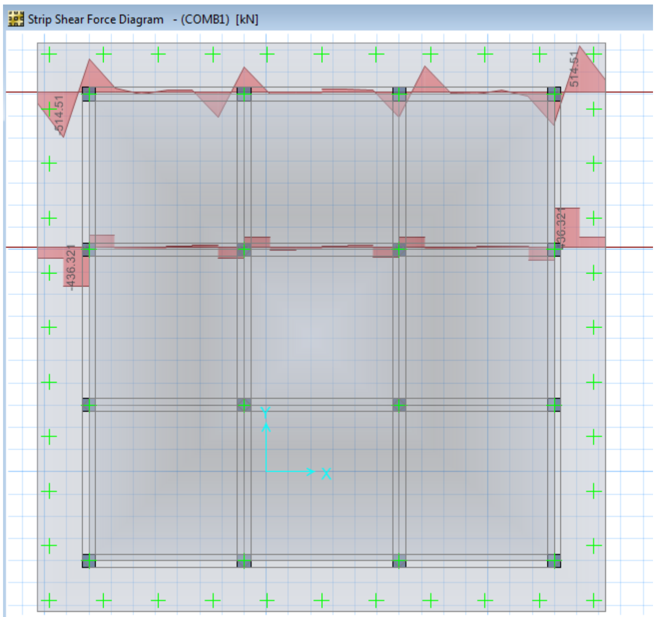


Fig-5.4.5.2: Shear force diagramof box type raft for soil-2 (i.e.Sandy Soil with low percentage of Gravel)

5.4.5.3: Shear Force Diagramof box type raft onClayey Sand Silt with Gravels:

Variation of shear force along interior and exterior strip of columns,of box type raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.4.5.3. It is showing the maximum positive(i.e. on interior strip 437.28 kN; on exterior strip 514.09 kN) and maximum negative(i.e. on interior strip -437.28 kN; on exterior strip -514.09 kN) shear force values for the two strips.

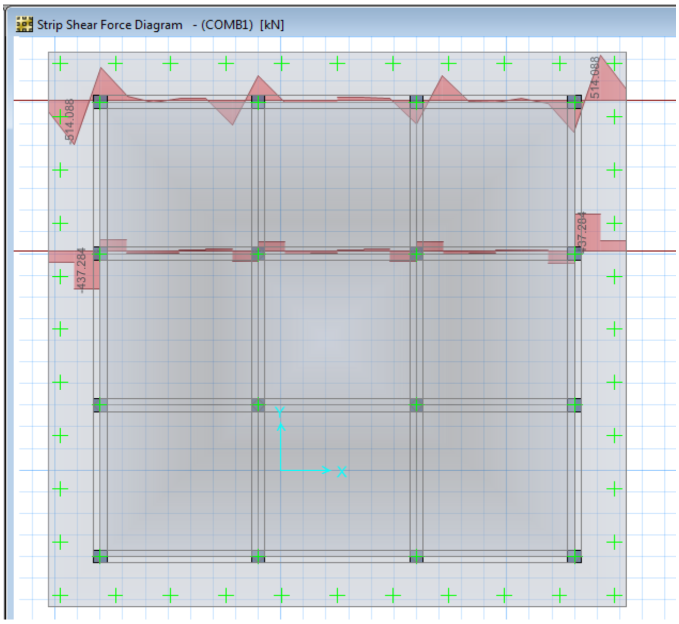


Fig-5.4.5.3: Shear force diagramof box type raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.4.5.4: Shear Force Diagramof box type raft onSandy Silt:

Variation of shear force along interior and exterior strip of columns,of box type raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.4.5.4. It is showing the maximum positive(i.e. on interior strip 438.17 kN; on exterior strip 513.59 kN) and maximum negative (i.e. on interior strip -438.17 kN; on exterior strip -513.59 kN) shear force values for the two strips.

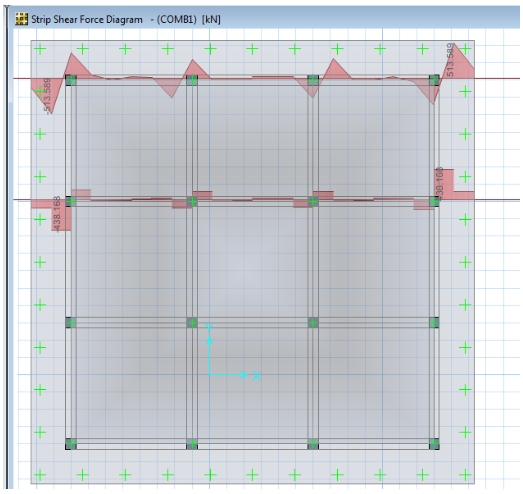


Fig-5.4.5.4: Shear force diagramof box type raft for soil-4 (i.e. Sandy Silt)

5.4.5.5: Shear Force Diagramof box type raft onSand-Silt mix with or without Gravel:

Variation of shear force along interior and exterior strip of columns,of box type raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.4.5.5. It is showing the maximum positive(i.e. on interior strip 441.01 kN; on exterior strip 510.97 kN) and maximum negative (i.e. on interior strip -441.01 kN; on exterior strip -510.97 kN) shear force values for the two strips.

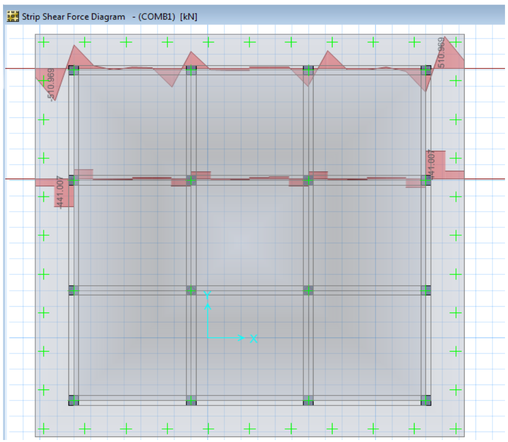


Fig-5.4.5.5:Shear force diagramof box type raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.4.5.6: Shear Force Diagramof box type raft onHard Mooram with Kanker:

Variation of shear force along interior and exterior strip of columns,of box type raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.4.5.6. It is showing the maximum positive(i.e. on interior strip 443.31 kN; on exterior strip 506.72 kN) and maximum negative(i.e. on interior strip -443.31 kN; on exterior strip -506.72 kN) shear force values for the two strips.

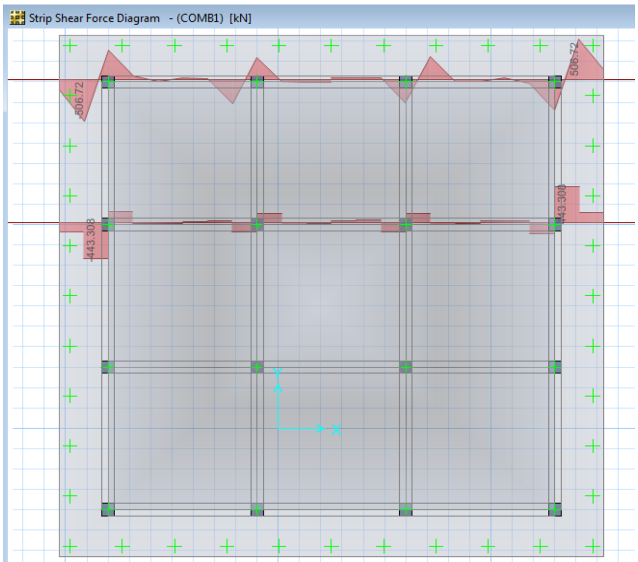


Fig-5.4.5.6:Shear force diagramof box type raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.4.5: Max. Shear Force in box type raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (Ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Max. Shear Force (kN)
1	Sandy Clayey Silt	10000	195	515
2	Sandy Soil with low percentage of gravel	14000	205	515
3	Clayey Sand Silt with Gravels	15000	235	514
4	Sandy Silt	16000	245	513
5	Sand-Silt Mix with or without gravel	20000	195	511
6	Hard Mooram with Kanker	25000	270	507

5.4.6 Shear force diagramof pile raft on Different Soil types

Shear force diagram along interior and exterior strip of columns,of pile raft for the six different soil types are discussed in this section and a comparison for maximum shear force values of this type of rafton all six types of soilis given in Table no. 5.4.6.

5.4.6.1: Shear Force Diagramof pile raft on Sandy Clayey Silt:

Variation of shear force along interior and exterior strip of columns,of pile raft forsoil-1 (i.e., Sandy Clayey Silt)is shown below in fig. 5.4.6.1. It is showing the maximum positive(i.e. on interior strip 1635.65 kN; on exterior strip 1137.83 kN) and maximum negative (i.e. on interior strip -1635.65 kN; on exterior strip -11337.83 kN)shear force values for the two strips.

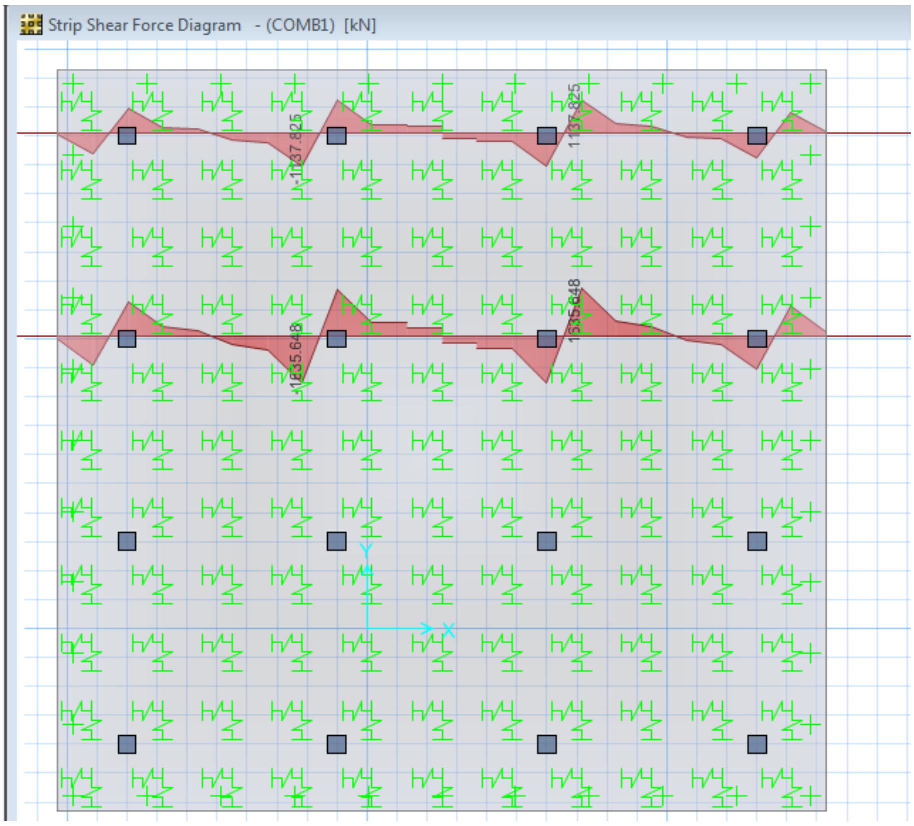


Fig-5.4.6.1: Shear force diagramof pile raft for soil-1 (i.e., Sandy Clayey Silt)

5.4.6.2: Shear Force Diagramof box type raft onSandy Soil with low percentage of Gravel:

Variation of shear force along interior and exterior strip of columns,of pile raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.4.6.2. It is showing the maximum positive(i.e. on interior strip 1627.88 kN; on exterior strip 1130.77 kN) and maximum negative(i.e. on interior strip -1627.88 kN; on exterior strip -1130.77 kN) shear force values for the two strips.

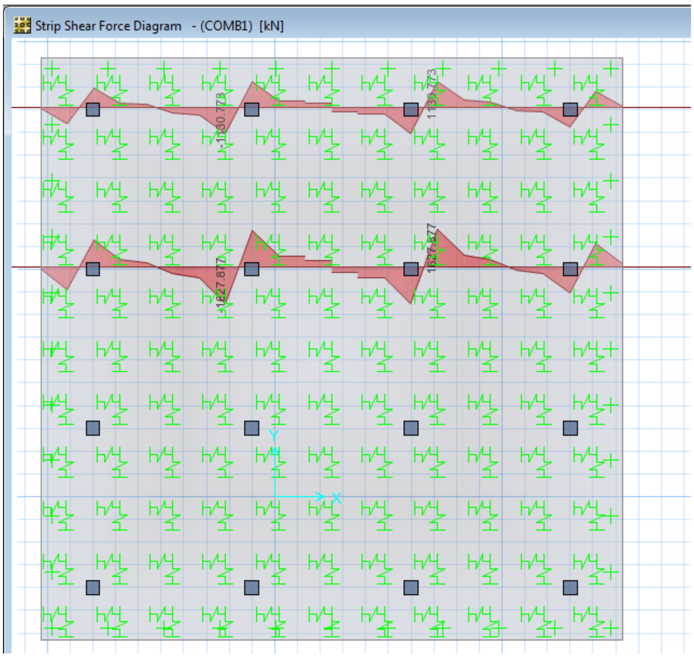


Fig-5.4.6.2: Shear force diagramof pile raft for soil-2 (i.e. Sandy Soil with low percentage of Gravel)

5.4.6.3: Shear Force Diagramof pile raft onClayey Sand Silt with Gravels:

Variation of shear force along interior and exterior strip of columns,of pile raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.4.6.3. It is showing the maximum positive(i.e. on interior strip 1626.06 kN; on exterior strip 1129.13 kN) and maximum negative(i.e. on interior strip -1626.06 kN; on exterior strip -1129.13 kN) shear force values for the two strips.

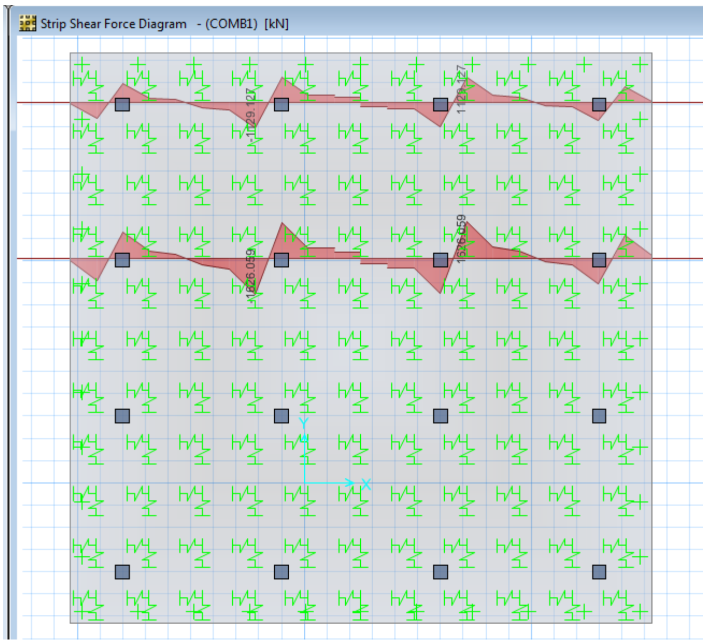


Fig-5.4.6.3: Shear force diagramof pile raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.4.6.4: Shear Force Diagramof pile raft onSandy Silt:

Variation of shear force along interior and exterior strip of columns,of pile raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.4.6.4. It is showing the maximum positive(i.e. on interior strip 1624.29 kN; on exterior strip 1127.53 kN) and maximum negative(i.e. on interior strip -1624.29 kN; on exterior strip -1127.53 kN) shear force values for the two strips.

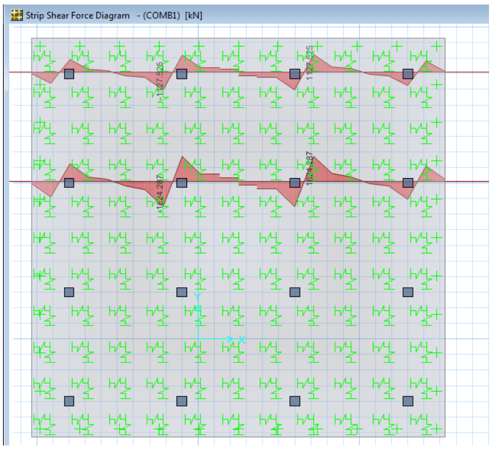


Fig-5.4.6.4: Shear force diagramof pile raft for soil-4 (i.e. Sandy Silt)

5.4.6.5: Shear Force Diagramof pile raft onSand-Silt mix with or without Gravel:

Variation of shear force along interior and exterior strip of columns,of pile raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.4.6.5. It is showing the maximum positive(i.e. on interior strip 1617.62 kN; on exterior strip 1121.51 kN) and maximum negative(i.e. on interior strip -1617.62 kN; on exterior strip -1121.51 kN) shear force values for the two strips.

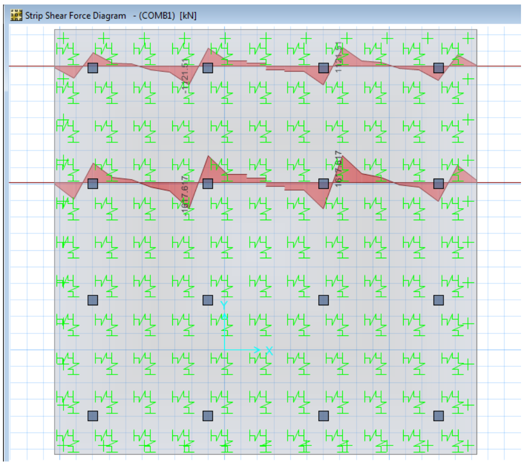


Fig-5.4.6.5:Shear force diagramof pile raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.4.6.6: Shear Force Diagramof pile raft onHard Mooram with Kanker:

Variation of shear force along interior and exterior strip of columns,of pile raft forsoil-6 (i.e., Hard Mooram with Kanker)is shown below in fig. 5.4.6.6. It is showing the maximum positive(i.e. on interior strip 1610.11 kN; on exterior strip 1114.77 kN) and maximum negative(i.e. on interior strip -1610.11 kN; on exterior strip -1114.77 kN) shear force values for the two strips.

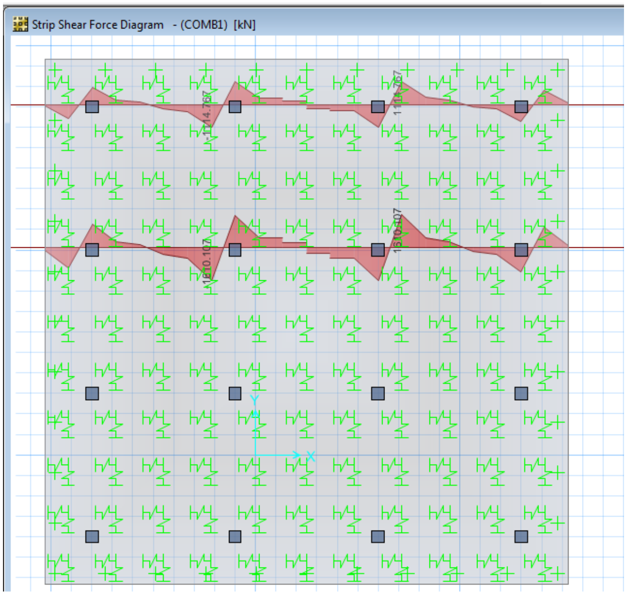


Fig-5.4.6.6:Shear force diagramof pile raft for soil-6 (i.e., Hard Mooram with Kanker)

Table-5.4.6: Max. Shear Force inpile raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (s.b.c) (kN/m²)	Max. Shear Force (kN)
1	Sandy Clayey Silt	10000	195	1636
2	Sandy Soil with low percentage of gravel	14000	205	1628
3	Clayey Sand Silt with Gravels	15000	235	1626
4	Sandy Silt	16000	245	1624
5	Sand-Silt Mix with or without gravel	20000	195	1618
6	Hard Mooram with Kanker	25000	270	1610

5.5 Bending moments diagrams of Rafts

In this section, bending moment diagram along interior and exterior strip of columns,of all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are sequentially mentioned and discussed.

5.5.1 Bending Moment Diagramof flat plate raft on different soil types

Bending moment diagram along interior and exterior strip of columns,of flat plate raft for the six different soil types are discussed in this section and a comparison for maximum bending momentvalues of this type of rafton all six types of soilis given in Table no. 5.5.1.

5.5.1.1: Bending MomentDiagramof flat plate raft on Sandy Clayey Silt:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.5.1.1. It is showing the maximum positive(i.e. on interior strip 2140.81 kNm; on exterior strip 1493.01 kNm) and maximum negative(i.e. on interior strip -473.09 kNm; on exterior strip -388.35 kNm)bending moment values for the two strips.

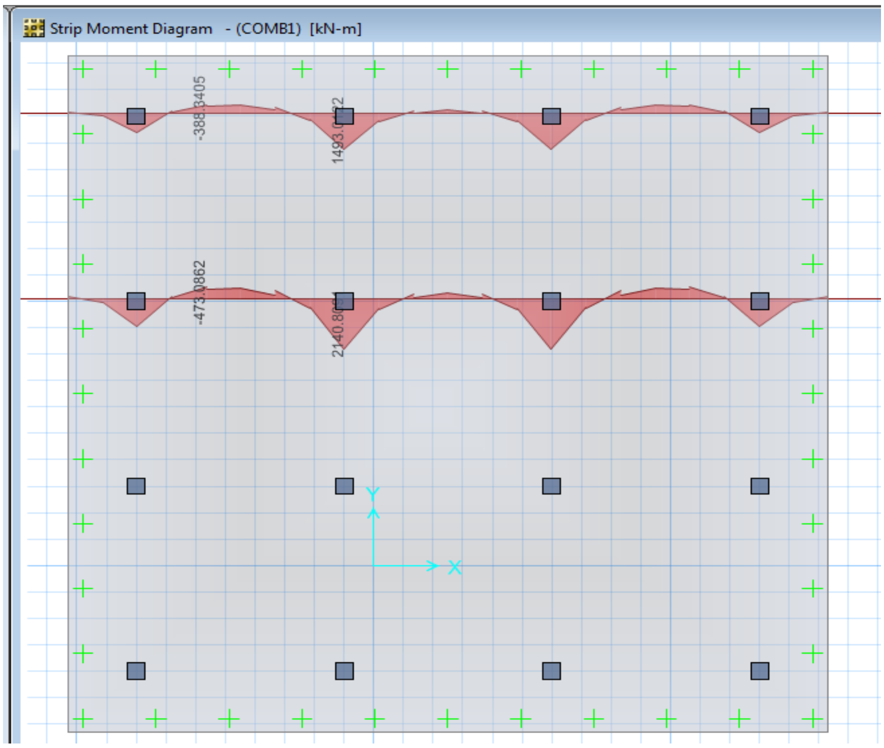


Fig-5.5.1.1: Bending moment diagramof flat plate raft for soil-1 (i.e. Sandy Clayey Silt

5.5.1.2: Bending Moment Diagramof flat plate raft onSandy Soil with low percentage of Gravel:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.5.1.2. It is showing the maximum positive(i.e. on interior strip 2103.36 kNm; on exterior strip 1461.97 kNm) and maximum negative(i.e. on interior strip -485.38 kNm; on exterior strip -396.29 kNm) bending moment values for the two strips.

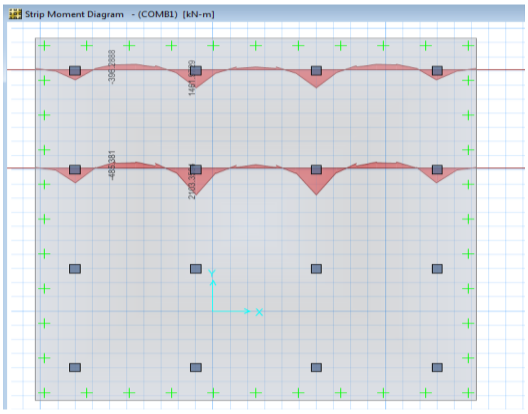


Fig-5.5.1.2: Bending moment diagram of flat plate raft for soil-2 (i.e.Sandy Soil with low percentage of Gravel)

5.5.1.3: Bending Moment Diagramof flat plate raft onClayey Sand Silt with Gravels:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.5.1.3. It is showing the maximum positive(i.e. on interior strip 2095.83 kNm; on exterior strip 1455.77 kNm) and maximum negative(i.e. on interior strip -487.69 kNm; on exterior strip -397.74 kNm) bending moment values for the two strips.

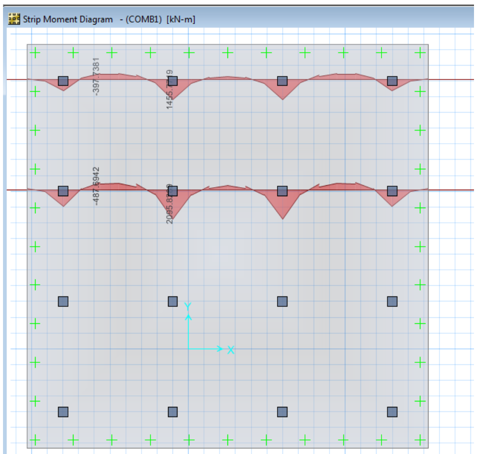


Fig-5.5.1.3: Bending moment diagramof flat plate raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.5.1.4: Bending Moment Diagramof flat plate raft onSandy Silt:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.5.1.4. It is showing the maximum positive(i.e. on interior strip 2088.86 kNm; on exterior strip 1450.05 kNm) and maximum negative(i.e. on interior strip -489.78 kNm; on exterior strip -399.02 kNm) bending moment values for the two strips.

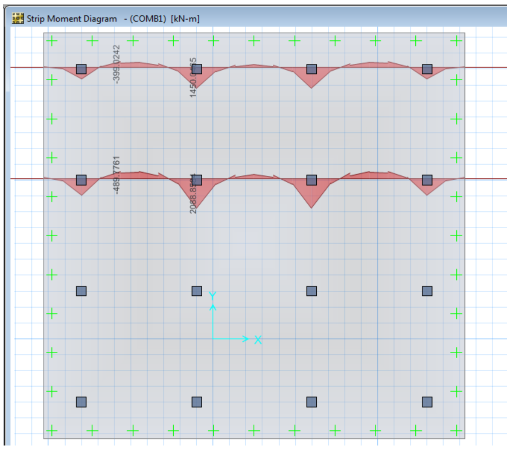


Fig-5.5.1.4: Bending moment diagramof flat plate raft for soil-4 (i.e. Sandy Silt)

5.5.1.5: Bending Moment Diagramof flat plate raft onSand-Silt mix with or without Gravel:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.5.1.5. It is showing the maximum positive(i.e. on interior strip 2065.44kNm; on exterior strip 1430.92kNm) and maximum negative(i.e. on interior strip -496.27kNm; on exterior strip -402.88kNm) bending moment values for the two strips.

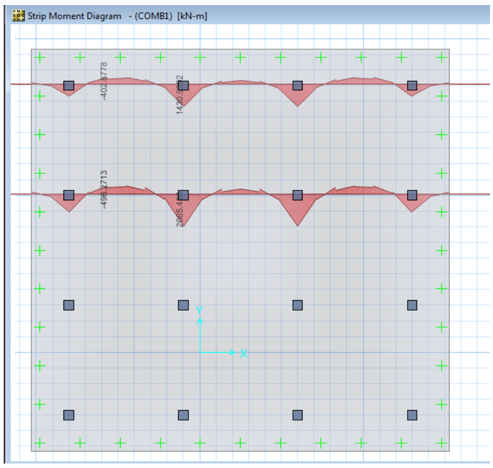


Fig-5.5.1.5: Bending moment diagramof flat plate raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.5.1.6: Bending Moment Diagramof flat plate raft onHard Mooram with Kanker:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.5.1.6. It is showing the maximum positive(i.e. on interior strip 2043.28 kNm; on exterior strip 1413.00 kNm) and maximum negative(i.e. on interior strip -501.49 kNm; on exterior strip -405.66 kNm) bending moment values for the two strips.

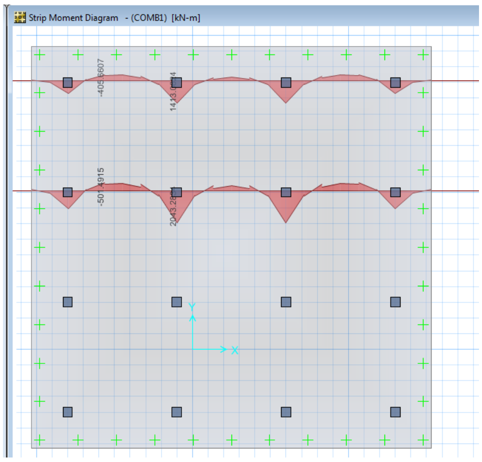


Fig-5.5.1.6: Bending moment diagram of flat plate raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.5.1: Max. Bending Moment inflat plate raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) ($kN/m^2/m$)	Soil Bearing Capacity (kN/m^2)	Max. Bending Moment (kN-m)
1	Sandy Clayey Silt	10000	195	2141
2	Sandy Soil with low % of gravel	14000	205	2103
3	Clayey Sand Silt with Gravels	15000	235	2096
4	Sandy Silt	16000	245	2089
5	Sand-Silt Mix with or without gravel	20000	195	2065
6	Hard Mooram with Kanker	25000	270	2043

5.5.2 Bending Moment Diagram of slab beam raft on different soiltypes

Bending moment diagram alonginterior and exterior strip of columns,of slab beam raft for the six different soil types are discussed in this section and a comparison for maximum bending moment values of this type of rafton all six types of soilis given in Table no. 5.5.2.

5.5.2.1: Bending Moment Diagramof slab beam raft on Sandy Clayey Silt:

Variation of bending moment along interior and exterior strip of columns,of slab beam raft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.5.2.1. It is showing the maximum positive(i.e. on interior strip 326.60 kNm; on exterior strip 244.78 kNm) and maximum negative(i.e. on interior strip -63.83 kNm; on exterior strip -59.24 kNm) bending moment values for the two strips

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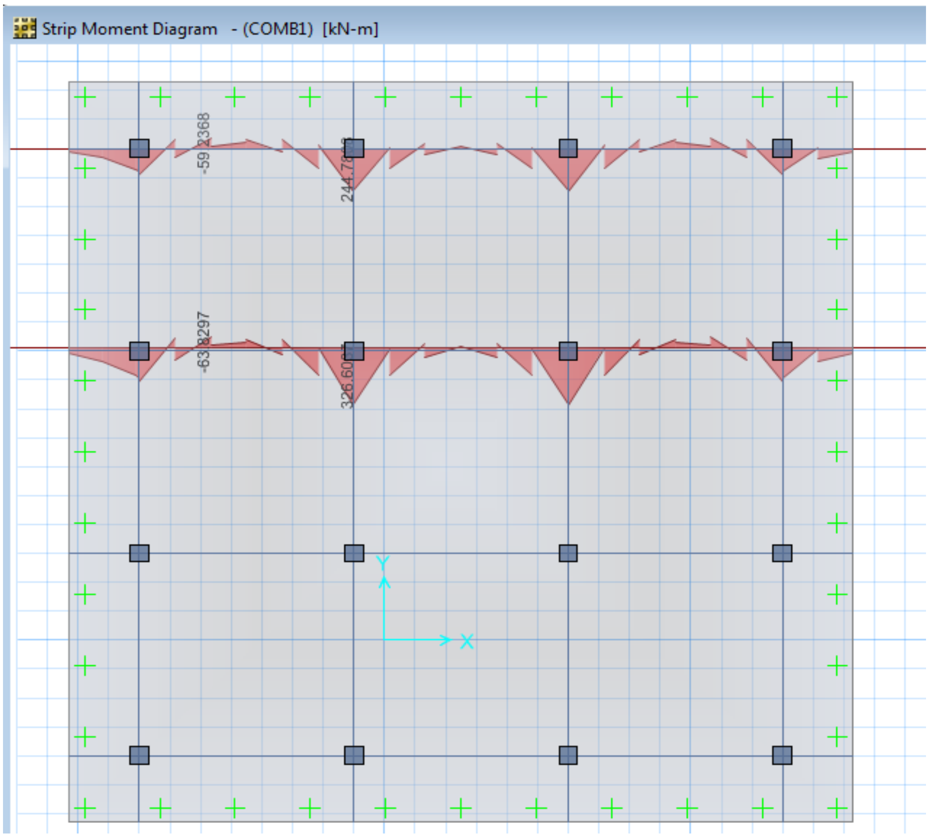

Fig-5.5.2.1: Bending moment diagramof slab beam raft for soil-1 (i.e. Sandy Clayey Silt)

5.5.2.2: Bending Moment Diagramof slab beam raft onSandy Soil with low percentage of Gravel:

Variation of bending moment along interior and exterior strip of columns,of slab beam raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.5.2.2. It is showing the maximum positive(i.e. on interior strip 320.60 kNm; on exterior strip 240.18 kNm) and maximum negative(i.e. on interior strip -64.96 kNm; on exterior strip -59.31 kNm) bending moment values for the two strips.

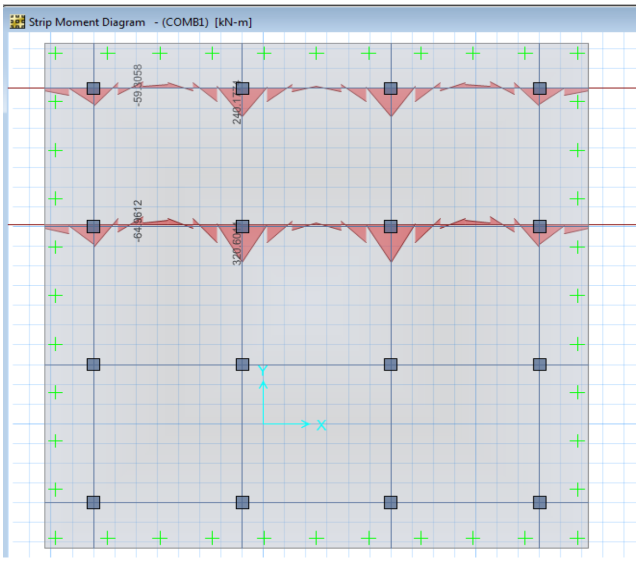

Fig-5.5.2.2: Bending moment diagramof slab beam raft for soil-2 (i.e.Sandy Soil with low percentage of Gravel)

5.5.2.3: Bending Moment Diagramof slab beam raft onClayey Sand Silt with Gravels:

Variation of bending moment along interior and exterior strip of columns,of slab beam raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.5.2.3. It is showing the maximum positive(i.e. on interior strip 319.45 kNm; on exterior strip 239.3 kNm) and maximum negative(i.e. on interior strip -65.08 kNm; on exterior strip -59.23 kNm) bending moment values for the two strips.

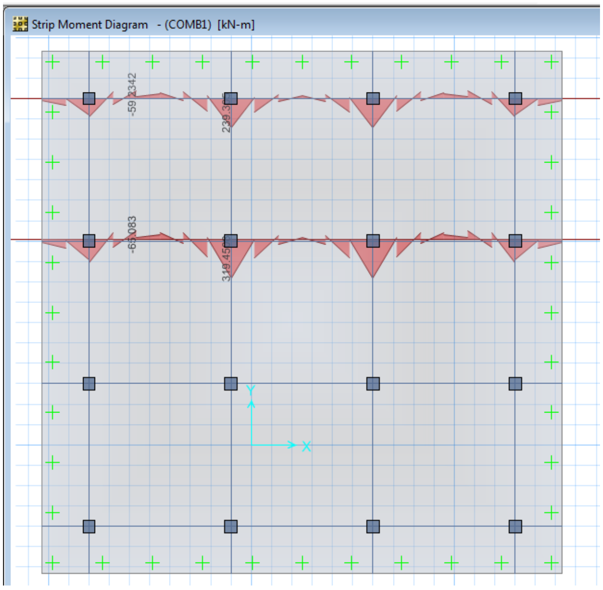

Fig-5.5.2.3: Bending moment diagramof slab beam raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.5.2.4: Bending Moment Diagramof slab beam raft onSandy Silt:

Variation of bending moment along interior and exterior strip of columns,of slab beam raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.5.2.4. It is showing the maximum positive(i.e. on interior strip 318.39 kNm; on exterior strip 238.51 kNm) and maximum negative(i.e. on interior strip -65.16 kNm; on exterior strip -59.14 kNm) bending moment values for the two strips.

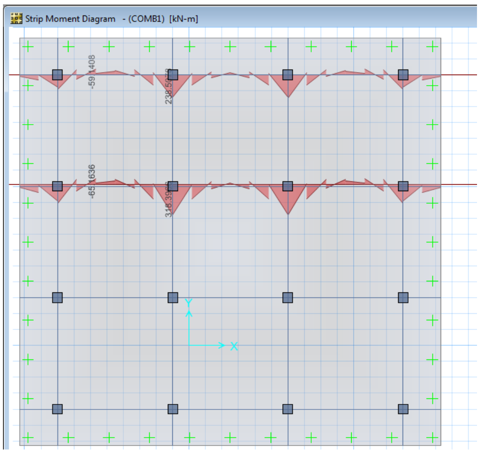

Fig-5.5.2.4: Bending moment diagramof slab beam raft for soil-4 (i.e. Sandy Silt)

5.5.2.5: Bending Moment Diagramof Slab Beam raft onSand-Silt mix with or without Gravel:

Variation of bending moment along interior and exterior strip of columns,of slab beam raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.5.2.4. It is showing the maximum positive(i.e. on interior strip 314.89 kNm; on exterior strip 235.87 kNm) and maximum negative(i.e. on interior strip -65.2 kNm; on exterior strip -58.62 kNm) bending moment values for the two strips.

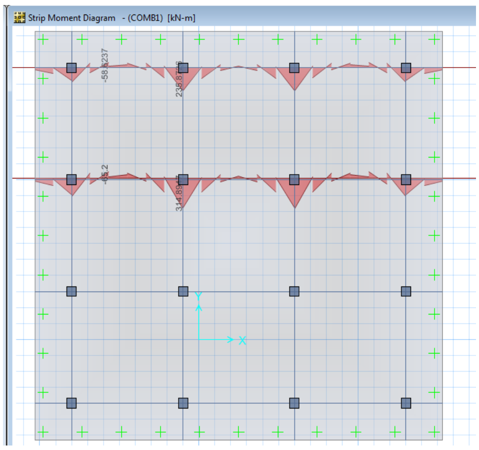

Fig-5.5.2.5: Bending moment diagramof slab beam raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.5.2.6: Bending Moment Diagramof slab beam raft onHard Mooram with Kanker:

Variation of bending moment along interior and exterior strip of columns,of slab beam raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.5.2.4. It is showing the maximum positive(i.e. on interior strip 311.57 kNm; on exterior strip 233.38 kNm) and maximum negative(i.e. on interior strip -64.88 kNm; on exterior strip -57.81 kNm) bending moment values for the two strips.

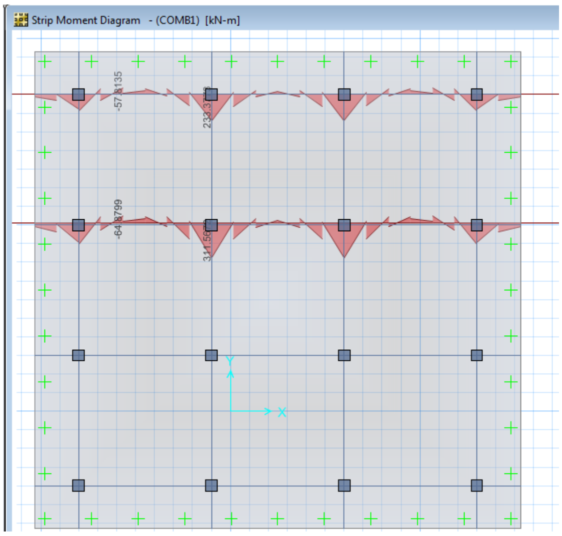

Fig-5.5.2.6: Bending moment diagramof slab beam raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.5.2:Max. Bending Moment in Slab beam raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Max. Bending Moment (kN-m)
1	Sandy Clayey Silt	10000	195	327
2	Sandy Soil with low percentage of gravel	14000	205	321
3	Clayey Sand Silt with Gravels	15000	235	320
4	Sandy Silt	16000	245	318
5	Sand-Silt Mix with or without gravel	20000	195	315
6	Hard Mooram with Kanker	25000	270	312

5.5.3 Bending Moment Diagramof flat plate raftthickened under column on Different Soiltypes

Bending moment diagram along interior and exterior strip of columns,of flat plate raft thickened under column for the six different soil types are discussed in this section and a comparison for maximum bending moment values of this type of rafton all six types of soilis given in Table no. 5.5.3.

5.5.3.1: Bending Moment Diagramof flat plate raft thickened under columnon Sandy Clayey Silt:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.5.3.1. It is showing the maximum positive(i.e. on interior strip 2906.56 kNm; on exterior strip 2074.51 kNm) and maximum negative(i.e. on interior strip -432.85 kNm; on exterior strip -372.71 kNm) bending moment values for the two strips.

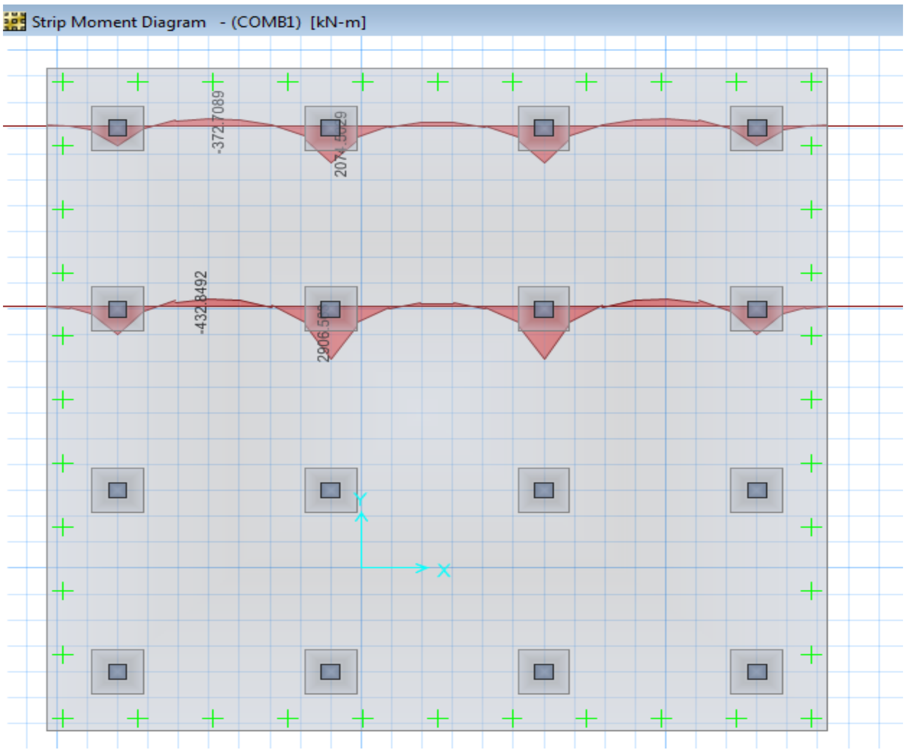

Fig-5.5.3.1: Bending moment diagram of flat plate raft thickened under column for soil-1 (i.e. Sandy Clayey Silt)

5.5.3.2: Bending Moment Diagramof flat plate raft thickened under columnonSandy Soil with low percentage of gravel:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.5.3.2. It is showing the maximum positive(i.e. on interior strip 2869.01 kNm; on exterior strip 2033.65 kNm) and maximum negative(i.e. on interior strip -441.25 kNm; on exterior strip -377.10kNm) bending moment values for the two strips.

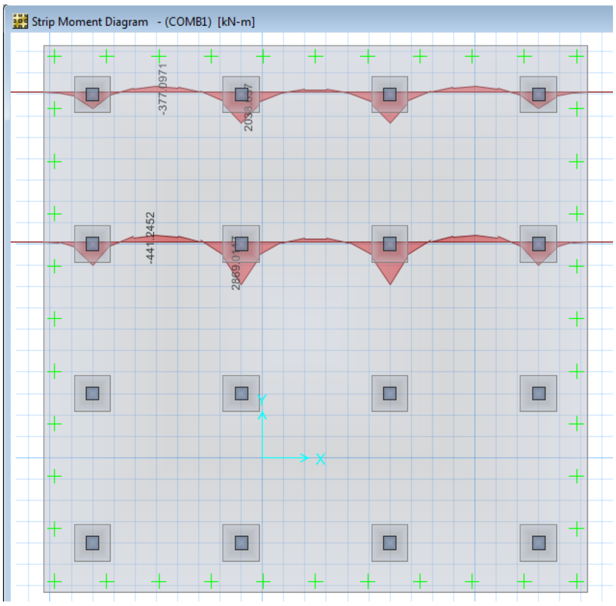

Fig-5.5.3.2: Bending moment diagramof flat plate raft thickened under column for soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.5.3.3: Bending Moment Diagramof flat plate raft thickened under columnonClayey Sand Silt with Gravels:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.5.3.2. It is showing the maximum positive(i.e. on interior strip 2861.75kNm; on exterior strip 2031.8kNm) and maximum negative(i.e. on interior strip -442.55kNm; on exterior strip -377.65kNm) bending moment values for the two strips.

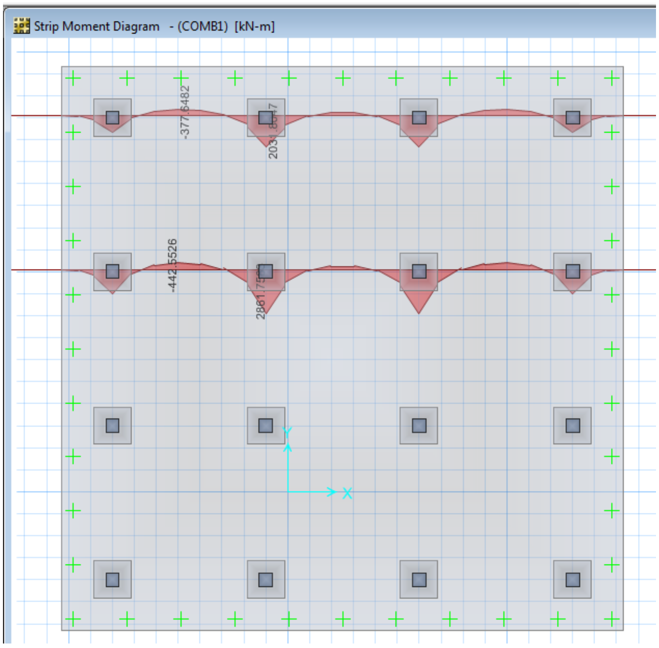

Fig-5.5.3.3: Bending moment diagramof flat plate raft thickened under column for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.5.3.4: Bending Moment Diagramof flat plate raft thickened under columnonSandy Silt:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft thickened under columnforsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.5.3.4. It is showing the maximum positive(i.e. on interior strip 2855.11 kNm; on exterior strip 2025.56 kNm) and maximum negative(i.e. on interior strip -446.30 kNm; on exterior strip -378.50 kNm) bending moment values for the two strips.

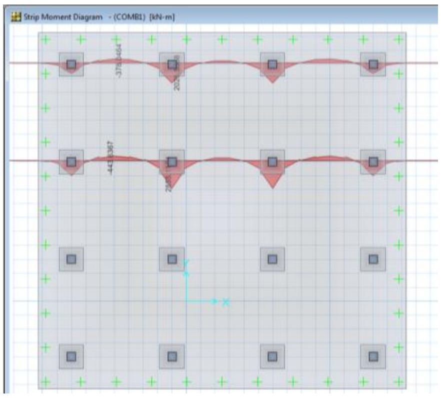

Fig-5.5.3.4: Bending moment diagramof flat plate raft thickened under column for soil-4 (i.e. Sandy Silt)

5.5.3.5: Bending Moment Diagramof flat plate raft thickened under columnonSand-Silt Mix with or without gravel:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-5 (i.e. Sand-Silt Mix with or without gravel)is shown below in fig. 5.5.3.5. It is showing the maximum positive(i.e. on interior strip 2833.24 kNm; on exterior strip 2005.11 kNm) and maximum negative(i.e. on interior strip -446.30 kNm; on exterior strip -378.50 kNm) bending moment values for the two strips.

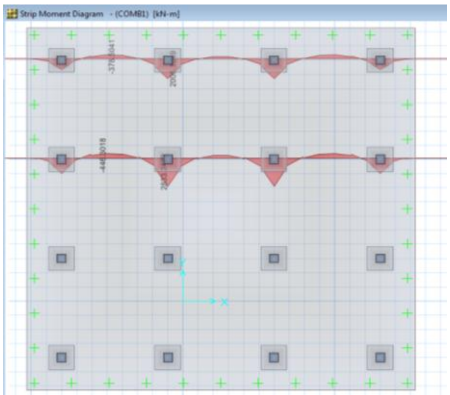

Fig-5.5.3.5: Bending moment diagramof flat plate raft thickened under column for soil-5 (i.e. Sand-Silt Mix with or without gravel)

5.5.3.6: Bending Moment Diagramof flat plate raft thickened under columnonHard Mooram with Kanker:

Variation of bending moment along interior and exterior strip of columns,of flat plate raft thickened under column forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.5.3.6. It is showing the maximum positive(i.e. on interior strip 2812.97 kNm; on exterior strip 1986.51 kNm) and maximum negative(i.e. on interior strip -447.20 kNm; on exterior strip -377.45 kNm) bending moment values for the two strips.

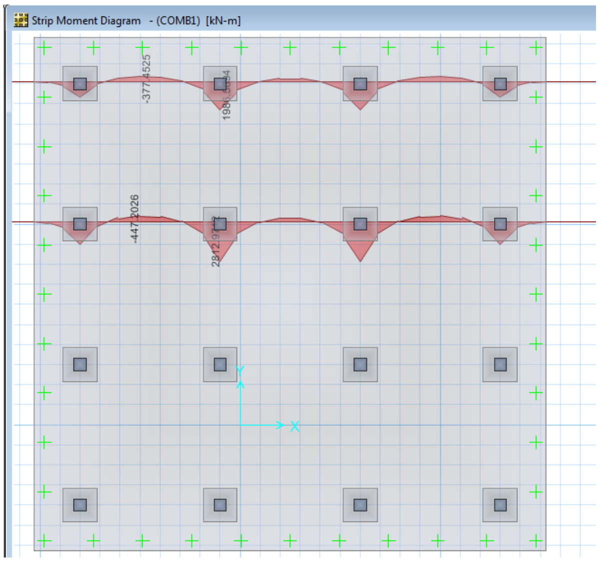

Fig-5.5.3.6: Bending moment diagramof flat plate raft thickened under column for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.5.3: Max. Bending Moment in flat plate raft thickened under column on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Max. Bending Moment (kN-m)
1	Sandy Clayey Silt	10000	195	2907
2	Sandy Soil with low percentage of gravel	14000	205	2869
3	Clayey Sand Silt with Gravels	15000	235	2862
4	Sandy Silt	16000	245	2855
5	Sand-Silt Mix with or without gravel	20000	195	2833
6	Hard Mooram with Kanker	25000	270	2813

5.5.4 Bending Moment Diagramof Flat Plate with Pedestal raft on Different Soiltypes

Bending moment diagram along interior and exterior strip of columns,of flat plate with pedestal raft for the six different soil types are discussed in this section and a comparison for maximum bending moment values of this type of rafton all six types of soilis given in Table no. 5.5.4.

5.5.4.1: Bending Moment Diagramof flat plate with pedestal raft on Sandy Clayey Silt:

Variation of bending moment along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.5.4.1. It is showing the maximum positive (i.e. on interior strip 1407.55 kNm; on exterior strip 1114.47 kNm) and maximum negative(i.e. on interior strip -322.07 kNm; on exterior strip -305.31 kNm) bending moment values for the two strips.

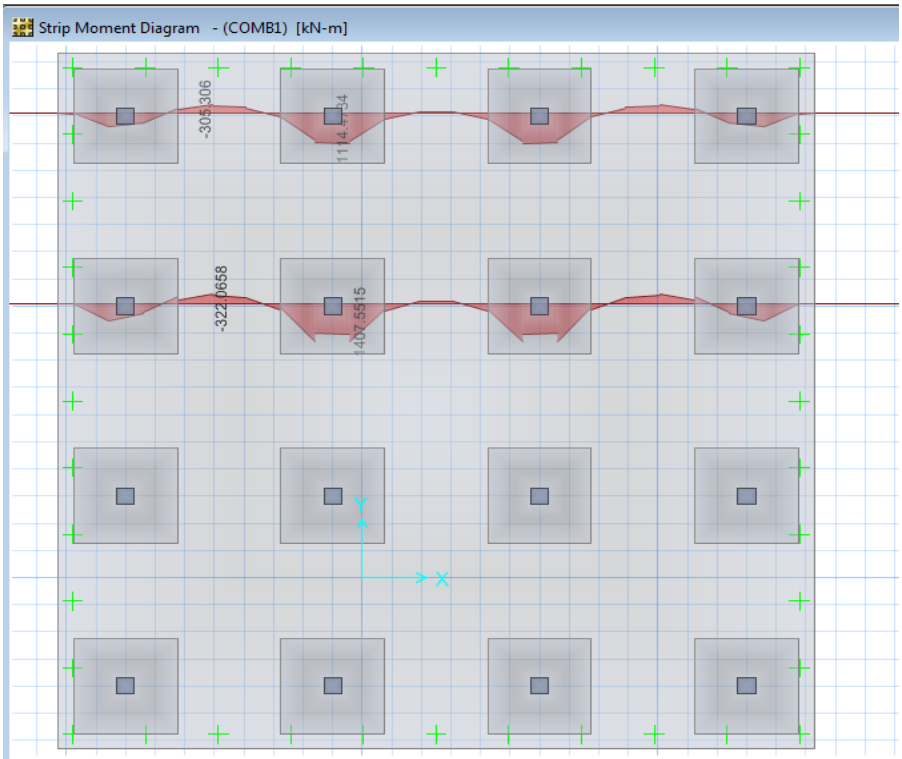

Fig-5.5.4.1: Bending moment diagramof flat plate with pedestal raft for soil-1 (i.e. Sandy Clayey Silt)

5.5.4.2: Bending Moment Diagramof flat plate with pedestal raft onSandy Soil with low percentage of gravel:

Variation of bending moment along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-2 (i.e. Sandy Soil with low percentage of gravel)is shown below in fig. 5.5.4.2. It is showing the maximum positive(i.e. on interior strip 1392.88 kNm; on exterior strip 1099.01 kNm) and maximum negative (i.e. on interior strip -311.10 kNm; on exterior strip -293.20kNm) bending moment values for the two strips.

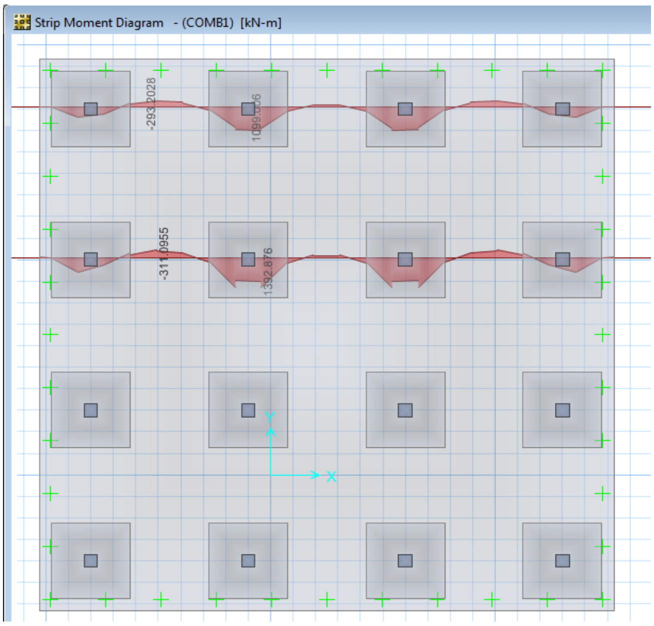

Fig-5.5.4.2: Bending moment diagramof flat plate with pedestal raft for soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.5.4.3: Bending Moment Diagramof flat plate with pedestal raft onClayey Sand Silt with Gravels:

Variation of bending moment along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.5.4.3. It is showing the maximum positive(i.e. on interior strip 1390.15 kNm; on exterior strip 1095.84 kNm) and maximum negative(i.e. on interior strip -336.96 kNm; on exterior strip -290.86 kNm) bending moment values for the two strips.

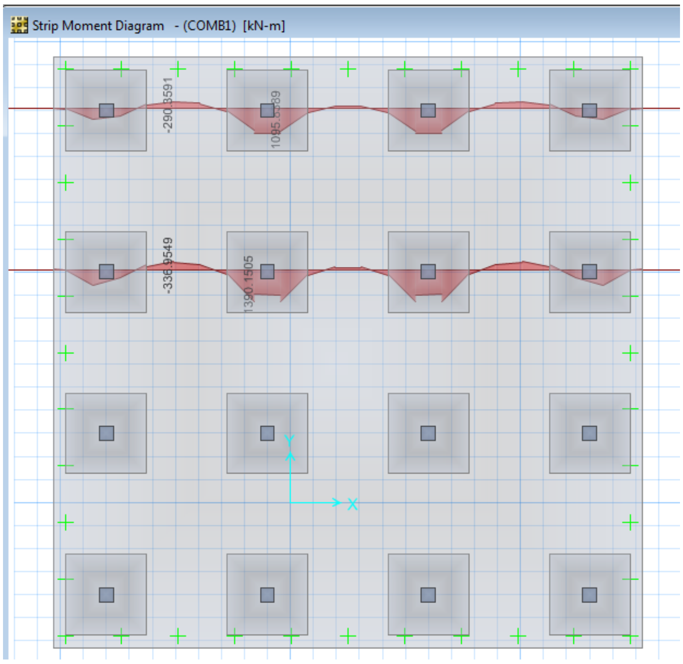

Fig-5.5.4.3: Bending moment diagramof flat plate with pedestal raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.5.4.4: Bending Moment Diagramof flat plate with pedestal raft onSandy Silt:

Variation of bending moment along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.5.4.4. It is showing the maximum positive (i.e. on interior strip 1388.17 kNm; on exterior strip 1092.67 kNm) and maximum negative(i.e. on interior strip -334.09 kNm; on exterior strip -287.60 kNm) bending moment values for the two strips.

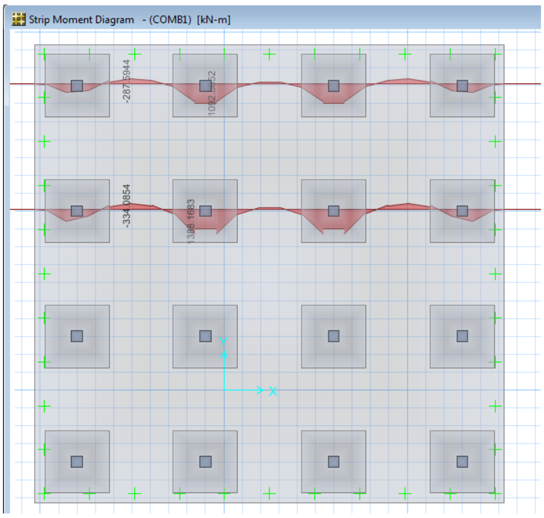

Fig-5.5.4.4: Bending moment diagramof flat plate with pedestal raft for soil-4 (i.e. Sandy Silt)

5.5.4.5: Bending Moment Diagramof flat plate with pedestal raft onSand-Silt Mix with or without gravel:

Variation of bending moment along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-5 (i.e. Sand-Silt Mix with or without gravel)is shown below in fig. 5.5.4.5. It is showing the maximum positive(i.e. on interior strip 1381.12 kNm; on exterior strip 1082.43 kNm) and maximum negative (i.e. on interior strip -323.40 kNm; on exterior strip -277.31 kNm)bending moment values for the two strips.

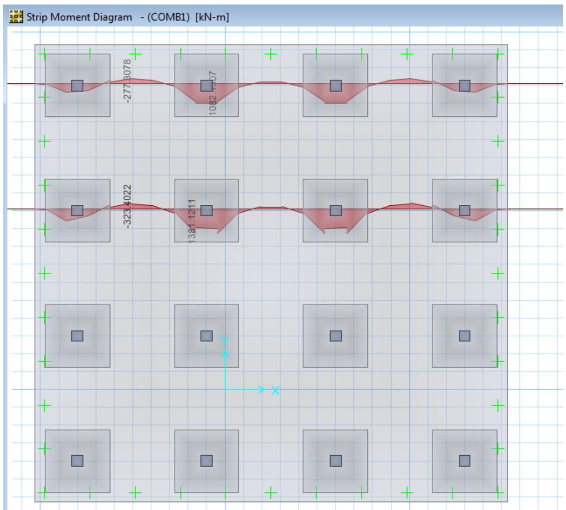

Fig-5.5.4.5: Bending moment diagramof flat plate with pedestal raft for soil-5 (i.e. Sand-Silt Mix with or without gravel)

5.5.4.6: Bending Moment Diagramof flat plate with pedestal raft onHard Mooram with Kanker:

Variation of bending moment along interior and exterior strip of columns,of flat plate with pedestal raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.5.4.6. It is showing the maximum positive(i.e. on interior strip 1373.54 kNm; on exterior strip 1071.00 kNm) and maximum negative(i.e. on interior strip -311.68 kNm; on exterior strip -266.03 kNm) bending moment values for the two strips.

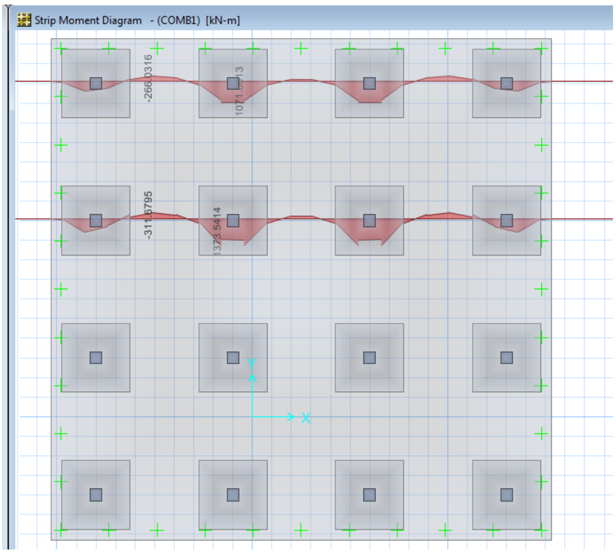

Fig-5.5.4.6: Bending moment diagramof flat plate with pedestal raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.5.4: Max. Bending Moment in flat plate with pedestal raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Max. Bending Moment (kN-m)
1	Sandy Clayey Silt	10000	195	1406
2	Sandy Soil with low percentage of gravel	14000	205	1393
3	Clayey Sand Silt with Gravels	15000	235	1390
4	Sandy Silt	16000	245	1388
5	Sand-Silt Mix with or without gravel	20000	195	1381
6	Hard Mooram with Kanker	25000	270	1374

5.5.5 Bending Moment Diagramof box type raft on different soiltypes

Bending moment diagram along interior and exterior strip of columns,of box type raft for the six different soil types are discussed in this section and a comparison for maximum bending moment values of this type of rafton all six types of soilis given in Table no. 5.5.5.

5.5.5.1: Bending Moment Diagramof box type raft on Sandy Clayey Silt:

Variation of bending moment along interior and exterior strip of columns,of box typeraft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.5.5.1. It is showing the maximum positivebending moment (i.e. on interior strip 560.92 kNm; on exterior strip 517.26 kNm) and showing a negligible negative bending moment values for the two strips.

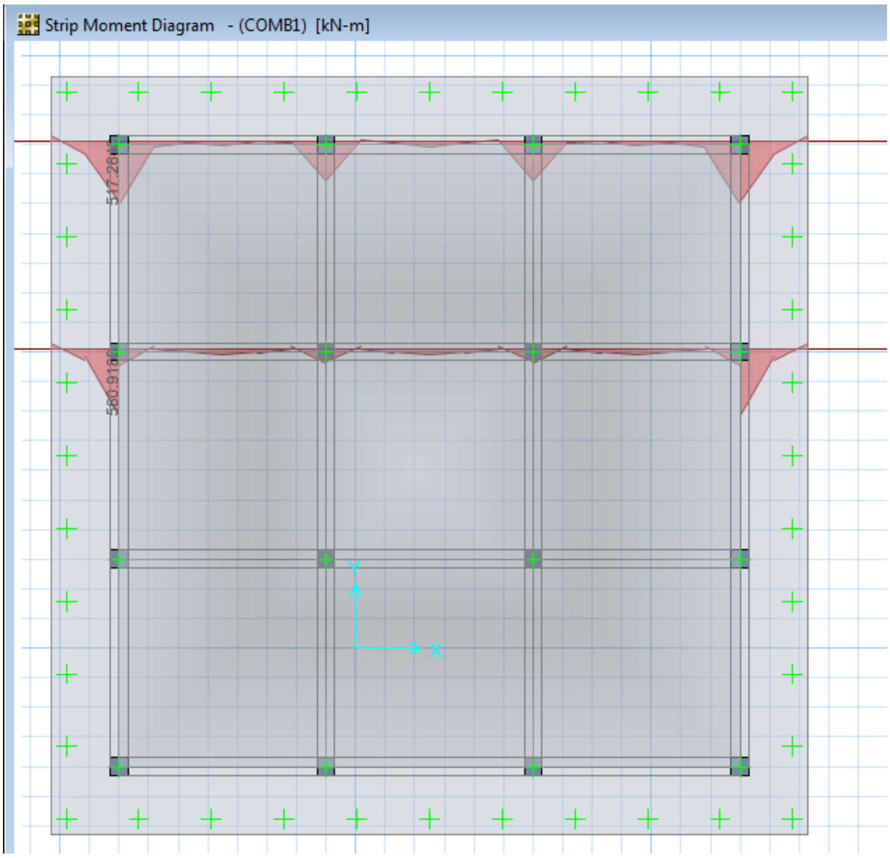

Fig-5.5.5.1: Bending moment diagramof box type raft for soil-1 (i.e. Sandy Clayey Silt)

5.5.5.2: Bending Moment Diagramof box type raft onSandy Soil with low percentage of Gravel:

Variation of bending moment along interior and exterior strip of columns,of box type raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.5.5.2. It is showing the maximum positivebending moment (i.e. on interior strip 567.84kNm; on exterior strip 517.58kNm) and showing a negligible negative bending moment values for the two strips.

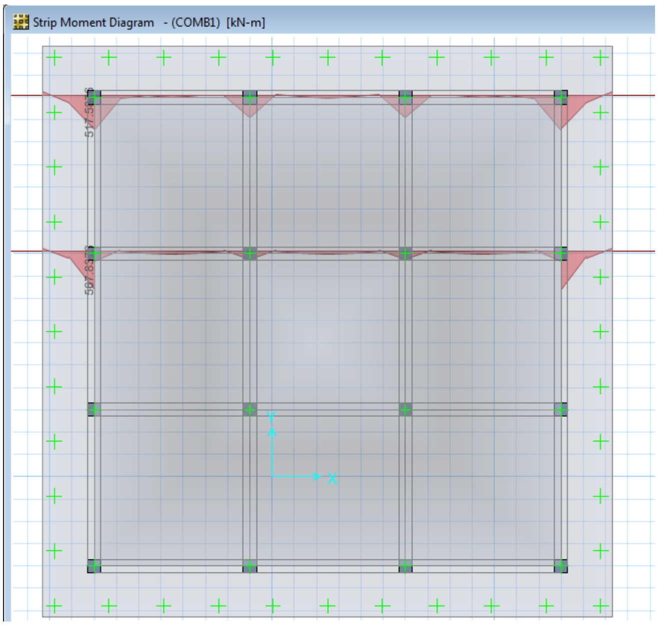

Fig-5.5.5.2: Bending moment diagramof box type raft for soil-2 (i.e.Sandy Soil with low percentage of gravel)

5.5.5.3: Bending Moment Diagramof box type raft onClayey Sand Silt with Gravels:

Bending moment diagram along interior and exterior strip of columns,of box type raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.5.5.3. It is showing the maximum positive bending moment (i.e. on interior strip 569.16 kNm; on exterior strip 517.41 kNm) and showing a negligible negative bending moment values for the two strips.

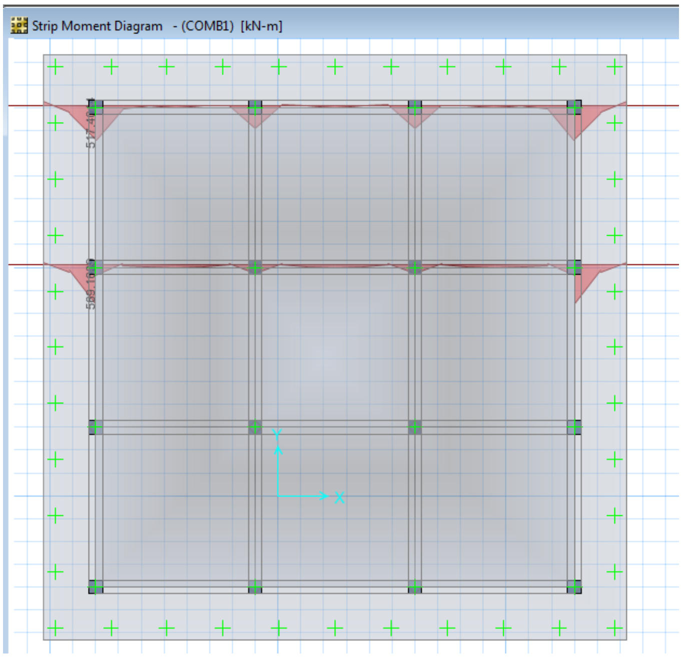

Fig-5.5.5.3: Bending moment diagramof box type raft for soil-3 (i.e., Clayey Sand Silt with Gravels)

5.5.5.4: Bending Moment Diagramof box type raft onSandy Silt:

Variation of bending moment along interior and exterior strip of columns,of box type raft forsoil-4 (i.e., Sandy Silt)is shown below in fig. 5.5.5.4. It is showing the maximum positive bending moment (i.e. on interior strip 570.36 kNm; on exterior strip 517.12 kNm) and showing a negligible negative bending moment values for the two strips.

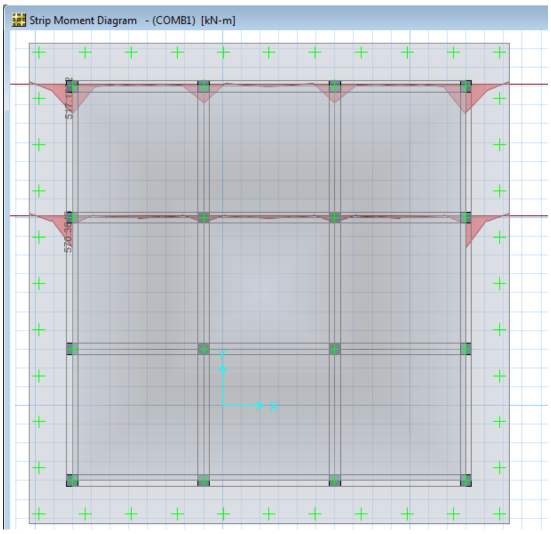

Fig-5.5.5.4: Bending moment diagramof box type raft for soil-4 (i.e., Sandy Silt)

5.5.5.5: Bending Moment Diagramof b ox type raft onSand-Silt mix with or without Gravel:

Variation of bending moment along interior and exterior strip of columns,of box type raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.5.5.5. It is showing the maximum positive bending moment(i.e. on interior strip 573.97 kNm; on exterior strip 515.31 kNm) and showing a negligible negative bending moment values for the two strips.

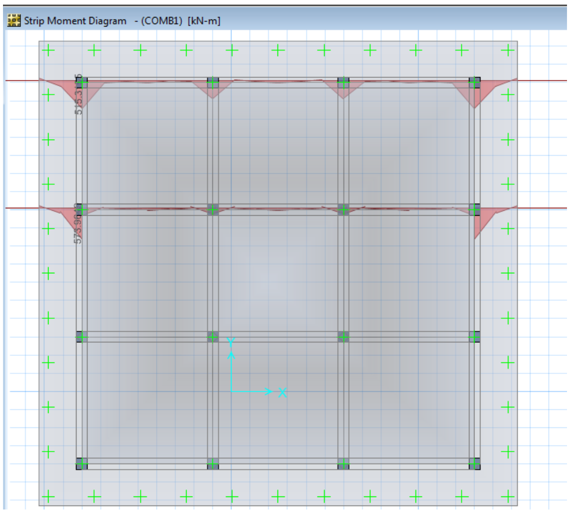

Fig-5.5.5.5: Bending moment diagramof box type raft for soil-5 (i.e. Sand-Silt mix with or without Gravel)

5.5.5.6: Bending Moment Diagramof box type raft onHard Mooram with Kanker:

Variation of bending moment along interior and exterior strip of columns,of box type raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.5.5.6. It is showing the maximum positive bending moment (i.e. on interior strip 576.35 kNm; on exterior strip 511.83 kNm) and showing a negligible negative bending moment values for the two strips.

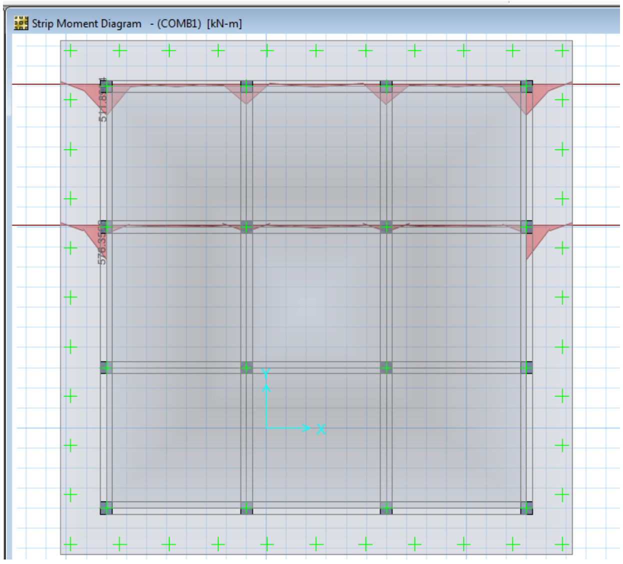

Fig-5.5.5.6: Bending moment diagramof box type raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.5.5: Max. Bending Moment in box type raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Max. Bending Moment (kN-m)
1	Sandy Clayey Silt	10000	195	561
2	Sandy Soil with low percentage of gravel	14000	205	568
3	Clayey Sand Silt with Gravels	15000	235	569
4	Sandy Silt	16000	245	570
5	Sand-Silt Mix with or without gravel	20000	195	574
6	Hard Mooram with Kanker	25000	270	576

5.5.6 Bending Moment Diagramof pile raft on different soil types

Bending moment diagram along interior and exterior strip of columns,of pile raft for the six different soil types are discussed in this section and a comparison for maximum bending moment values of this type of rafton all six types of soilis given in Table 5.5.6.

5.5.6.1: Bending Moment Diagramof pile raft on Sandy Clayey Silt:

Variation of bending moment along interior and exterior strip of columns,of pile raft forsoil-1 (i.e. Sandy Clayey Silt)is shown below in fig. 5.5.6.1. It is showing the maximum positive(i.e. on interior strip 2038.30 kNm; on exterior strip 1411.38 kNm) and maximum negative (i.e. on interior strip -565.11 kNm; on exterior strip -467.24 kNm) bending moment values for the two strips.

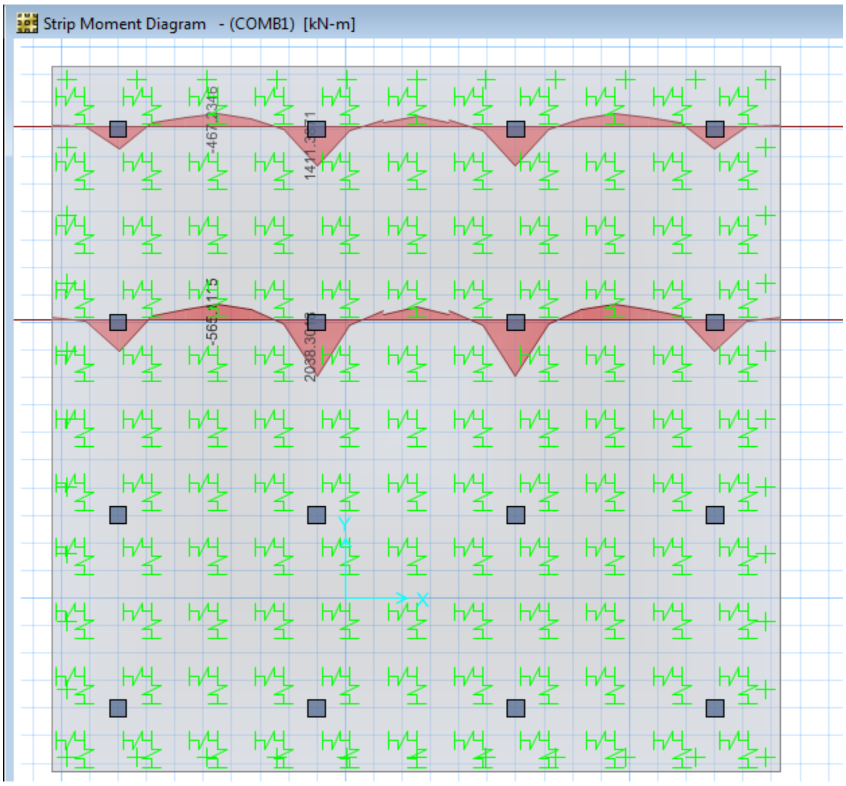

Fig-5.5.6.1: Bending moment diagramof pile raft for soil-1 (i.e. Sandy Clayey Silt)

5.5.6.2: Bending Moment Diagramof pile raft onSandy Soil with low percentage of Gravel:

Variation of bending moment along interior and exterior strip of columns,of pile raft forsoil-2 (i.e. Sandy Soil with low percentage of Gravel)is shown below in fig. 5.5.6.2. It is showing the maximum positive (i.e. on interior strip 2029.78 kNm; on exterior strip 1404.78 kNm)and maximum negative(i.e. on interior strip -560.88 kNm; on exterior strip -462.45 kNm) bending moment values for the two strips.

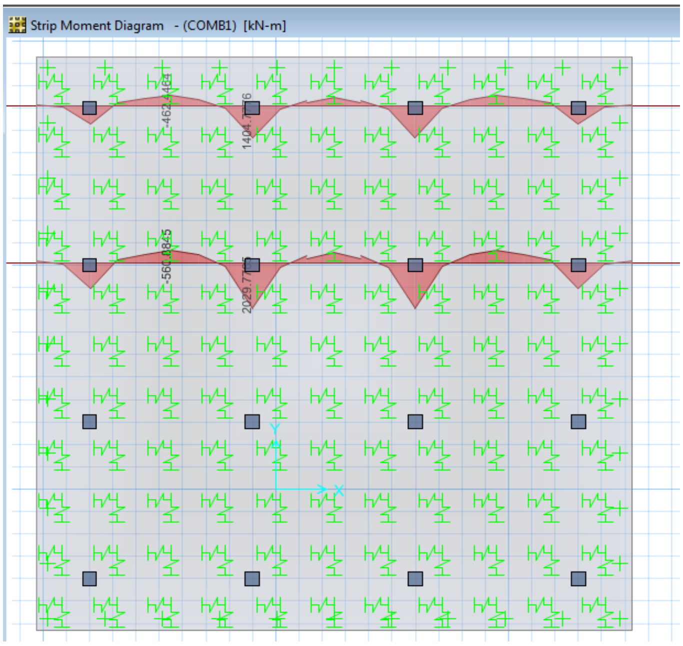

Fig-5.5.6.2: Bending moment diagramof pile raft for soil-2 (i.e. Sandy Soil with low percentage of Gravel)

5.5.6.3: Bending Moment Diagramof pile raft onClayey Sand Silt with Gravels:

Variation of bending moment along interior and exterior strip of columns,of pile raft forsoil-3 (i.e. Clayey Sand Silt with Gravels)is shown below in fig. 5.5.6.3. It is showing the maximum positive(i.e. on interior strip 2027.77 kNm; on exterior strip 1403.32 kNm) and maximum negative (i.e. on interior strip -559.88 kNm; on exterior strip -461.22 kNm) bending moment values for the two strips.

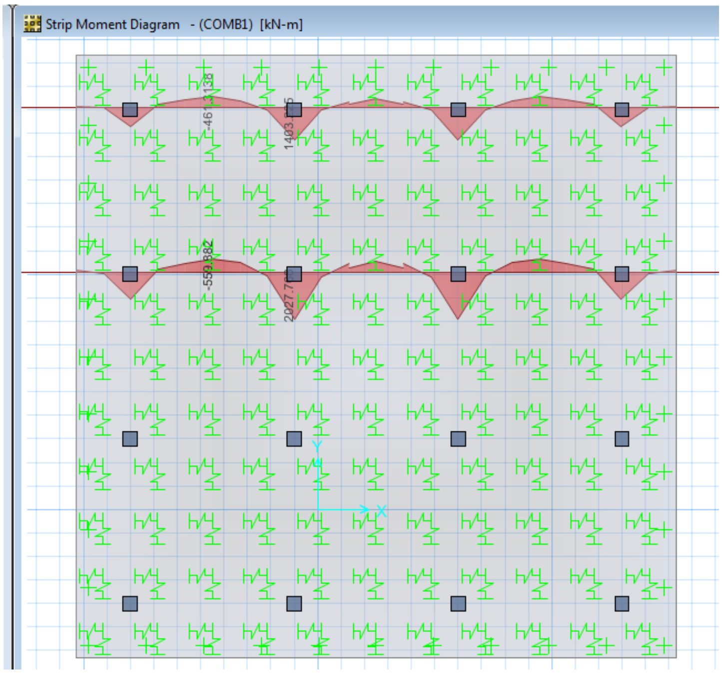

Fig-5.5.6.3: Bending moment diagramof pile raft for soil-3 (i.e. Clayey Sand Silt with Gravels)

5.5.6.4: Bending Moment Diagramof pile raft onSandy Silt:

Variation of bending moment along interior and exterior strip of columns,of pile raft forsoil-4 (i.e. Sandy Silt)is shown below in fig. 5.5.6.4. It is showing the maximum positive (i.e. on interior strip 2025.8 kNm; on exterior strip 1401.71 kNm) and maximum negative(i.e. on interior strip -558.90 kNm; on exterior strip -460.21 kNm) bending moment values for the two strips.

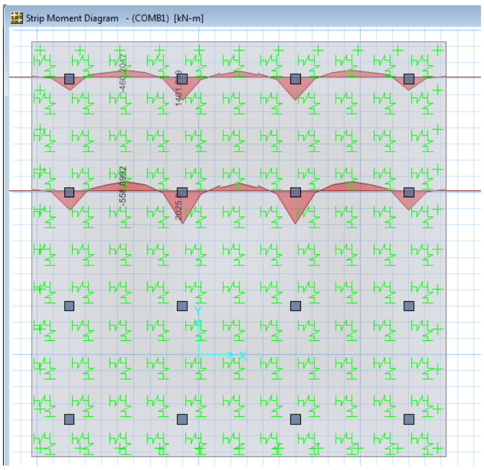

Fig-5.5.6.4: Bending moment diagramof pile raft for soil-4 (i.e. Sandy Silt)

5.5.6.5: Bending Moment Diagramof pile raft onSand-Silt Mix with or without gravel:

Variation of bending moment along interior and exterior strip of columns,of pile raft forsoil-5 (i.e. Sand-Silt mix with or without Gravel)is shown below in fig. 5.5.6.5. It is showing the maximum positive(i.e. on interior strip 2018.35 kNm; on exterior strip 1395.98 kNm) and maximum negative(i.e. on interior strip -555.15 kNm; on exterior strip -455.98 kNm) bending moment values for the two strips.

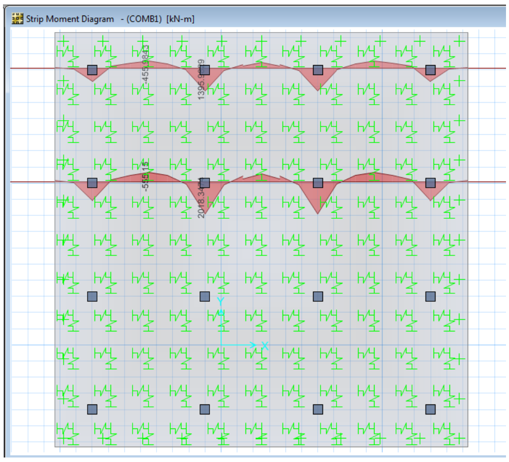

Fig-5.5.6.5: Bending moment diagramof pile raft for soil-5 (i.e. Sand-Silt Mix with or without gravel)

5.5.6.6: Bending Moment Diagramof pile raft onHard Mooram with Kanker:

Variation of bending moment along interior and exterior strip of columns,of pile raft forsoil-6 (i.e. Hard Mooram with Kanker)is shown below in fig. 5.5.6.6. It is showing the maximum positive(i.e. on interior strip 2009.85 kNm; on exterior strip 1389.15 kNm) and maximum negative (i.e. on interior strip -550.82kNm; on exterior strip -451.13kNm) bending moment values for the two strips.

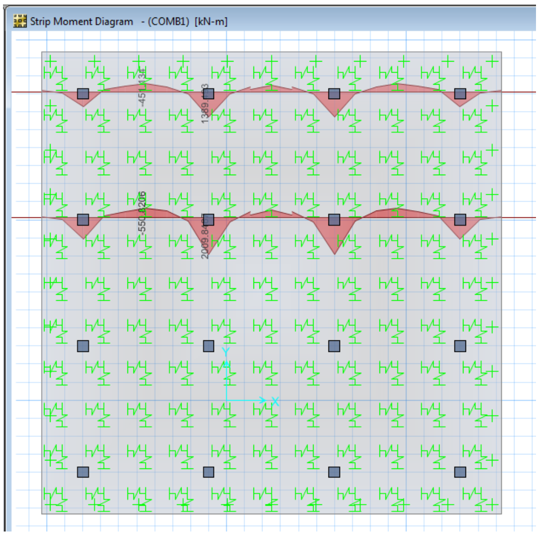

Fig-5.5.6.6: Bending moment diagramof pile raft for soil-6 (i.e. Hard Mooram with Kanker)

Table-5.5.6: Max. Bending Moment inpile raft on different soil conditions:

Soil Type	Soil Description	Modulus of Sub grade Reaction (ks) (kN/m²/m)	Soil Bearing Capacity (kN/m²)	Max. Bending Moment (kN-m)
1	Sandy Clayey Silt	10000	195	2038
2	Sandy Soil with low percentage of gravel	14000	205	2030
3	Clayey Sand Silt with Gravels	15000	235	2028
4	Sandy Silt	16000	245	2026
5	Sand-Silt Mix with or without gravel	20000	195	2018
6	Hard Mooram with Kanker	25000	270	2010

5.6 Comparative study

This section is divided in following four parts:

1. Maximum settlement valuesof all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are given in Table 5.6.1, and a comparison between maximum settlement of these different rafts on these six soil types is represented by a bar chart in fig.5.6.1.

2. Maximum punching shear valuesof four types of raft, (i) flat plate raft, (ii) flat plate raft thickened under column, (iii) flat plate with pedestal raft, and (iv) pile raft, on six different soil types are given in Table 5.6.2, and a comparison between maximum punching shear values of these different rafts on these six soil types is represented by a bar chart in fig.5.6.2. As in case of slab beam raft and box type raft, two way shear is countered by the shear reinforcement in beams in case of slab beam raft and countered by the RCC walls connecting columns in case of box type raft. So it is not considered here for the comparison.

3. Maximum shear force valuesof all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are given in Table 5.6.3, and a comparison between maximum shear force of these different rafts on these six soil types is represented by a bar chart in fig.5.6.3.

4. Maximum bending moment valuesof all six types of raft, (i) flat plate raft, (ii) slab beam raft, (iii) flat plate raft thickened under column, (iv) flat plate with pedestal raft, (v) box type raft, and (vi) pile raft, on six different soil types are given in Table 5.6.4, and a comparison between maximum bending moment of these different rafts on these six soil types is represented by a bar chart in fig.5.6.4.

Table-5.6.1: Comparison between maximum Settlements:

Soil Type	MAXIMUM SETTLEMENT(in mm)					
	Flat Plate Raft	Slab Beam Raft	Flat Plate Thickened Under Column Raft	Flat Plate With Pedestal Raft	Box Type Raft	Pile Raft
Soil-1	21.3613	21.13	20.973	20.542	19.6	4.04
Soil-2	15.547	15.475	15.267	15.0433	14.738	3.85
Soil-3	14.572	14.529	14.311	14.127	13.923	3.79
Soil-4	13.7184	13.699	13.473	13.324	13.206	3.75
Soil-5	11.147	11.206	10.954	10.912	11.042	3.58
Soil-6	9.077	9.1972	8.929	8.976	9.283	3.39

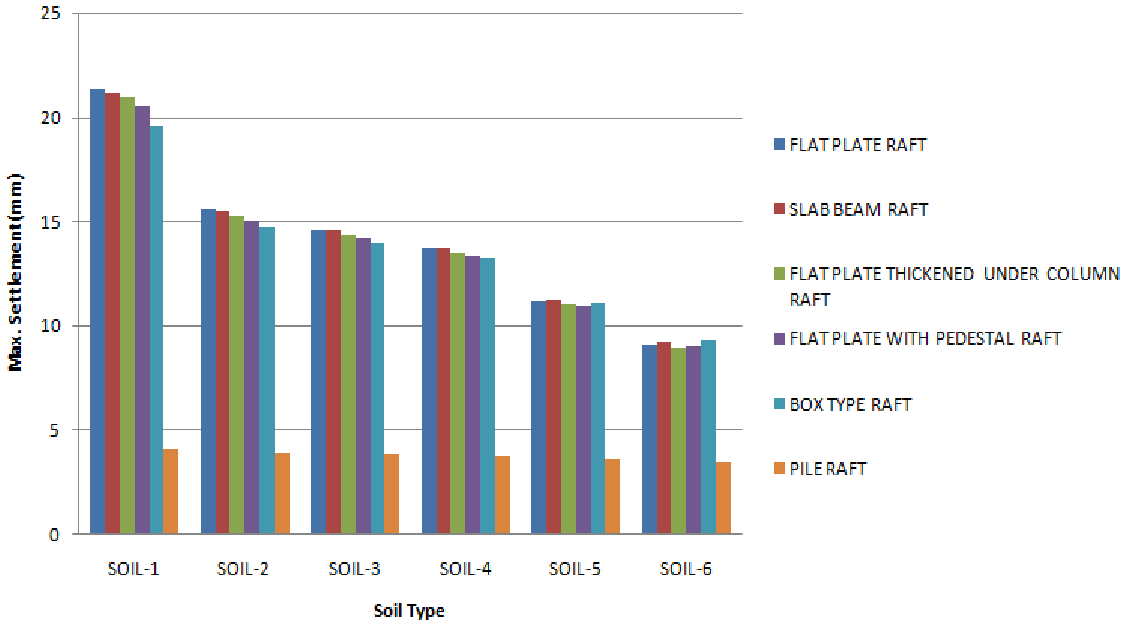

Fig-5.6.1: Comparison between max. settlement of different raft on different soils

Table-5.6.2: Comparison between max. Punching Shear in raft:

Soil Type	MAXIMUM PUNCHINGSHEAR			
	Flat Plate Raft	Flat Plate Thickened Under Column Raft	Flat Plate With Pedestal Raft	Pile Raft
Soil-1	1.101	0.8753	1.1422	1.1275
Soil-2	1.1005	0.873	1.1395	1.1255
Soil-3	1.1004	0.8725	1.1389	1.1250
Soil-4	1.1002	0.872	1.1382	1.1245
Soil-5	1.0996	0.8701	1.1358	1.1227
Soil-6	1.099	0.868	1.1328	1.1206

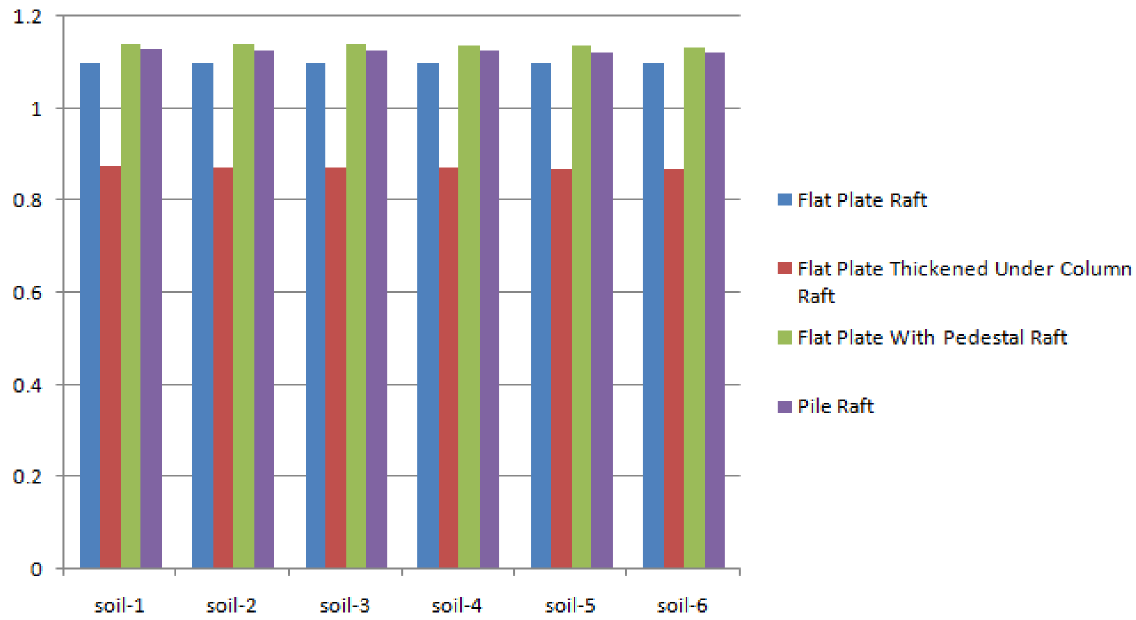

Fig-5.6.2: Comparison between max. punching shear in different raft on different soils

Table-5.6.3: Comparison between maximum Shear Force:

SOIL TYPE	MAXIMUM SHEAR FORCE (in kN)					
	FLAT PLATE RAFT	SLAB BEAM RAFT	FLAT PLATE THICKENED UNDER COLUMN RAFT	FLAT PLATE WITH PEDESTAL RAFT	BOX TYPE RAFT	PILE RAFT
SOIL-1	1565.965	284.835	2224.501	3027.124	515.231	1635.648
SOIL-2	1560.835	282.853	2218.887	3025.445	514.510	1627.877
SOIL-3	1559.747	282.432	2217.698	3025.069	514.088	1626.059
SOIL-4	1558.719	282.033	2216.572	3024.708	513.589	1624.287
SOIL-5	1555.088	280.611	2212.566	3023.385	510.969	1617.617
SOIL-6	1551.330	279.123	2208.356	3021.945	506.720	1610.107

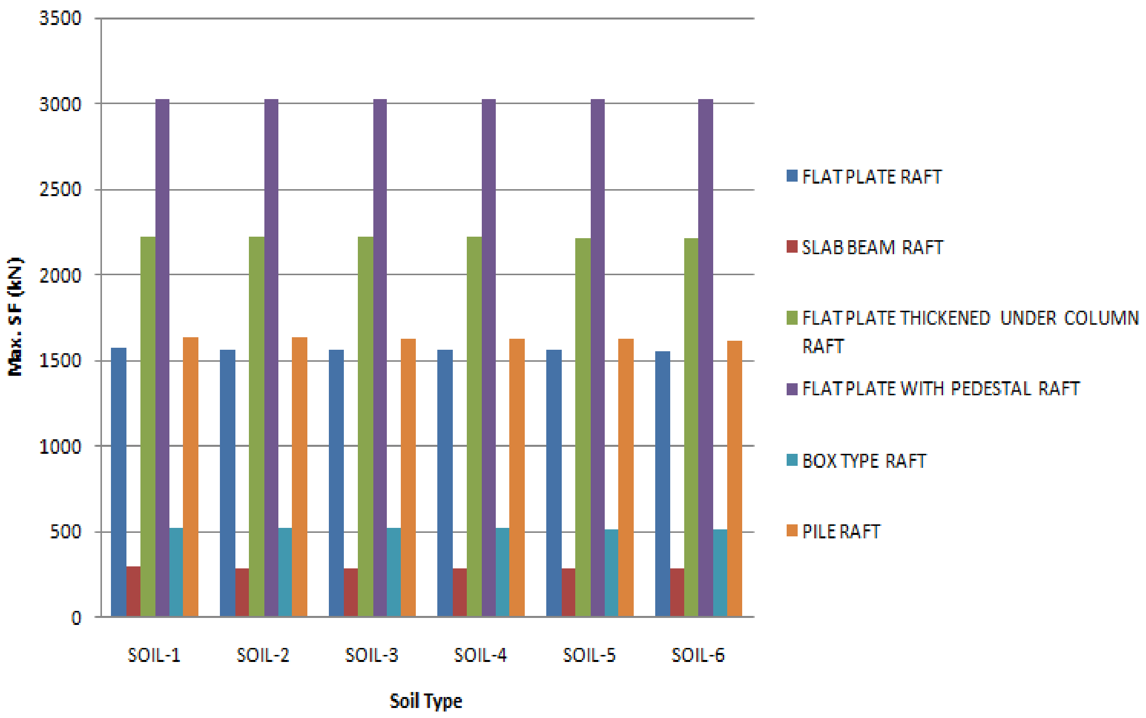

Fig-5.6.3: Comparison between max. shear force in different rafts on different soils

Table-5.6.4: Comparison between maximum Bending Moments

SOIL TYPE	MAXIMUM BENDING MOMENT (in kN-m)					
	FLAT PLATE RAFT	SLAB BEAM RAFT	FLAT PLATE THICKENED UNDER COLUMN RAFT	FLAT PLATE WITH PEDESTAL RAFT	BOX TYPE RAFT	PILE RAFT
SOIL-1	2140.809	326.604	2906.563	1407.550	560.916	2038.302
SOIL-2	2103.359	320.609	2869.012	1392.876	567.838	2029.778
SOIL-3	2095.829	319.450	2861.750	1390.151	569.160	2027.766
SOIL-4	2088.858	318.390	2855.110	1388.168	570.364	2025.800
SOIL-5	2065.436	314.890	2833.240	1381.121	573.965	2018.347
SOIL-6	2043.280	311.567	2812.970	1373.541	576.350	2009.848

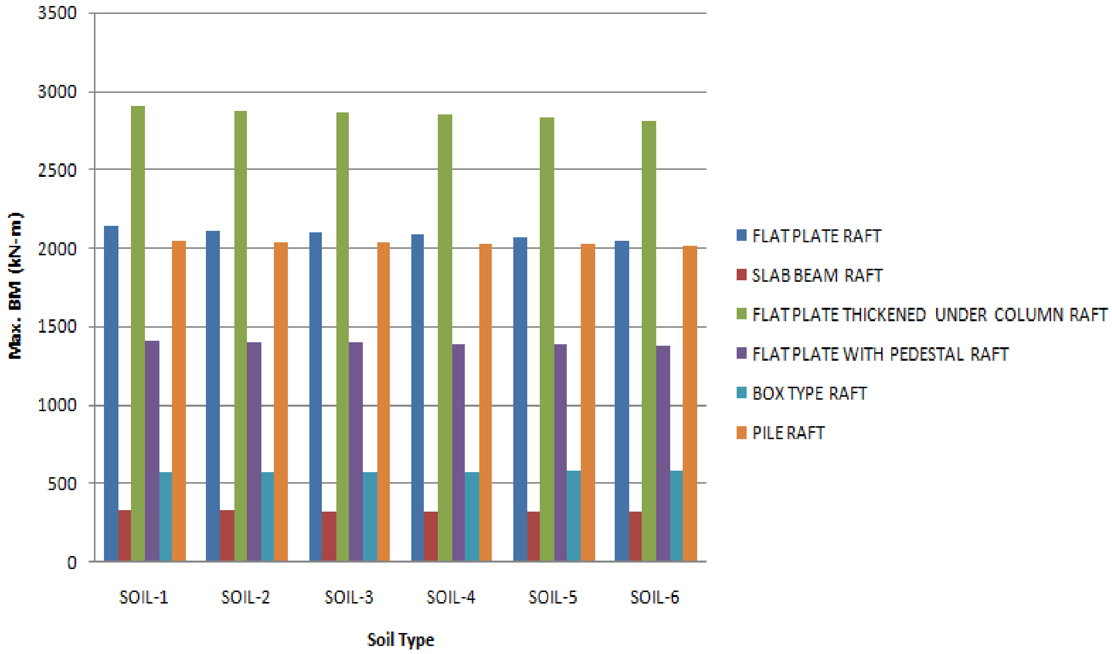

Fig-5.6.4: Comparison between max. bending moments in different rafts on different soi

Chapter-6
Conclusion and Scope for Future work

In this project, different types of raft models were developed using the software SAFE-v12 to analyze raft foundations. These model account for the effect of interaction among raft, pile and soil. The raft model were divided into 1m strips along x and y directions. This employs the raft being divided into small sections of 1mx1m size. The results obtained from this study of model were listed and compared in previous sections and concluded below. The results from the model provides comparative study of different types of raft on different soil types.

6.1 Conclusion

1. Based upon the analysis, it can be concluded that, in all types of raftsleast amount of settlement can be observed in soil type-6, i.e. Hard Mooram with Kankersoil.
2. From the comparative study of results of punching shear, it can be concluded that raft with flat plate thickened under column, is a better alternative to counter punching shear.
3. As in case of slab beam raft, two way shear is countered by shear reinforcement provided in beams, therefore no punching is observed in slab beam raft and also in case of box type raft, RCC walls provide rigidity against two way shear.
4. From the tables of shear force and bending moment, it can be concluded that magnitude of SF and BM is much lesser in slab beam raft arrangement as compared to other type of rafts. Hence it can be concluded that slab beam raft is a better alternative for distribution of shear force and bending moment.
5. Due to hollow geometry of box type raft it can be used as basement or as storage tanks.
6. The bending moment and Shear force is much more concentrated below the columns in case of flat plate with pedestal raft, flat plate thickened under column raft and flat plate raft.

7. Based on this results we conclude that among these 6 types of soil, Beam and Slab Raft foundation is found to be distributing loads evenly all over the raft as compared to the other rafts.
8. Based on the results of pile raft foundations, the settlement is very less as compared to other type of rafts.

6.2Scope for Future work

The present study has covered a reasonably wide range of parameters (i.e., overall settlement, differential settlement, punching shear, shear force and bending moment) on the behavior of six different types of raft foundation for six different types of soil. Further studies can be carry out on the following aspects.

- The other basic shapes of the raft foundations like, circular andfolded plate shapes of the raft foundations can be considered.
- The effect of any cut out or hole in raft foundation can be assessed.
- The number of floors of the superstructure can be increased for a higher loading on raft and the effect can be assessed.
- Effects of underground water were not considered in this study. The effect of pore water pressure can be assessed into a future investigation

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