Punching Shear Analysis on Performance of Different Types of Footings

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***Abstract*— There are many failure mechanisms that occurs in structural members like slabs and foundation by shear under the action of concentrated loads. The action of concentrated loads is on a smaller area in the structural members. In most cases, this reaction is the one from the column acting against the foundation. Eventually the foundation will fail. One possible method of failure is that the load punches through the slab. 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 supported by different footings is been studied here. The building modelling and analysis is done using Extended Three-Dimensional Analysis of Building System software. The modelling and analysis of different types of footings are carried out using CSI SAFE finite element analysis package for slabs and foundations by changing the bearing capacity of soil, type of loading and location of footings. Footings of the building in normal soil and weak soil are studied and compared in detail. Various parameters such as the punching shear, soil bearing capacity, 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, Punching Shear, Soil bearing capacity**

I. INTRODUCTION

The lowest part of the civil structure or building which is in direct contact with the soil is known as foundation. It helps in the transfer of loads from the structure to the soil safely. Design of foundations are considered to be an essential factor in structural design & analysis. The foundation is an utmost part of a structure which transfers the load from the superstructure to the soil. For the study, a 12 storied building supported with different footings is modelled and analysed here with the help of two software's ETABS and SAFE.

A. Types of Footings

There are mainly two types of foundations such as shallow and deep foundations. A shallow foundation transfers the load to the soil near to the surface. Here the depth of the foundation is generally less than its width. Whereas, a deep foundation transfers 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, raft footing, combined footings etc. Whereas deep foundation consists of pile foundation, pier foundation etc.

B. Punching Shear

In structural elements such as slabs and foundations, a type of failure mechanism namely punching shear takes place due to the action of shear under concentrated loads. The concentrated loads act on a smaller area in the members. As a result, column act against the slab and slab will fail. The main mechanism of failure is that the column punches through the slab. This failure mechanism is called punching shear.

II. OBJECTIVES

In this study, punching shear analysis of different footings are studied. Along with punching shear, 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
- To study the behavior of structure for parameters like:
  - Soil bearing capacity
  - Bending Moment
  - Shear Force
  - Footing Stress
  - Eccentricity
  - Punching Shear

III. METHODOLOGY

The methodology of the study is as follows.

- Modelling & 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 weak soil
- Punching Shear Analysis
- Comparison of Results

IV. MODELLING OF BUILDING

The modelling of the building is done using the software ETABS.

The model description are as follows

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- M30 grade concrete
- Fe415 grade steel
- 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

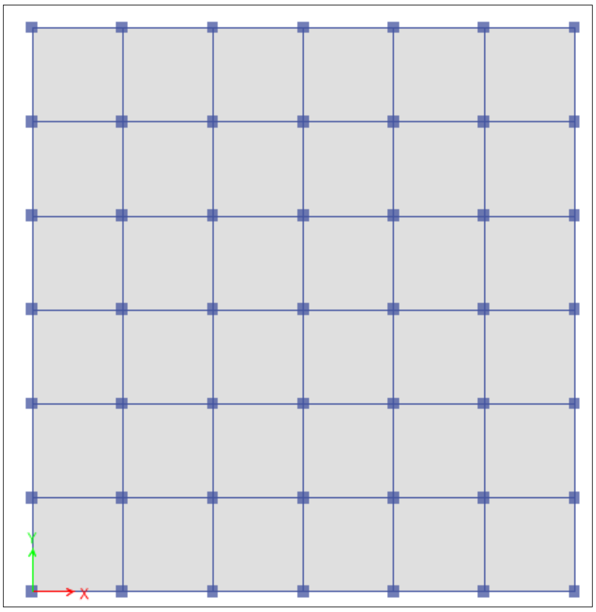

Fig.1. Plan

The concrete grade and rebar grades of beam, column and slab are safe as per is 456: 2000 when analysed in ETABS.

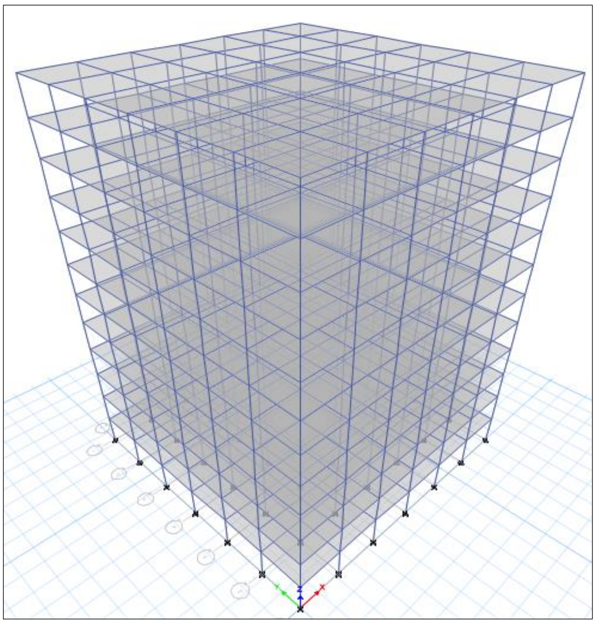

Fig.2. 3d Model

V. LOAD CALCULATIONS

Table 1. Dead load *(As per IS 875: 1987 Part 1)*

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

Table 2. Live load *(As per IS 875: 1987 Part 2)*

SPECIFICATION	LOAD
Commercial Building	3 KN/m²

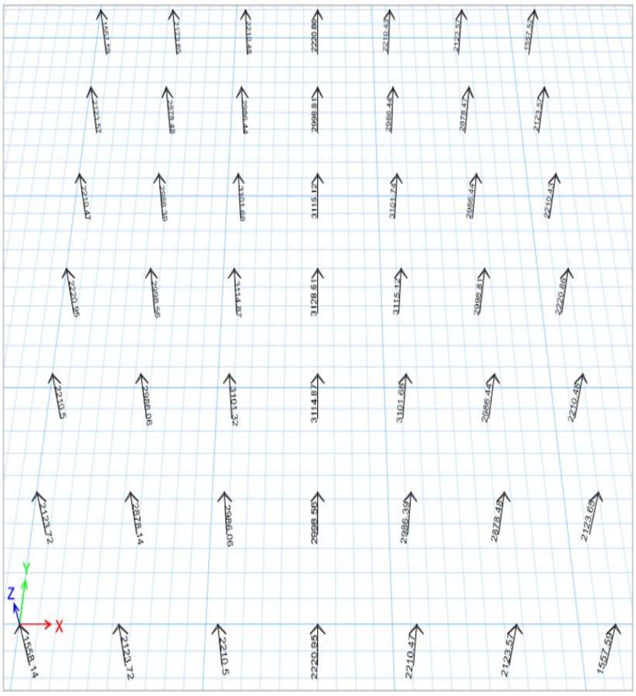

Fig.3. Exported Loads from ETABS

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 designed 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.

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A. Isolated Footing

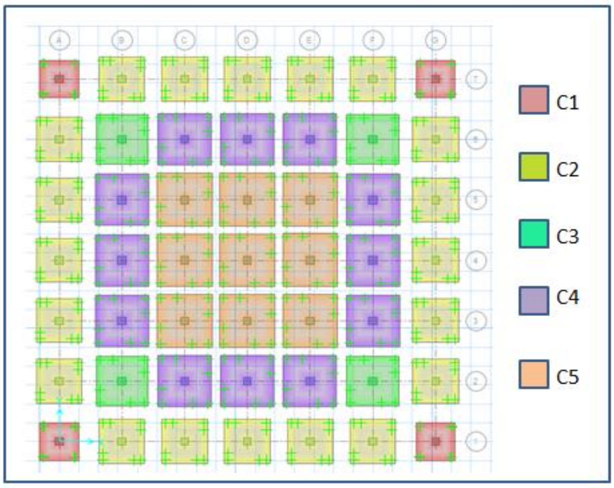

Fig.4. Optimized Isolated Footing

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 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

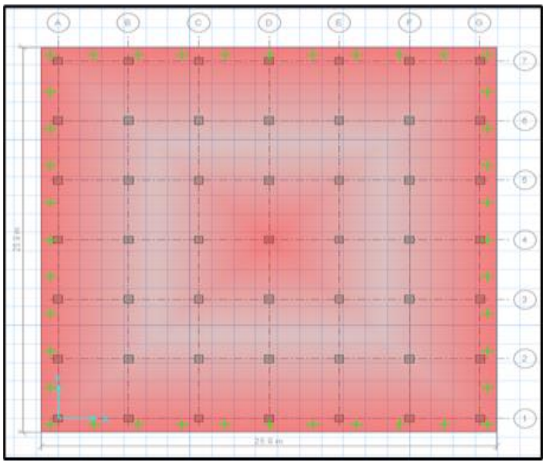

Fig.5. Optimized Raft without Drop Footing

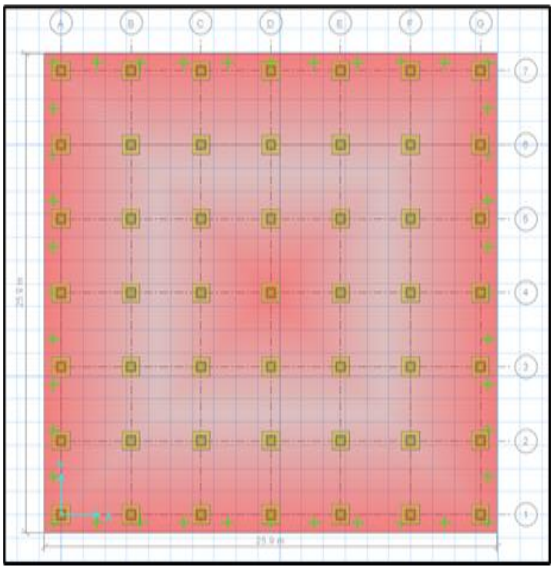

Fig.6. Optimized Raft with Drop Footing

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 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

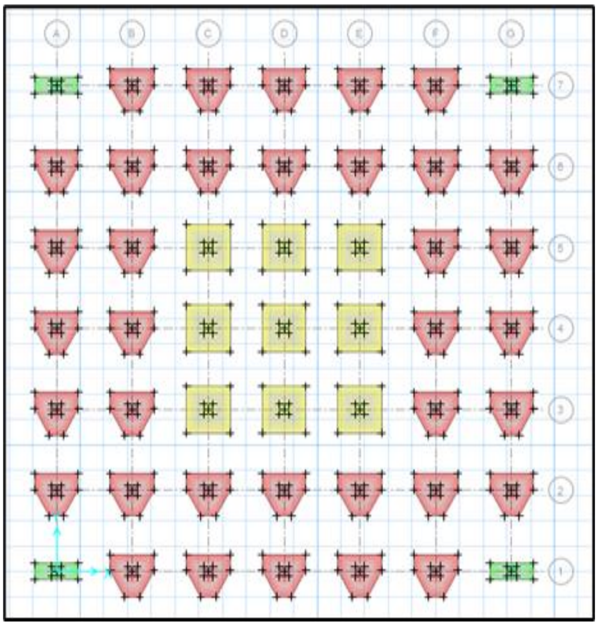

Fig.7. Optimized Pile Foundation

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.

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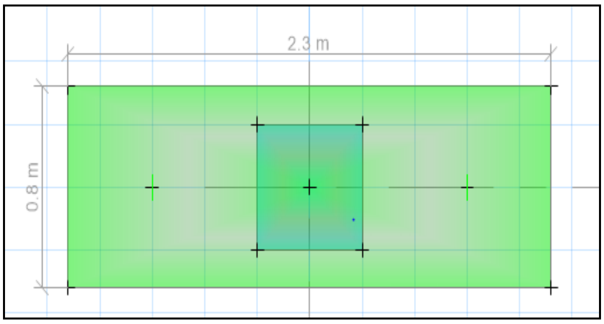

Fig.8. Two-Pile cap (depth = 800mm)

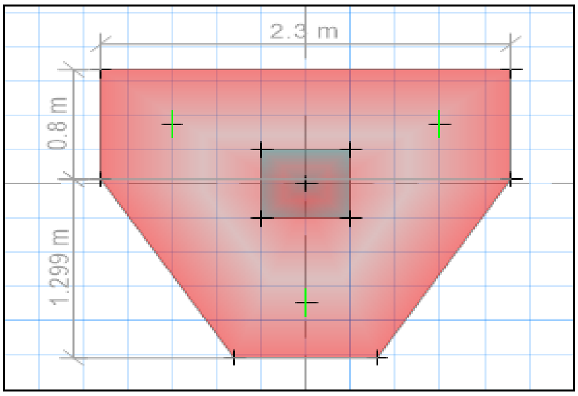

Fig.9. Three-Pile cap (depth = 1000mm)

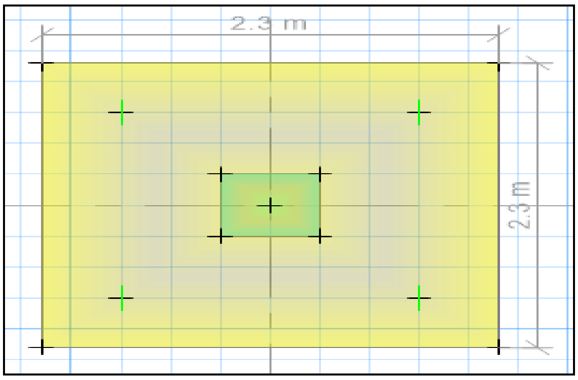

Fig.10. Four-Pile cap (depth = 800mm)

D. Eccentric Footing

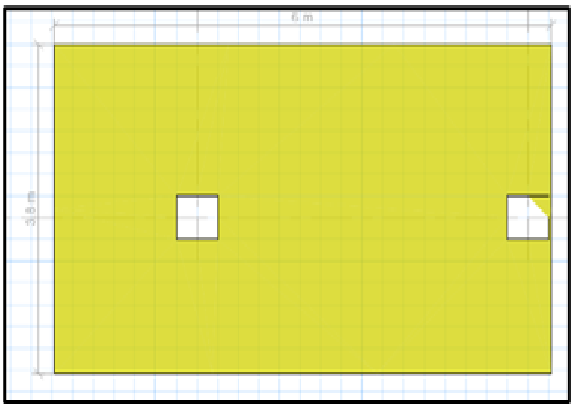

Fig.11. Optimized Combined Rectangular Footing

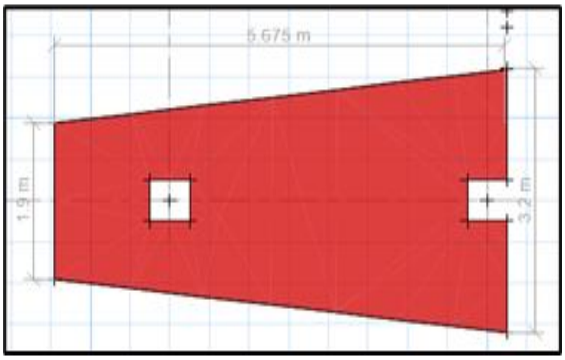

Fig.12. Optimized Combined Trapezoidal Footing

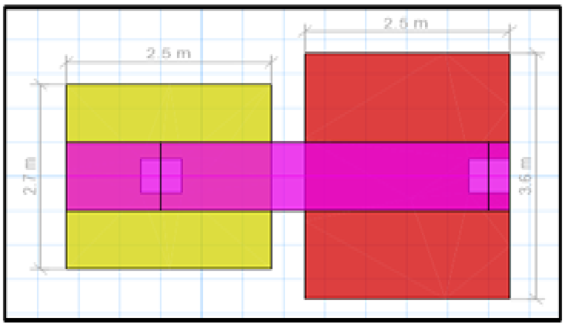

Fig.13. Optimized Strap Footing

VII. PUNCHING SHEAR ANALYSIS

Punching shear analysis of the different types of footings are done in SAFE software. The punching shear value between 0.9 to 1 gives the most economic and stable foundations. Analysis of punching shear is done in normal soil and in weak soil. The study then progresses by comparing the results and determining the foundations suitable for each type of conditions.

A. Punching Shear Analysis in Normal Soil

Fig.14. Punching Shear Ratio of Isolated Footing

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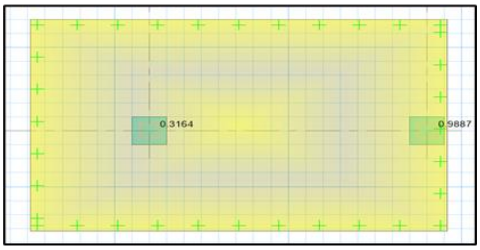

Fig.15. Punching Shear Ratio of Combined Rectangular Footing

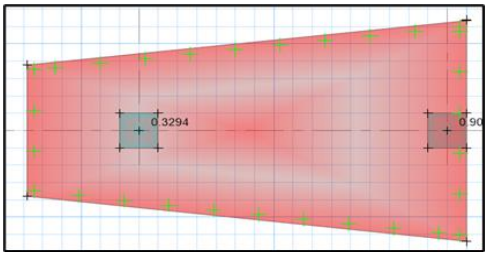

Fig.16. Punching Shear Ratio of Combined Trapezoidal Footing

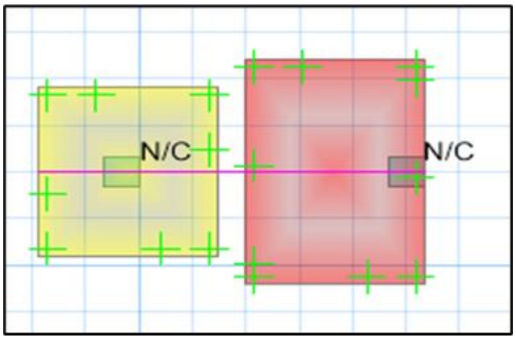

Fig.17. Punching Shear Ratio of Strap Footing

Punching shear greater than 1 lead to unsafe sections and is negligible in case of strap footing. It is because the strap footing has increased reinforcement and strap beam connection for preventing punching shear failure mechanism.

B. Punching Shear Analysis in Weak Soil

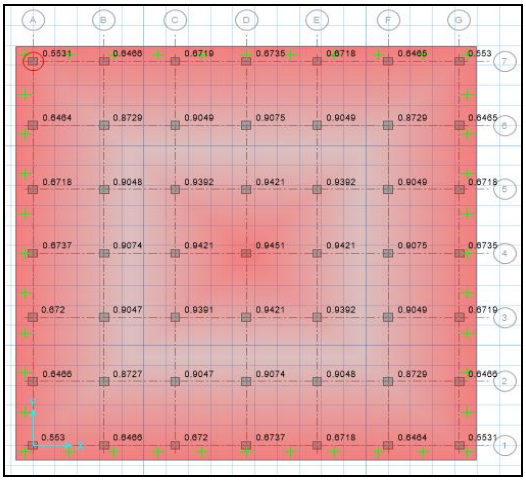

Fig.18. Punching Shear Ratio of Raft without Drop Footing

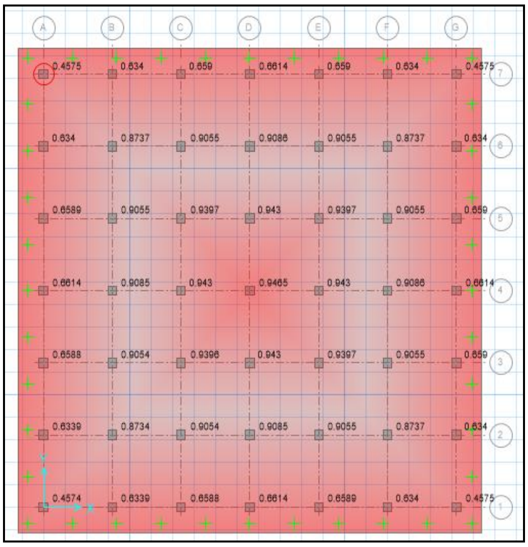

Fig.19. Punching Shear Ratio of Raft with Drop Footing

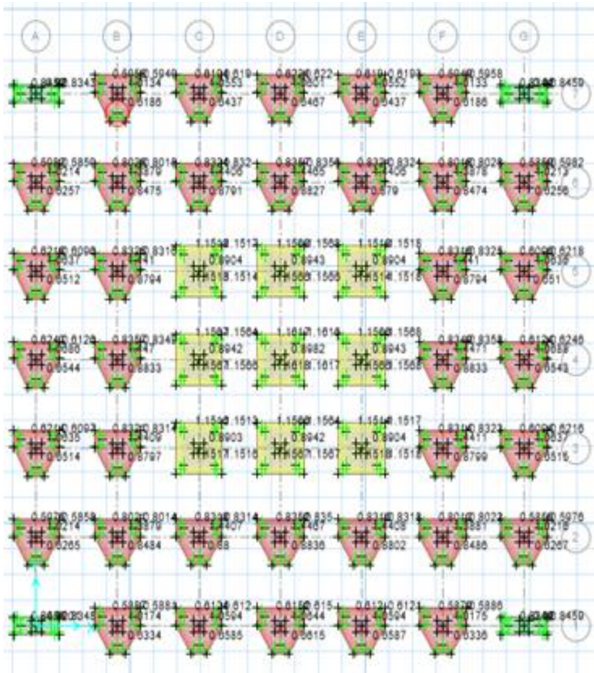

Fig.20. Punching Shear Ratio of Pile Foundation

Punching shear is limited to 0.9 to 1 to get optimum depth of raft and is not applicable in the case of pile foundation. In pile foundation, the column cannot punch through the slab as the foundation is supported by piles. Hence it is not applicable.

VIII. RESULTS

The building model is analyzed 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 analyzed. Punching shear analysis for different footings are done for parameters such as soil bearing capacity, bending moment, shear force and footing stress.

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A. Punching Shear Vs Soil Bearing Capacity

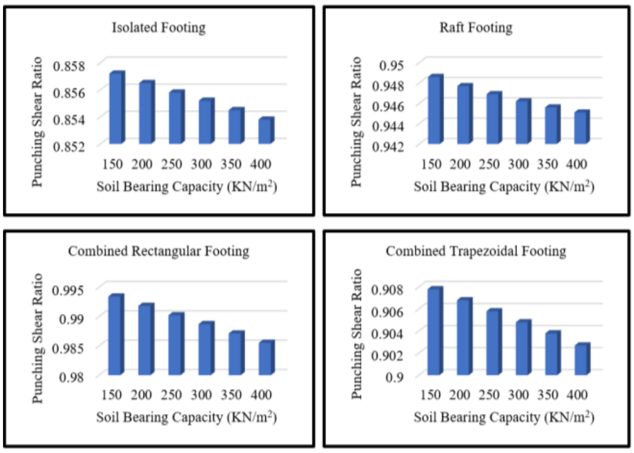

Fig.21. Punching Shear vs Soil Bearing Capacity

B. Punching Shear Vs Bending Moment

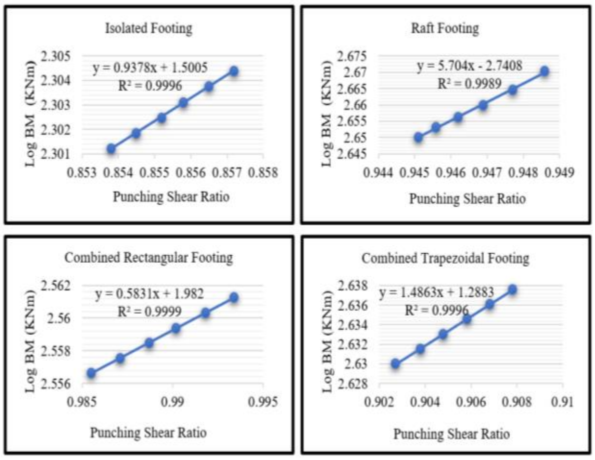

Fig.22. Punching Shear vs Bending Moment

C. Punching Shear Vs Shear Force

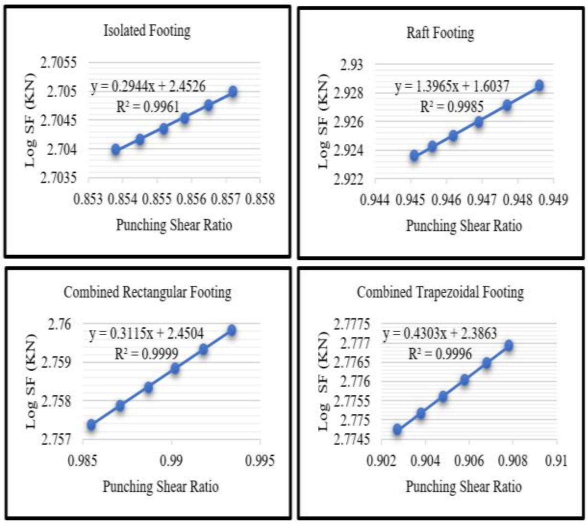

Fig.23. Punching Shear vs Shear Force

D. Punching Shear Vs Footing Stress

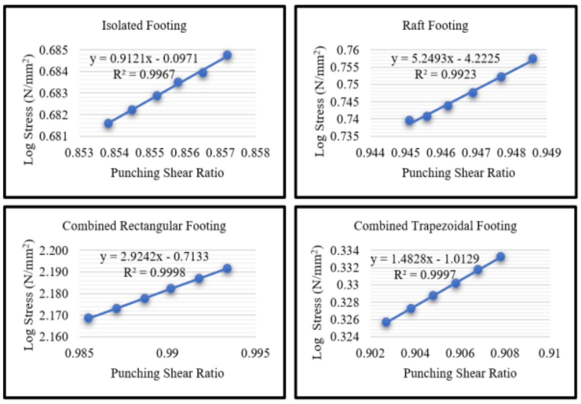

Fig.24. Punching Shear vs Footing Stress

IX. CONCLUSIONS

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. Punching shear value just below 1 gives the perfect optimization. Value greater than 1 or very much less than 1 will result in failure of structure. The effect of punching shear is negligible in case of strap footing and pile footing. The internal force of footing is irrespective of punching shear ratio. Punching shear mainly depends on the depth of the footings.

- **Soil bearing capacity:** With increase in soil bearing capacity, the punching shear ratio decreases 0.081% for isolated footing, 0.01% for raft footing, 0.16% for combined rectangular footing and 0.11% for combined trapezoidal footing.

- **Bending moment:** With increase in punching shear ratio, the bending moment increases 0.94% for isolated footing, 5.74% for raft footing, 0.5831% for combined rectangular footing and 1.48% for combined trapezoidal footing.

- **Shear force:** With increase in punching shear ratio, the shear force increases 0.29% for isolated footing, 1.39% for raft footing, 0.31% for combined rectangular footing and 0.43% for combined trapezoidal footing.

- **Footing stress:** With increase in punching shear ratio, the footing stress increases 0.91% for isolated footing, 5.25% for raft footing, 2.92% for combined rectangular footing and 1.48% for combined trapezoidal footing.

For every increase in punching shear ratio, combined rectangular footing has the lowest increase in bending moment (0.5831%). For every increase in punching shear ratio, isolated footing has the lowest shear force increase (0.29%). For every increase in punching shear ratio, raft footing has the highest stress increase (5.25%).

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