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Uplift Analysis on Performance of Different Types of Footings

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ABSTRACT: Uplift pressure is said to be a design load that areconsidered for those structures which are constructed below the groundwater table level. If the depth of the excavation is deeper, then, the greater will be the upward pressure applied by the water.Uplift pressure is also known as hydrostatic uplift. It is better defined as the upward pressure that is applied to the structure, which in turn has the potential to raise it relative to its surroundings. While constructing a structure it should be designed properly so that it can provide greater resistance against the uplift forces in order to avoid risks due to the occurrence of water pressure. So, while designing, the uplift pressure must be taken into consideration since maintenance and rehabilitation of foundation is not possible to be carried out easily in the future. Also, the parameters such as bearing capacity of soil, type of loading, location of footing etc. affect the stability of the footings in different mechanisms.

In this paper, the modelling and analysis of a 12 storied building which are supported by different footings is been studied. The modelling and analysis of the building is done using Extended Three-Dimensional Analysis of Building System software. Whereas, the modelling and analysis of different footings are carried out using CSI SAFE finite element analysis package for slabs and foundations. Various parameters such as the internal force, bending moment, shear force, footing stress are determined. The behavior of footings in terms of the parameters are evaluated. The results are then compared.

KEYWORDS: Eccentric loading, Footing stress,Soil bearing capacity, Uplift

I. INTRODUCTION

The low artificially built part of a structure which transmits the structural load to the ground is called foundation. It is always constructed just below the ground level so that the lateral stability of the structure is increased. It includes the portion of the structure below the ground level and is built, so as to provide a firm and level surface for transmitting the load of the structure onto a large area of the soil that is lying underneath. Thesolid ground on which the foundation rests is known as the foundation bed.

a) Types of Footings

There are mainly two types of foundations such as shallow and deep foundations.Ashallow foundation transfers the load to the soil near to the surface. In the case of shallow foundation, the depth of the foundation is generally less than its width. Whereas, a deep foundation helps to transfer the load to the soil deep down. Its depth is usually greater than 3m below the ground. Shallow foundation includes footings such as isolated footing, wall footing,raft footing, combined footings etc. Whereas deep foundation consists of pile foundation, pier foundation, well foundations.

b) Purpose of a foundation

All civil structures are provided with foundations at its base to fulfil the following purposes:

- To distribute the load of the structure over a large bearing
- To prevent unequal settlement
- To prevent lateral movement of the supporting material
- To secure a levelled and firm bed for building operations
- To increase stability of the structure as a whole
- To anchor the structure deeply into the ground to preventoverloading

II. OBJECTIVES

In this study, uplift analysis of different footings is studied. Along with uplift pressure, parameters affecting the stability of the foundation are also evaluated.

- ➢ To study the behavior of buildings supported by different types of foundations
- ➢ To study the behavior of footings by changing different factors affecting its performance

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- To study the behavior of structure for parameters like:
- Internal Force
- Bending Moment
- Shear Force
- Footing Stress

III. METHODOLOGY

The methodology of the study is as follows:

- Modelling and analysis of a 12 storied building in ETABS software
- Exporting column loads from ETABS to SAFE software
- Modelling & designing of different footings in SAFE software
- Optimization of different types of footings
- Analysis of isolated footings under eccentric loading
- Study on eccentricity in isolated footing
- Evaluation of footings in normal soil
- Evaluation of footings in weak soil
- Uplift Analysis
- Comparison of Results

IV. MODELLING OF BUILDING

For the present study, a 12 storied building is modelled and analysed in ETABS software. The following are the details of the 12 storied commercial building.

Table 1. Model Descriptions

SPECIFICATIONS	VALUES
Grade of Concrete	M30
Grade of Steel	Fe415
No. of Bays in X & Y Direction	6
Span of Bays	4m
Beam Size	230 mm x 500 mm
Column Size	500 mm x 500 mm
Slab Thickness	120 mm

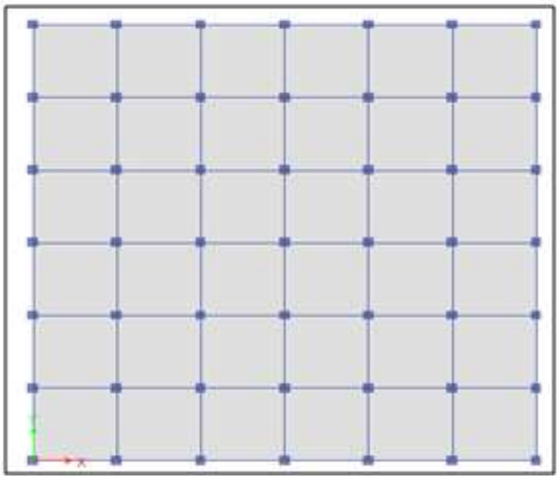

Fig.1. Plan

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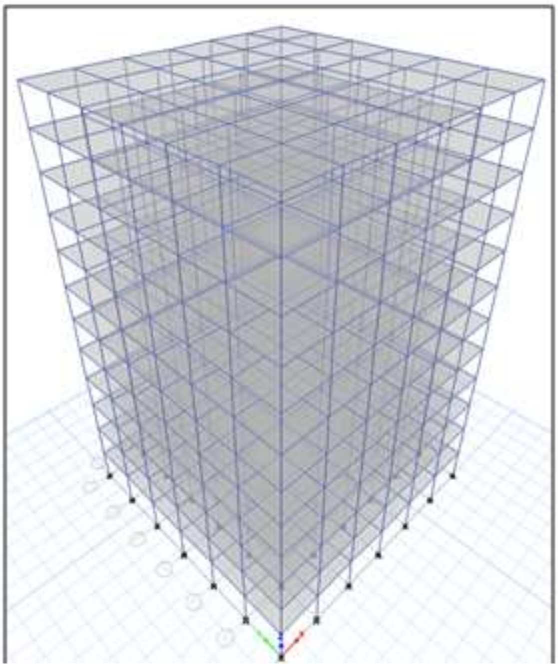

Fig.2. 3d Model

The concrete grade and rebar grades of beam, columnand slab are safe as per is 456: 2000 when analysed in ETABS.The equivalent static lateral force method is a simplified technique to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purposes. By using the method of equivalent static analysis in ETABS the loads are calculated. By assigning the zone factor the earthquake loads and all other loads acting on the structure is been determined. For the present study, the combination of live load and dead load is only taken. Using this load combination, the different types of foundations are modelled and analysed.

V. LOAD CALCULATIONS

Dead load is calculated as per IS 875 (Part I):1987, live load as per IS 875 (Part II): 1987 and the design is done as per IS 456: 2000, IS 1904: 1986 and IS 1080: 1980. Seismic load is not considered as it does not give highest value of load combination as per IS 875 (Part V): 1987. The load detailing's of the building are shown below:

Table 2. Dead load

SPECIFICATIONS	LOAD
Brick Wall	13.8 KN/m²
Floor Finish	1.2 KN/m²

Table 3. Live load

SPECIFICATION	LOAD
Commercial Building	3 KN/m²

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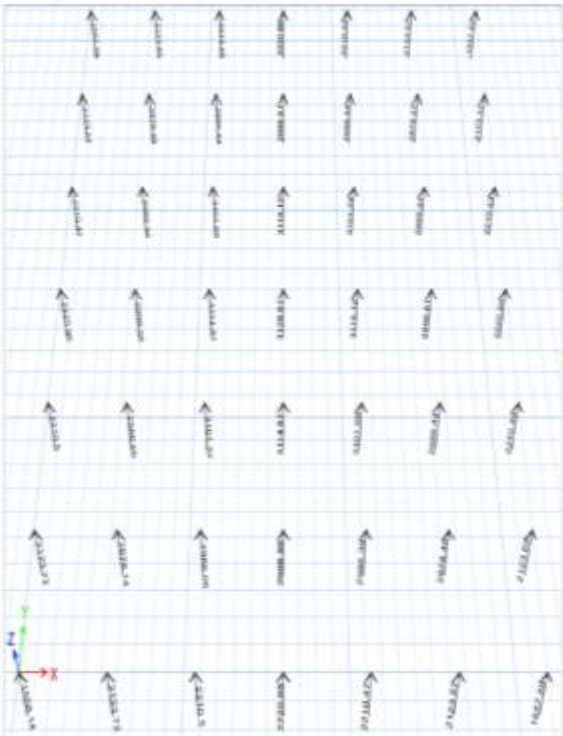

Fig.3. Exported Loads from ETABS

The column loads are first calculated in ETABS by using equivalent static analysis. Here for the further analysis the combination of dead load and live load acting under each column is been determined. That is, the axial loads on each footing are calculated. After calculating the loads, they are exported from ETABS software to CSI SAFE software. The different types of foundations are then modelled using the calculated axial load that acts under each column.The dimensions of each footing are calculated with the help of the axial loads obtained. For that the safe bearing capacity of different soils should be taken into consideration.

VI. MODELLING OF FOOTINGS IN SAFE

Different types of footings are modelled and analysed in SAFE based on a variety of parameters. Seven types of footings are selected for the study and are optimized. Each parameter is then evaluated for every footing. The results are tabulated and compared in detail.

a) Isolated Footing

Fig.4. Optimized Isolated Footing

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The dimensions of the footing are then optimized in such a way that the punching shear ration falls below one and the soil pressure is below the assumed safe bearing capacity of the soil. The optimization is done for making the structure more economic and safer. The optimized dimensions are shown in the figure shown below. After optimization, the self-weight of the footing got reduced by 19% when compared with the assumed dimensions.

The optimized dimension is shown below:
- C1 - 2.5 m x 2.5 m
- C2 - 2.9 m x 2.9 m
- C3 - 3.3 m x 3.3 m
- C4 - 3.4 m x 3.4 m
- C5 - 3.5 m x 3.5 m

b) Raft Footing

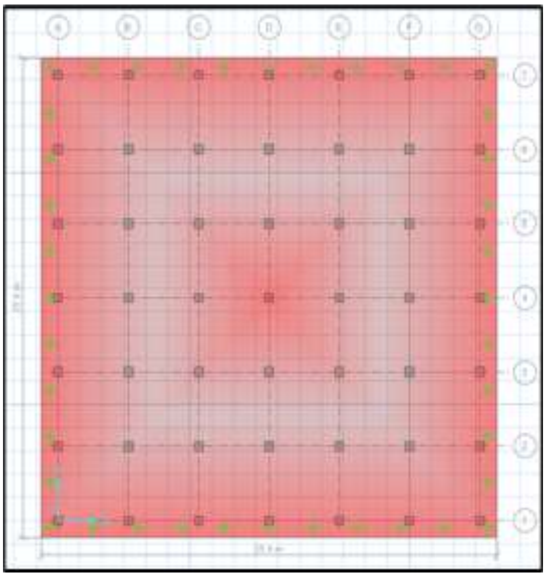

Fig.5. Optimized Raft without Drop Footing

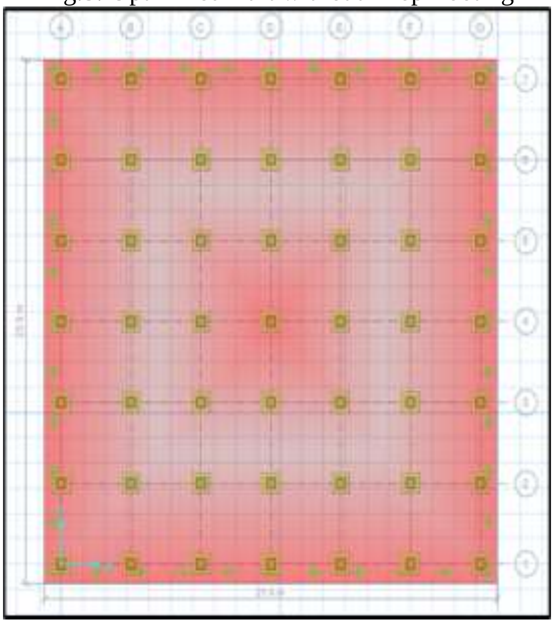

Fig.6. Optimized Raft with Drop Footing

The figure shows the optimized raft footing with and without drop. After optimization, the size of raft without drop obtained is 25.9m x 25.9m x 0.7m. For raft with drop the size obtained for footing is 25.9m x 25.9m x 0.5m and the size obtained for drop is 1.0m x 1.0m x 0.5m. As per IS

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1080, a minimum depth of 50 cm shall be used for mat foundation. It was found that the self-weight of raft foundation is reduced by 21.27% when drop is added.

c) Pile Foundation

Fig.7. Optimized Pile Foundation

The optimized pile foundation is shown here. The no: of piles under the pile cap is obtained by dividing column load by pile capacity. In CSI SAFE, pile cap is modelled and piles are given as point springs having stiffness of pile. The optimized pile cap details for the pile foundation are shown in the following figures.

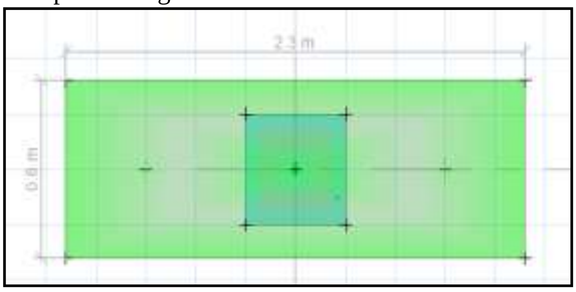

Fig.8. Two-Pile cap (depth = 800mm)

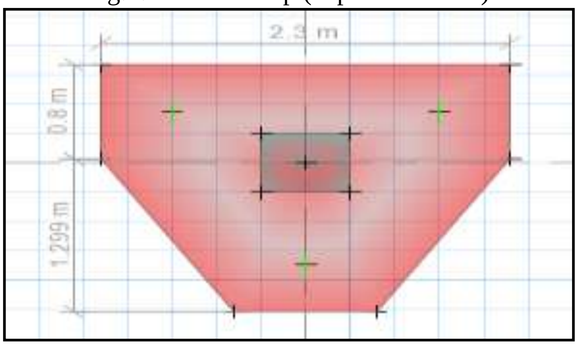

Fig.9. Three-Pile cap (depth = 1000mm)

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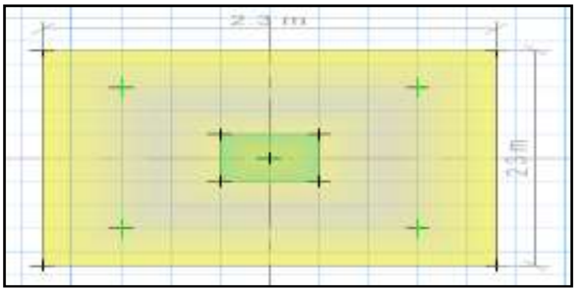

Fig.10. Four-Pile cap (depth = 800mm)

d) Eccentric Footing

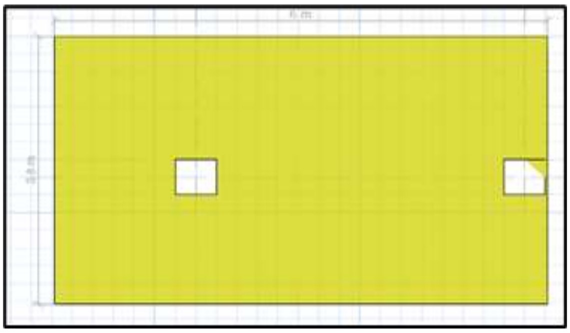
Fig.11. OptimizedCombined Rectangular Footing

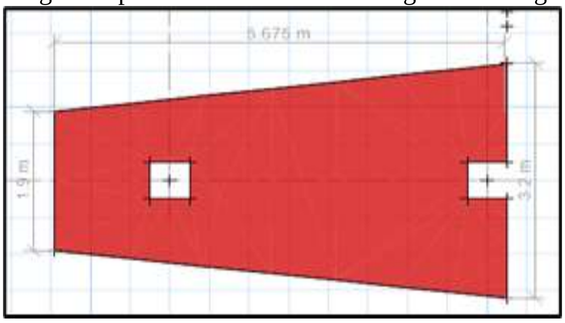

Fig.12. OptimizedCombined Trapezoidal Footing

Fig.13. Optimized Strap Footing

VII. PARAMETRIC STUDY

a) Internal Force

The distribution and magnitude of internal forces depends not only on the applied external load, but also depends on the geometry of the structural system. For different types of footings, the geometry also will be varying. Therefore, the magnitude and distribution of the internal force should be evaluated.

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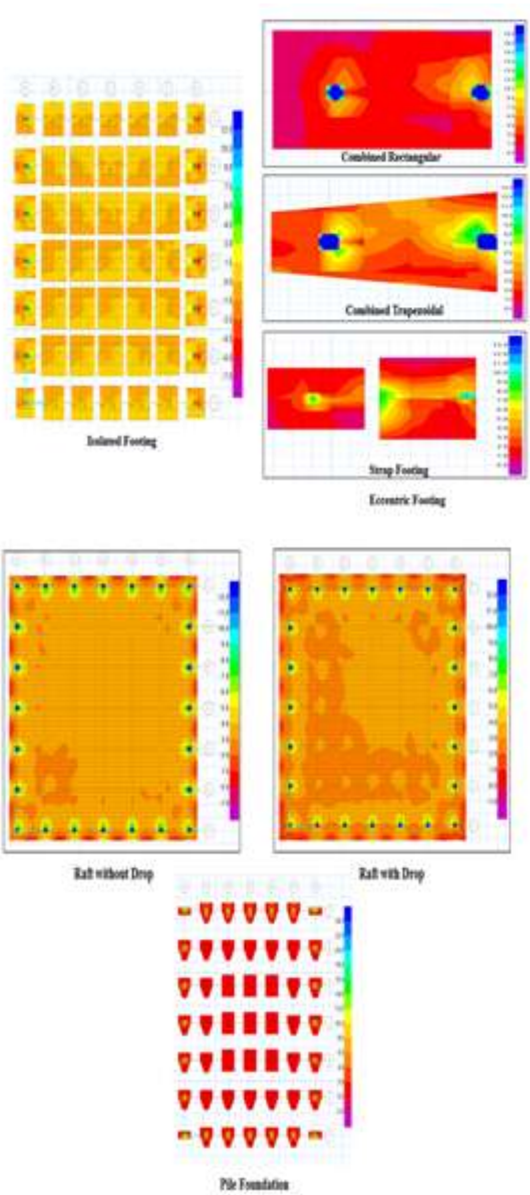

Fig.14. Internal Force Diagram of Footings in Normal Soil
Fig.15. Internal Force Diagram of Footings in Weak Soil

b) Bending Moment

Bending moment is a measure of the bending effect that can occur when an external force or moment is applied to a structural element. The bending Moment depends on depth of the footing. It also depends on axial load from column and the distribution of pressure at the base of the footing.The larger depth decreases area of steel.

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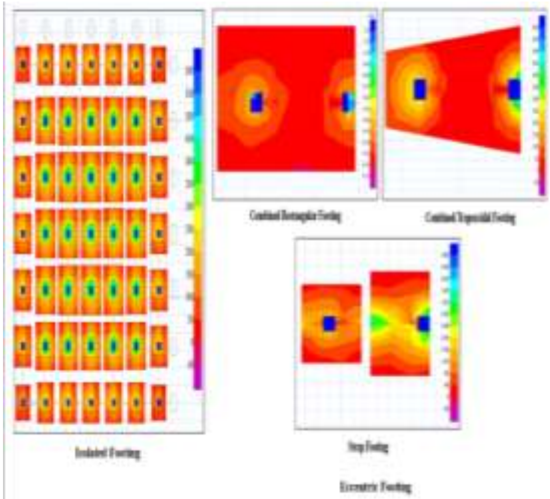

Fig.16. Bending Moment Diagram of Footings in Normal Soil

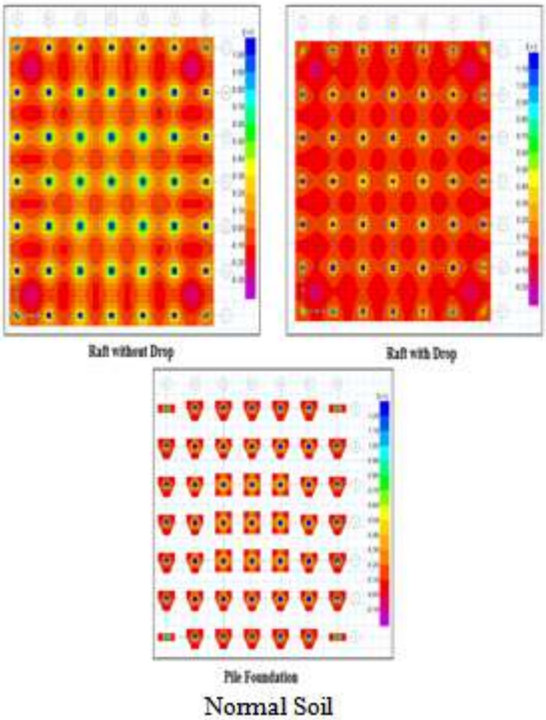

Fig.17. Bending Moment Diagram of Footings in Weak Soil

c) Shear Force

Shear Force is a force applied perpendicular to a surface, in opposition to an offset force acting in the opposite direction. This results in a shear strain.

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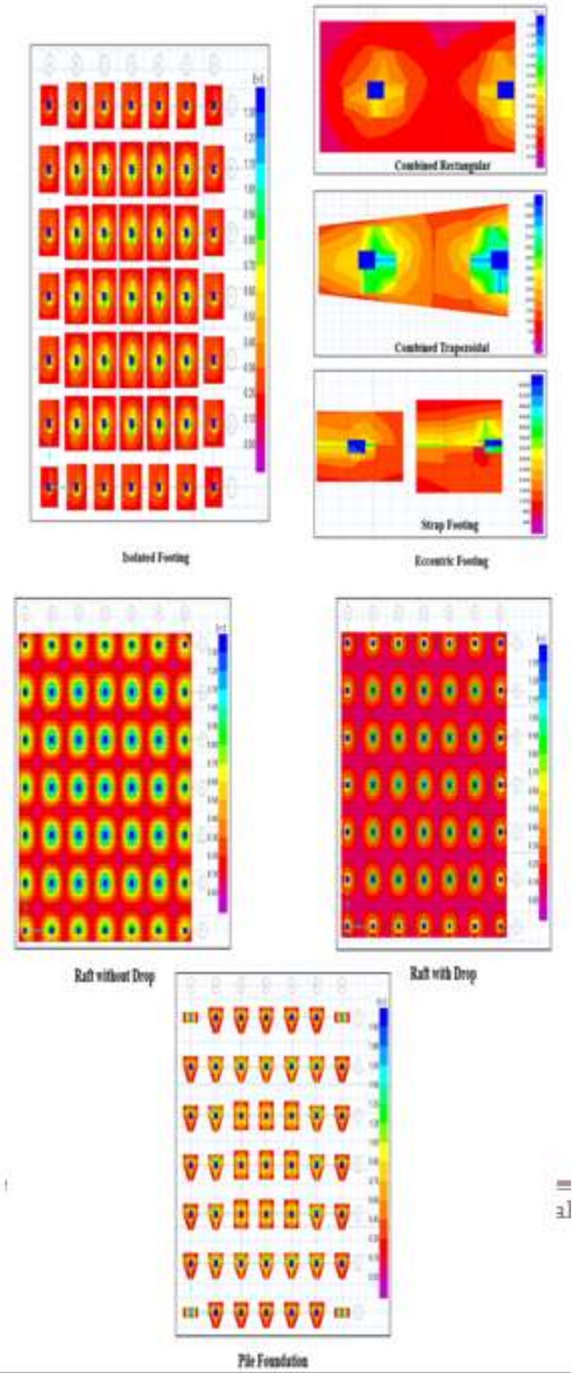

Fig.18. Shear Force Diagram of Footings in Normal Soil
Fig.19. Shear Force Diagram of Footings in Weak Soil

d) Footing Stress
Footing stress distribution depends on type of material beneath the footing and rigidity of footing.

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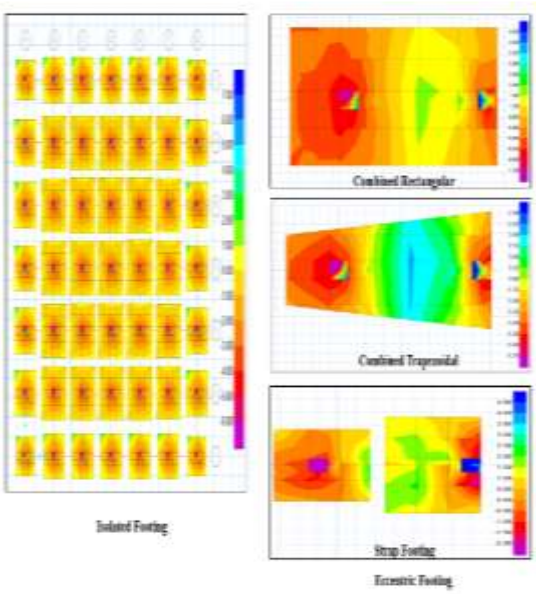

Fig.20. Footing Stress Diagram of Footings in Normal Soil

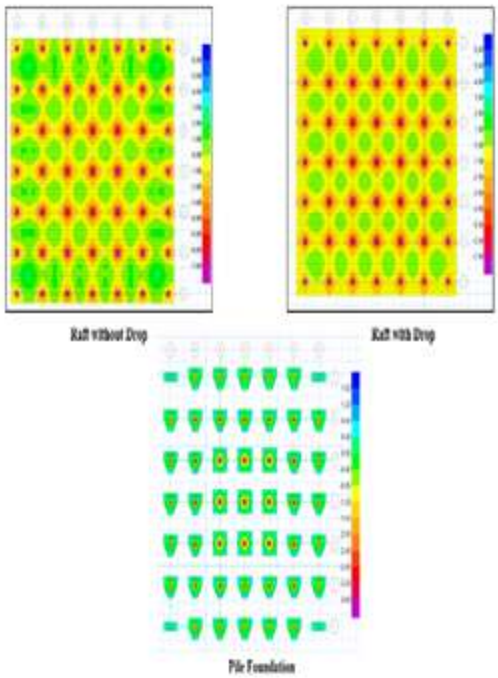

Fig.21. Footing Stress Diagram of Footings in Weak Soil

Internal Force: Internal force of footing is caused by accelerations on footings and due to displacement patterns, that takes place. It is almost similar for raft with & without drop footings.While considering eccentric footings, internal force is highest for rectangular footing & the other two types have almost same internal force.

Bending Moment: Bending Moment depends on depth of the footing. It depends on axial load from column and the distribution of pressure at the base of the footing.Here bending moment is less for raft with drop.While comparing eccentric footings, bending moment is highest for combined rectangular & lowest for strap footing.

Shear Force: Shear force is the rate of change of bending moment. It is almost equal for raft with and without drop footing.While comparing eccentric footing, shear force is highest for combined rectangular footing & is lowest for strap footing.

Footing Stress: Footing stress distribution depends on type of material beneath the footing and rigidity of footing. It is almost similar for raft with &

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without drop footing. While comparing eccentric footing, footing stress is highest for strap footing & is least for combined trapezoidal footing.

VIII. RESULTS

The building model isanalysed using equivalence static analysis. The column axial loads obtained from this analysis are exported from ETABS and then imported to SAFE. Using these column axial loads, different footings are modelled, designed and analysed.

Uplift pressure is a design load to be considered for the structures constructed below the groundwater table. When the depth of the excavation is deeper, the greater will be the upward pressure applied by the water.Knowing how to calculate the uplift pressure is very important for structural engineers as mostly many structures are constructed below the groundwater table. Through uplift analysis the relation between rise of water table and stability of the foundation is studied.

Uplift analysis for different footings is done for parameters such as internal force, bending moment, shear force and footing stress. Through this analysis, it is possible to determine the best performing foundation.

a) Uplift Vs Internal Force

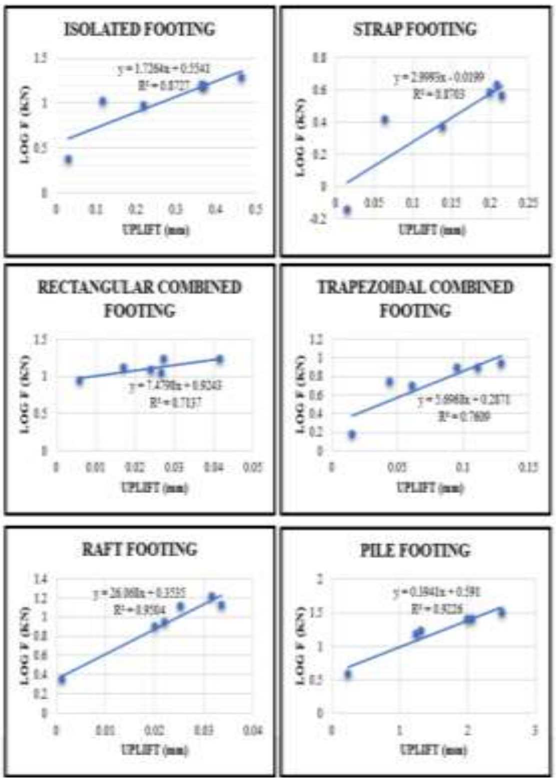

Fig.22. Uplift Vs Internal Force

b) Uplift Vs Bending Moment

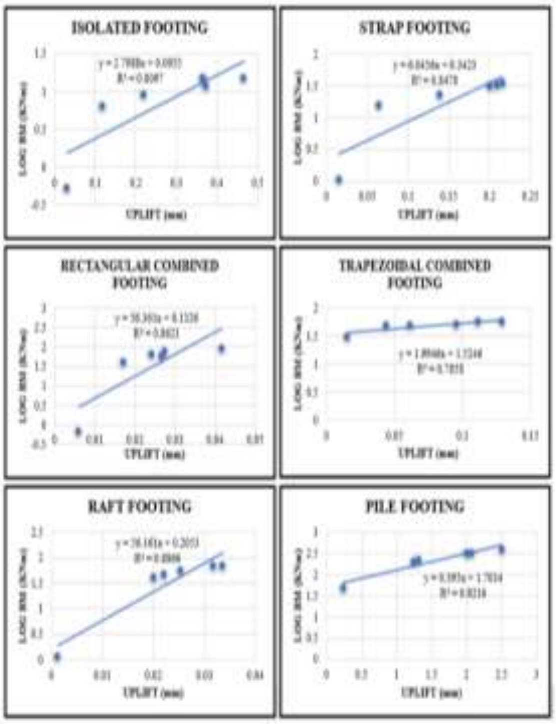

Fig.23. Uplift Vs Bending Moment

c) Uplift Vs Shear Force

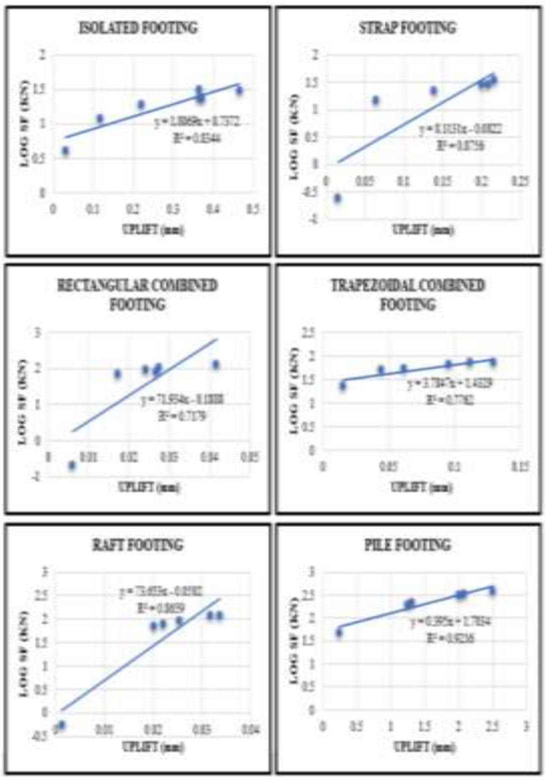

Fig.24. UpliftVs Shear Force

d) Uplift Vs Footing Stress

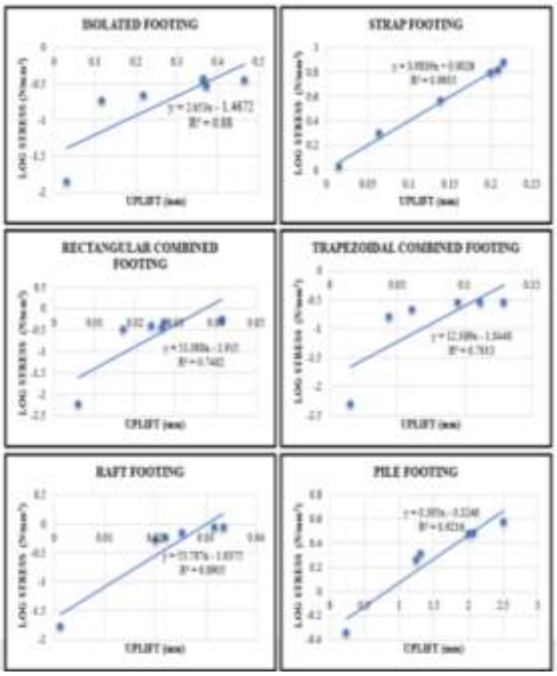

Fig.25. Uplift Vs Footing Stress

IX. CONCLUSION

In this study, A 12 storey building is modelled and analysed in ETABS. The column loads are then exported to SAFE. The different kinds of footings are then designed in SAFE. Optimization of the footings are done by considering safe bearing capacity and punching shear. The following are the results obtained from uplift analysis:

- Internal Force: For every unit increase in uplift, the internal force increases 1.73% for isolated footing, 3% for strap footing, 7.4% for combined rectangular footing, 5.7% for combined trapezoidal footing, 26.06% for raft footing, 0.39% for pile foundation.
- Bending Moment: For every unit increase in uplift, the bending moment increases 2.80% for isolated footing, 6.04% for strap footing, 56.36% for combined rectangular footing, 1.99% for combined trapezoidal footing, 56016% for raft footing, 0.39% for pile foundation.
- Shear Force: For every unit increase in uplift, the shear force increases 1.8% for isolated footing, 8.1% for strap footing, 71.93% for combined rectangular footing, 3.78% for combined trapezoidal footing, 73.65% for raft footing, 0.395% for pile foundation.
- Footing Stress**:**For every unit increase in uplift, the footing stress increases 2.65% for isolated footing, 3.98% for strap footing,51.1% for combined rectangular footing, 12.38% for combined trapezoidal footing, 53.78% for raft footing, 0.395% for pile foundation.

In uplift analysis, when internal force vs uplift, bending moment vs uplift, shear force vs uplift and footing stress vs uplift were considered, the pile foundation found to be superior next to isolated footing and strap footing. This is because, pile foundation had lowest increase in internal force, bending moment, shear force and footing stress.

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