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Comparative Analysis of Steel Bamboo and Strands Used as Reinforcement in Pile Foundation

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ABSTRACT: Pile foundation is a type of deep foundation which is used to transfer heavy loads from the structure to a hard rock strata much deep below the ground level. Pile foundations are used to transfer heavy loads of structures through columns to hard soil strata which is much below ground level where shallow foundations such as spread footings and mat footings cannot be used. This is also used to prevent uplift of the structure due to lateral loads such as earthquake and wind forces. Pile foundations are generally used for soils where soil conditions near the ground surface is not suitable for heavy loads. The depth of hard rock strata may be 5 m to 50 m (15 feet to 150 feet) deep from the ground surface. Pile foundation resists the loads from the structure by skin friction and by end bearing. The use of pile foundations also prevents differential settlement of foundations. The selection of pile foundation depends on the soil investigation data received from soil exploration bore holes at different depths. Selection of appropriate pile for the desired strength and requirement plays an important role in cost reduction and efficiency. This paper discusses about the selection of type of piles based on reinforcement. The load is applied on the basis of structure load. Reinforcement area and quantity has been calculated as per the design of pile foundation with steel rebar, bamboo, and strand tendons. Since all the building loads have to transfer by the soil beneath the building. Detailed pile foundation has been modelled in ETABS software. All the loadings for the foundation design are taken from the building analysis done using Response spectrum analysis in ETABS on case study taken of a G+24 building situated in Gujrat.

KEYWORDS: Foundation, Pile Foundation, Bamboo, Strands, ETABS, Equivalent Static method, Response Spectrum Method.

I. INTRODUCTION

Foundation is the lowest part of the building or the civil structure that is in direct contact with the soil which transfers loads from the structure to the soil safely. Generally, the foundation can be classified into two, namely shallow foundation and deep foundation. A shallow foundation transfers the load to a stratum present at a shallow depth. The deep foundation transfers the load to a deeper depth below the ground surface. A tall building like a skyscraper or a building constructed on very weak soil requires deep foundation. If the constructed building has the plan to extend vertically in future, then a deep foundation must be suggested.

The foundation for each structure is designed such that:

1. The underlying soil below the foundation structure does not undergo shear failure
2. The settlement caused during the first service load or have to be within the limit
3. Allowable bearing pressure can be defined as the pressure the soil can withstand without failure.

1.1 Pile Foundation

Pile foundation is a type of deep foundation which is used to transfer heavy loads from the structure to a hard rock strata much deep below the ground level. Pile foundations are used to transfer heavy loads of structures through columns to hard soil strata which is much below ground level where shallow foundations such as spread footings and mat footings cannot be used. This is also used to prevent uplift of the structure due to lateral loads such as earthquake and wind forces. Pile foundations are generally used for soils where soil conditions near the ground surface is not suitable for heavy loads. The depth of hard rock strata may be 5m to 50m (15 feet to 150 feet) deep from the ground surface.

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received from soil exploration bore holes at different depths. Selection of appropriate pile for the desired strength and requirement plays an important role in cost reduction and efficiency. In this article we discuss about the selection of type of piles based on soil conditions.

1.2 Functions of Pile Foundation

The main functions of the pile foundation in the construction of structures are enlisted below.

1. The principal function of the pile foundation is to transmit the loads coming over it safely to the ground. The transmission is performed whether it is vertical or horizontal or inclined loads.
2. The pile foundation can be constructed in cohesion less soil by undergoing techniques of displacement and vibration methods.
3. Pile foundation helps in reducing the settlement.
4. The pile foundation helps to increase the factor of safety of heavy load structures or buildings.
5. The pile foundation guarantees the vertical structures above with safety, security, and reliability.
6. The pile and pile cap arrangement in pile foundation help the load distribution to be performed in a uniform manner.

II. RELATED WORK

Satarupa Sengupta (2012) they studied three different types of materials viz. concrete, wood and bamboo are used to construct pile foundation. Specimens of clean sand and clay soil were used to prepare the soil for test and the physical properties of that soil were evaluated. Next, earthquake response analyses were conducted to clarify the effect of the nonlinear soil pile foundation system on the performance of pile foundation. The input shaking included sinusoidal earthquake accelerations. Pile displacement, acceleration, strain and earth pressure were found out using PULSE and MICRON software. Performance evaluation of the pile foundation was discussed on the basis of pile curvature. Based on the observed data during the tests on a single pile, and the results of analysis, the following conclusions were made. The displacement at the top of different piles was the highest and it gradually decreases towards their bottom. The values of displacement increases with the increase in the frequency of shaking. For a constant value of frequency the displacement was the lowest for concrete pile and then it acquires higher value for wooden pile and lastly the bamboo pile. [1]

Munawir A. et. al. (2013) studied Bearing Capacity on Slope Modeling with Composite Bamboo Pile Reinforcement. The footing that placed on slope surface will decrease bearing capacity of soil. The function of using composite bamboo pile is to increase bearing capacity of footing on slope and that is one of the innovative slope reinforcement methods which necessary for last few years. Slope modeling with composite bamboo reinforcement was using an experiment box with 1.50 m as length; 1.0 m as width and 1.0 m as height. It used sand soil with fine gradation and composite bamboo pile with various pile length and pile location. The load was modeled as a strip footing with continuous increasing load by load cell until the limit load has been reach. The problem occurred in laboratory has been analyzed with Finite Element Method. It changed 3D slope modeling to be 2D modeling. Composite bamboo pile has been chosen as a new utilization innovation of bamboo as reinforced pile and that's a positive value to optimize bamboo local material as steel reinforced replacement material. The result of experiment using composite bamboo as pile reinforcement on slope has increased slope bearing capacity. It shown with significant increasing of bearing capacity and maximum limit load can be reached on slope. [2]

Yadav B. D. et. al. (2017) investigated modeling and analysis of pile foundation. Multi storied buildings are common in urban society therefore its design is also important. The structures which are located in the seismic prone regions where neglecting earthquake loads in the design procedure will lead to uncertainty and will cause disaster. Therefore, IS Code recommending several seismic zones according to their occurrence and types of soils and nature of the tectonic plates. To understand the importance of seismic load on overall performance of RC structural system, a 3D mathematical model of RC structural frames which is of G+10 in height, the plan of the mathematical model is symmetrical about both axes i.e., longitudinal and transverse. The seismic analysis such as Equivalent static and Linear Dynamic (Response Spectrum) analysis as per IS 1893:2002 have been performed. The load is applied on two mutual orthogonal directions. The parameters such as fundamental natural time period, mode shapes, storey displacements, storey drifts and bases have been studied in detail. Since all the building loads have to transfer by the soil beneath the building. The soil characteristics presumes to be weak enough (may be black cotton soil), the depth of hard strata presumes to be at 6 meters from the Ground level, therefore providing foundations like Isolated or Combined or Raft will be more costlier, Therefore the optimum foundation will be Pile foundation suitable for this condition. Detailed



pile foundation has been modeled in SAFE v12. All the loadings for the foundation design are taken from the above building design. All the piles and pile caps have been designed and detailed for practical feasibility according to IS 456:2000. [3]

Mohammad F. M. (2017) reviewed on the use of bamboo for earthwork construction. Bamboo becomes a promising engineering material widely utilized for constructions. It is likely a composite material with fibred reinforcement in one direction to make its good flexural strength. Bamboo has been traditionally made use for structural components. Recently, the applications of bamboo for earthwork constructions are reported both experimental and real project. Pile foundations for houses, bamboo pile and nail for slope stability, foundation grid for embankment, and bamboo pile-mattress for railway and reclamation project are among others of the application. This paper discusses the use of bamboo for earthwork construction. Particular discussion is addressed to bamboo pile-mattress that successfully installed for various project in Indonesia. The appropriate field characteristic for bamboo application is specified. The design step and theoretical based are discussed as well. [4]

Thadapaneni K. et. al. (2017) studied analysis of pile foundation subjected to lateral and vertical loads. Pile foundations are common foundations for bridge abutment, piers and buildings resting on soft soil strata. The pile is subjected to both vertical and horizontal forces. The objective of the current study is Lateral & Vertical loaded analysis of pile by using various methods. Vertical load analysis of pile is done by P-Y curves and Vesic's methods in cohesive & cohesion less soils with different soil parameters. The piles are modelled as linear elements. The effect of soil structure interaction is taken into account by assuming it as vertical and horizontal soil spring (winkler soil spring). Lateral subgrade modulus and vertical subgrade modulus of soil (K_H and K_v) is calculated as per IS code 2911. The lateral load analysis is carried out in FEM (Finite Element Method) Staad.Pro software, L Pile software & by empirical equations (Brom's method and Vesic's method). The above problem solved as per the Brom's method mentioned in IS 2911 and comparative results are also presented. [5]

Parth Akbari et. al. (2017) reviewed the different types of soils such as clays with different consistency, sand with different density having different angle of internal friction with layers of sand and clay. They also included different pile cap parameters such as shape (Triangular, square & rectangular), length, and spacing of piles in groups and pattern of the pile group. The analysis and design of single pile & group of pile considering the variation in parameters of single pile, pile group, pile cap analysis and design was also been included in their study With the various combinations of soil parameters and loads. The ultimate bearing capacity of the pile and pile group for the given soil condition with the analysis & design gives the number of piles, dimension of the pile, and spacing of piles in the pile group for various soil conditions. From their study of many literatures referred they concluded that the deflection of a laterally loaded pile was found to increase when stress-displacement response of soil strata was higher. The amount of deflection of piles depends on the stiffness of the piles as well as of the soil deposit. [6]

Kazi, M. (2019) studied the G+20 residential building at Kharghar, Navi Mumbai, India for which a foundation was suggested and design foundation for the building, and land was found in Sandy soil as per soil investigation report SBC for site is 200 kN/m² and recommendation of Deep foundation i.e. Pile Foundation. The conclusions drawn from this study was that pile were provided in two different group, group one carries total 20 column carries loads 3000 to 6000kN therefore group pile design for maximum loads that was 6000kN with one meter diameter & 13m in length and group two carries total 09 columns carries load in between 6000 to 7000 kN therefore design the pile for maximum loads that was 7000kN with 800mm in diameter and 10m in length and water table situated at 3.5m from ground level. [7]

Seungho Kim et. al. (2017) The EXT pile method was applied to a construction site to determine its various effects. First, a pile load test was conducted at a selected construction site in order to determine the bearing capacity of the EXT pile. Then, they confirmed that the bearing capacity of the EXT pile was better than that of the PHC pile by around 24%. Based on these test results, the pile foundation design carried out the verification of saving piles numbers between the PHC pile and EXT pile. Finally, they confirmed that the EXT pile was efficient in terms of time and cost. On the basis of these findings, conclusions were, the EXT pile shows that an effective arrangement of piles was possible rather than a PHC pile of the same specification because it can increase the bearing capacity per unit area by using an extended steel plate on the bottom. Therefore, the EXT pile system can provide effective delivery of the weight of the structure to the ground in pile design work. [8]



Marto, A. et. al. (2018) presented the results obtained from the monitoring of trial embankments on soft clay using Hydrostatic Profiler (settlement) and Inclinator (lateral movement). Three embankments had been constructed and monitored; (i) Embankment on Bamboo- Geotextile Composite (BGC) reinforced, (ii) Embankment on High Strength Geotextile (HSG) reinforced and (iii) control or unreinforced (UR) embankment, constructed without any reinforcement to the soft clay. These three embankments were each 10m long, 16m wide and about 3m in height. 5m long of buffer zones separated each embankment. The completed height of BGC reinforced embankment was 2.97m, 2.968m for HSG reinforced embankment and 3.071m for UR embankment. All three embankments had been monitored from the start of the construction day until about 419 days. Results show that UR embankment settled about 744mm while for BGC reinforced embankment, the settlement was about 588mm only. The maximum lateral movement occurred at 4.5m depth. At 4.5m depth, BGC reinforced embankment experienced 9.4mm movement while for UR embankment, the movement was 13.6mm. The results shows that the performance of the BGC was better compared with HSG embankment and also UR embankment at the end of monitoring works. The results show a significant improved in the deformation of foundation soil reinforced with BGC system compared to UR embankment and also the HSG embankment. Hence, the use of bamboo as green material for soil reinforcement purposes installed at the interface between the embankment and the soft clay could increase the stability and reduced the deformation of the embankment. [9]

Maulana et. al. (2018) suggested potential of bamboo pile as reinforcement of peat soil under embankment. Implementation of preloading and reinforcing of bamboo grids on peat is expected to reduce compression and increase and bearing capacity of peat soils. Preloading can be applied by using an embankment material that can speed up compression, while to increase the bearing capacity due to embankment load can use a combination of reinforcement of bamboo grids and piles. Modeling was conducted in the laboratory by using peat soil media. The preloading model was conducted with embankment model using iron scrap on peat soil, which was supported by bamboo grid and pile with diameter of 2 cm with length of 20 cm, and spacing of 20 cm and 10 cm. The increase of bearing capacity due to reinforcement can be seen from the settlement and deflection behavior of both peat with bamboo piles and without piles will be discussed in this paper. [10]

Osamu Kaneko et. al. (2018) performed static analyses using a foundation structure model to simulate the process leading to distinctive damage to pile foundations during the 2011 off the Pacific coast of Tohoku earthquake. Notable aspects of the analytical method used for this simulation include consideration of the nonlinear load deformation characteristics of pile elements, the dependence of the rotational stiffness at the pile head on the axial load, and the nonlinear behavior of soil spring including the pile group effect. The results of the simulations of pile failure for each loading direction provide a useful explanation of the observed damage to pile foundations. The proposed analysis method can be considered a practical approach to the seismic design of foundations subject to severe earthquakes. They conducted seismic analyses to simulate the distinctive damage process of pile foundations where the characteristics of pile damage were observed to vary depending on pile position even in the same building and the same building frame, during the 2011 off the Pacific coast of Tohoku earthquake. The analysis results provide a reasonable explanation of the observed damage. The analysis model considered for the foundation structure provides a reliable evaluation of nonlinear behavior of the pile-soil system. The pile group effect was also taken into account depending on the pile position in relation to the loading direction. [11]

Saurabh M. Chaturvedia (2018) reviewed the current understanding of pile failure mechanism, its causes explained by many investigators. A hypothetical model of six floor building is analyzed using STAAD-PRO Software twice. Firstly building was analyzed considering no earthquake, & then it was analyzed considering earthquake effects for various earthquake parameters. From both cases reactions at column bases was obtained from STAAD result. Then two hypothetical cases of foundation soil condition were taken. First soil condition was that soil is Clayey soil (Black Cotton soil) up to greater depth, second soil condition was that soil strata comprises of 6m thick clay layer over a deep liquefiable sandy soil layer. For each soil condition & loading coming on column bases RCC design of bored cast in situ pile has been done as per IS 456 : 2000, IS 2911 (Part 1/ Sec 2) : 2010, IS 13920 : 1993 & IS 1893 (Part 1) : 2002. Ultimate vertical load bearing capacity of pile analysis was done by static analysis based on $c-\phi$ values in which bearing capacity factors suggested by IS 2911, Hansen & Terzaghi has been used. Conventional analysis of a single pile or pile group without considering the mat foundation along with piles result in severe tilting or settlement of the structure eventually leading to complete collapse of structure. It has been concluded that the foundation mat over the non- liquefied crust shares a considerable amount of load of the super structure & hence resist the complete collapse of structure. [12]



Objectives of investigation:

1. To analyse pile foundation with use of steel as reinforcement, bamboo and strand cable as reinforcement by using ETABS software.
2. Comparative study between steel, bamboo and strands used as reinforcement in pile foundation.
3. To compare steel quantity and cost of material between steel, bamboo and steel strand as reinforcement in pile foundation.

III. METHODOLOGY

In the current study, buildings are modelled using ETABS software. The analytical models of the building include all components that influence the mass, strength, stiffness and deformability of structure. The building structural system consists of beams, columns, and slab. The non-structural elements that do not significantly influence the building behaviour are not modelled. Modal analysis and Response spectrum analysis are performed on models. It is proposed to study the effectiveness of base isolation technique considering different sloping angles. The beam and column are modelled as two noded line element with 6 DOF at each node. The slab is modelled using 4 noded area elements. Case study of G+25 RCC building constructed in Gujrat with pile foundation has been considered in this study. We have used ETABS and RCDC software for analysis and design purpose. Pile foundation has been designed by using reinforcement as steel, bamboo and strand cables.

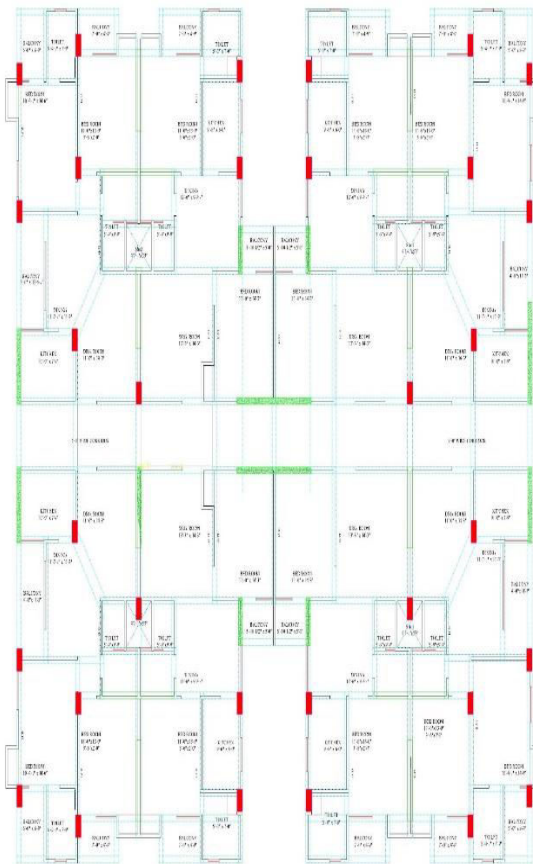


Fig.:-3.1 Plan of the Building in AutoCAD

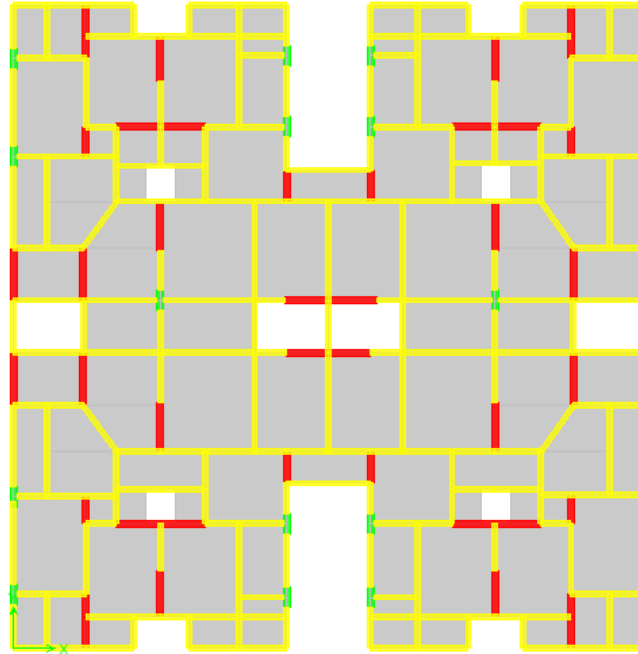


Figure 3.2 Plan of the Building in ETABS

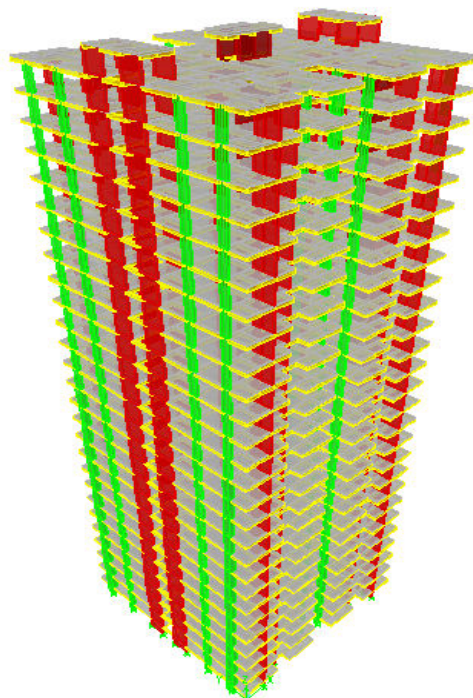


Figure 3.2 3D view of Building in ETABS



IV. RESULTS

The response spectrum analysis is carried out as mentioned in the previous chapter and then RCDC software has been used to estimate the pile configuration of selected columns. Column number C7, C29, C40 has been considered for comparisons purpose.

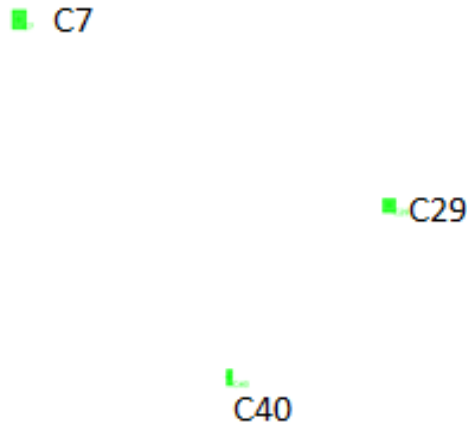


Fig: 4.1 Columns Considered in ETABS for comparison

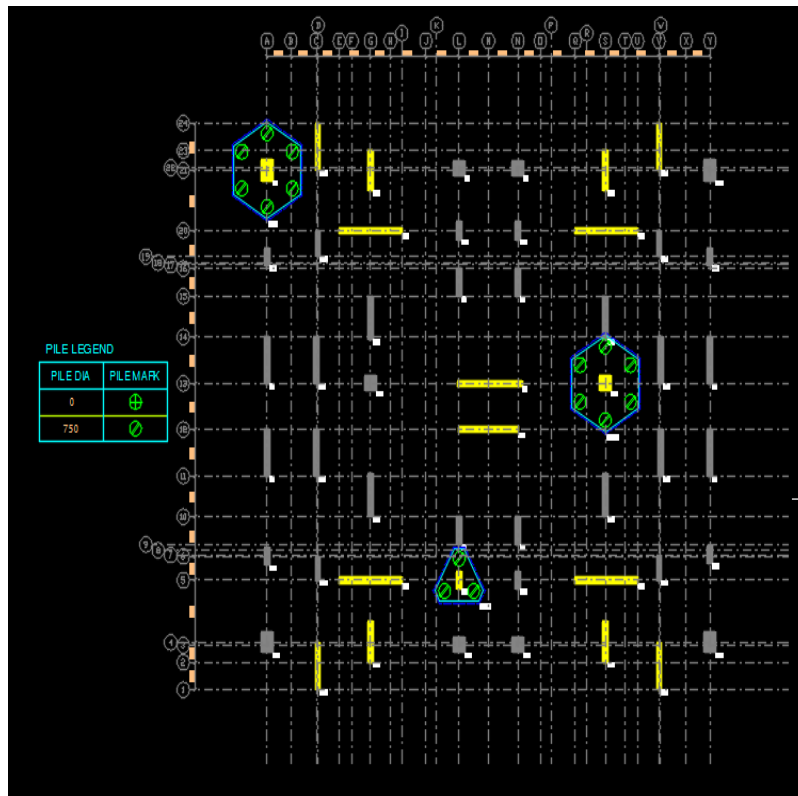


Figure 4.2 Pile Configuration in RCDC for selected columns

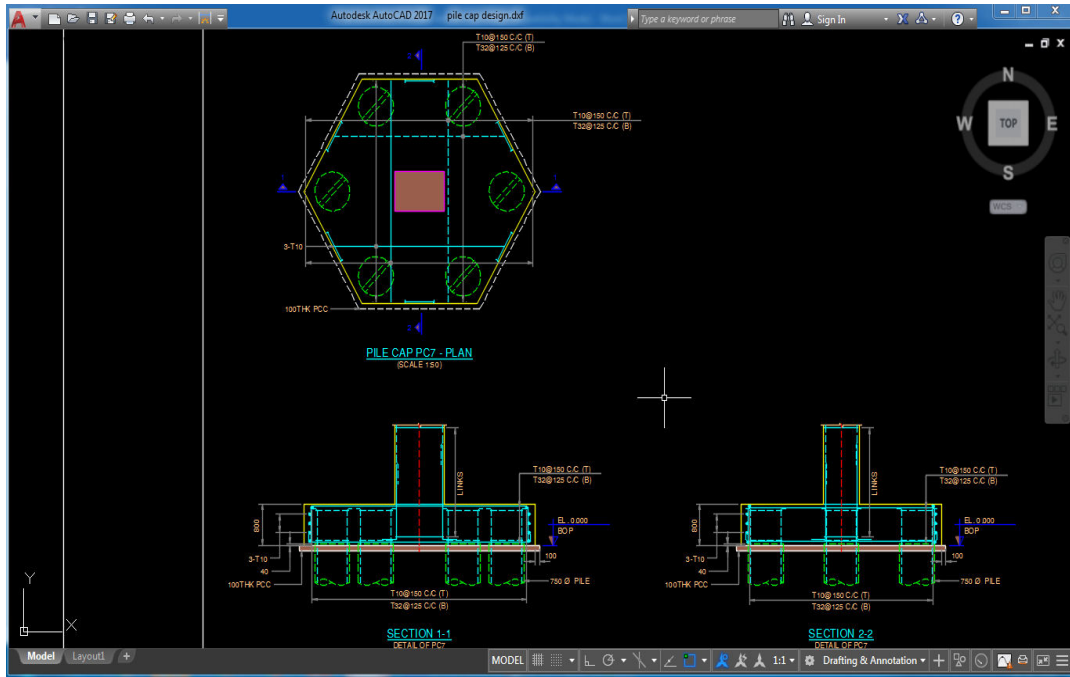


Figure 4.3 Design of pile cap for column C7

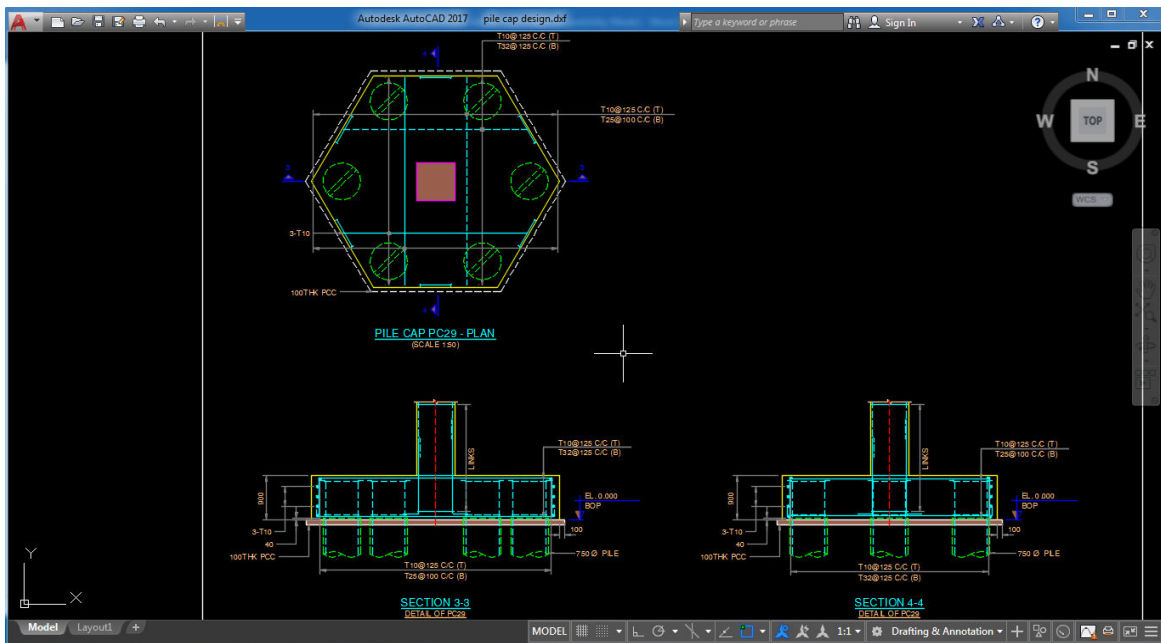


Fig: 4.4 Design of pile cap for column C29

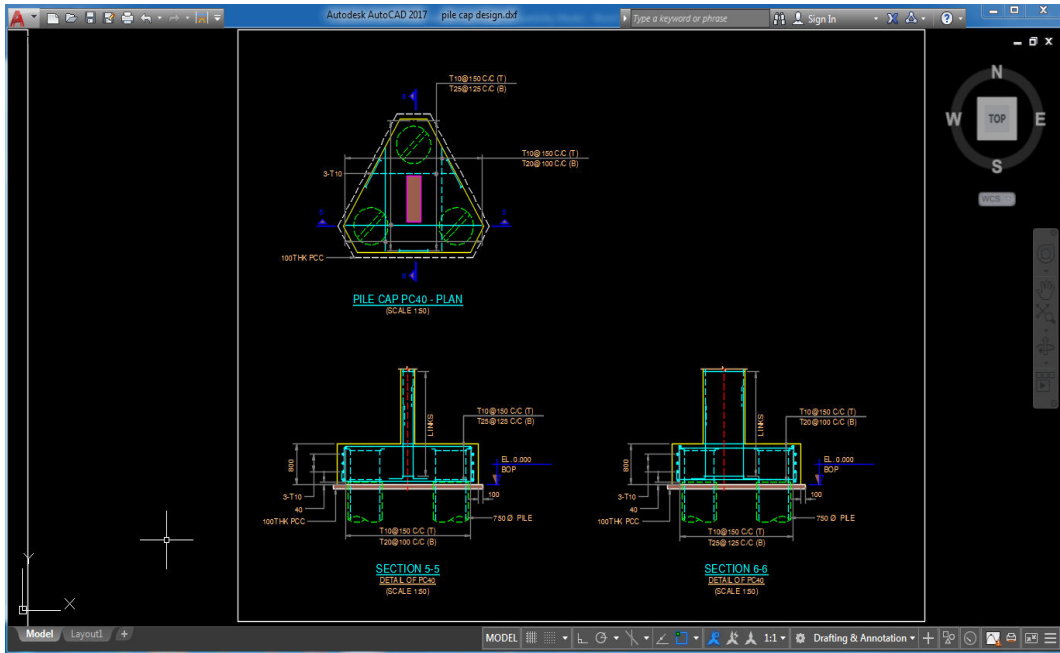


Fig: 4.5 Design of pile cap for column C40

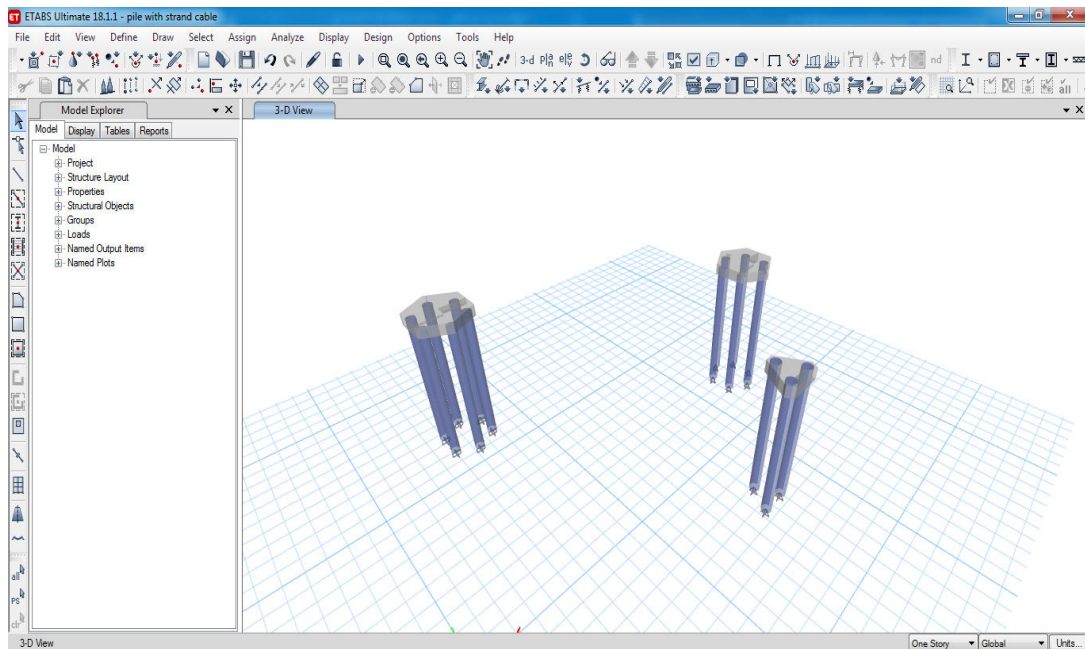


Fig: 4.6 Modelling of pile cap and piles for selected columns in ETABS

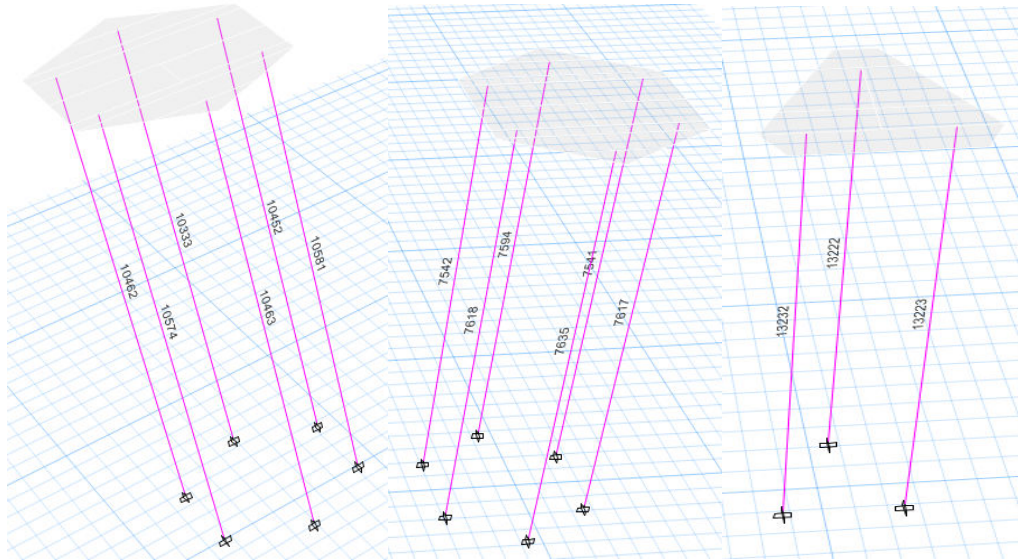


Fig: 4.7 Area of Reinforcement for reinforcement as steel rebar for C7 Pile cap, C29 Pile cap and C40 Pile cap in ETABS

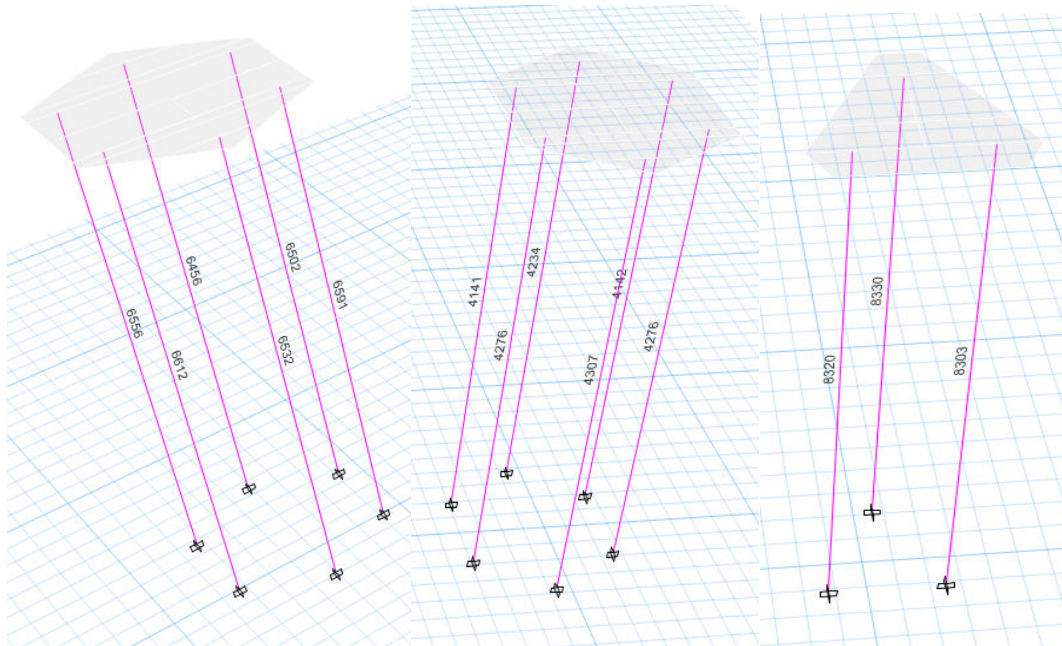


Fig: 4.8 Area of Reinforcement for reinforcement as steel strand cable for C7 Pile cap, C29 Pile cap and C40 Pile cap in ETABS

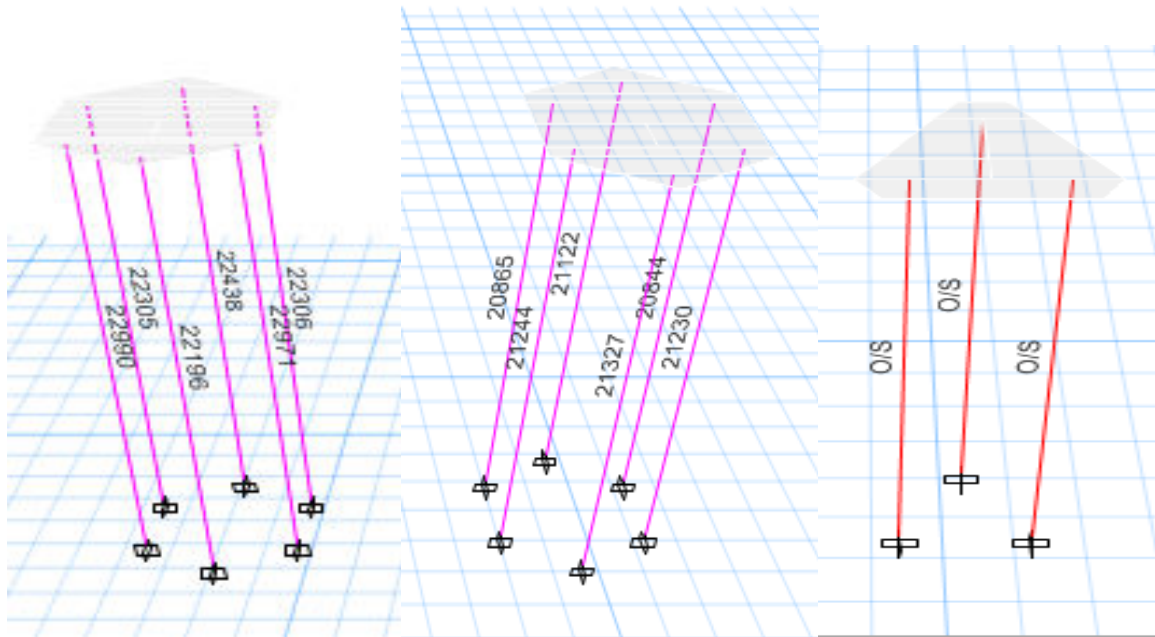


Fig: 4.9 Area of Reinforcement for reinforcement as Bamboo for C7 Pile cap, C29 Pile cap and C40 Pile cap in ETABS

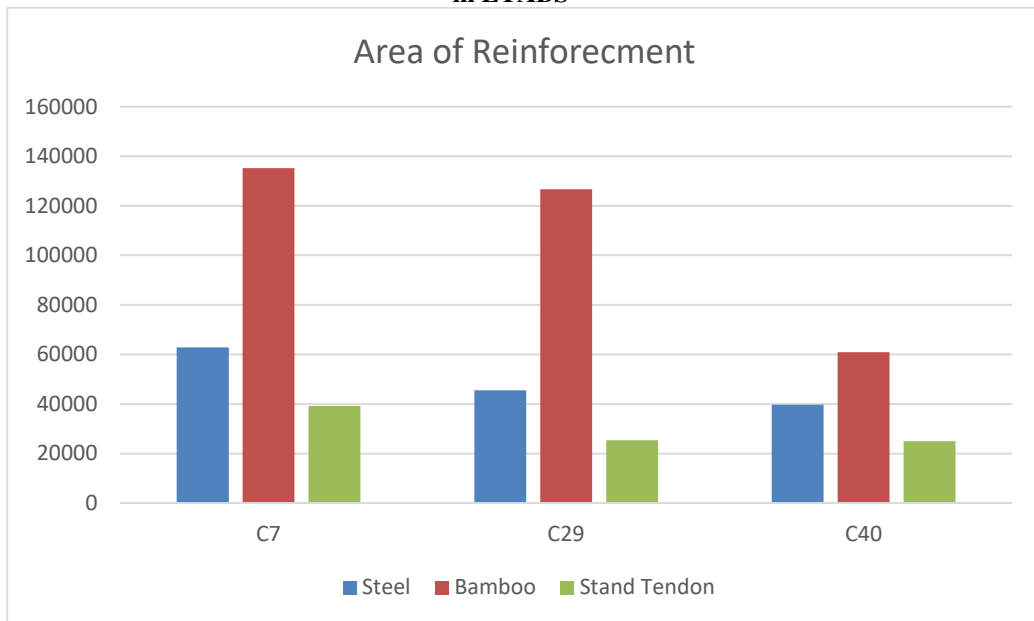


Figure 4.10: Comparison of area of reinforcement

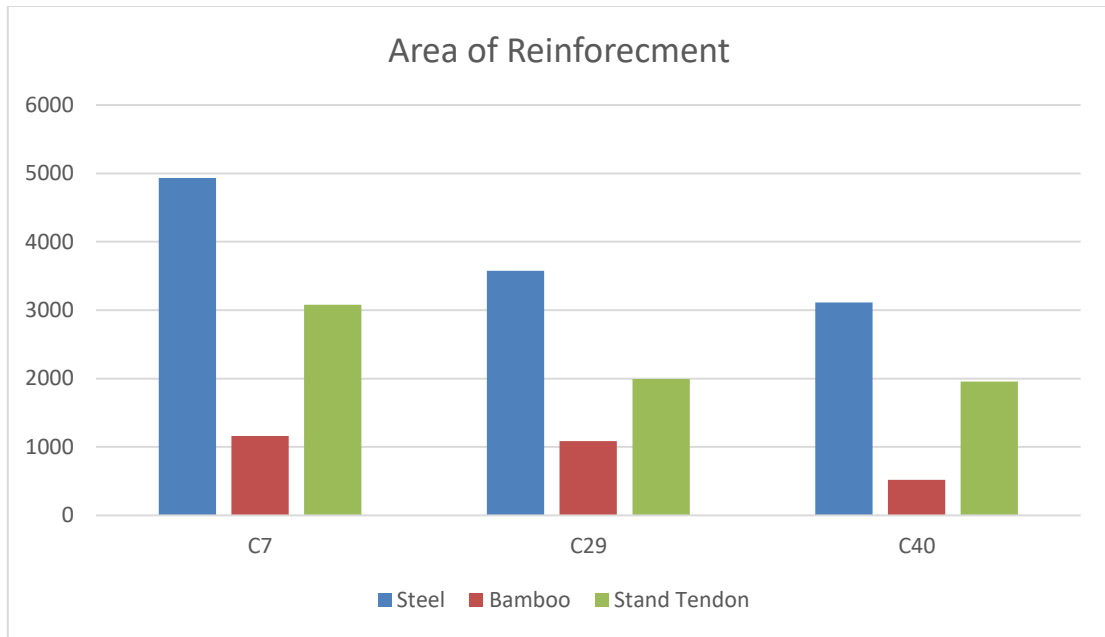


Figure 4.11: Comparison of Quantity of reinforcement

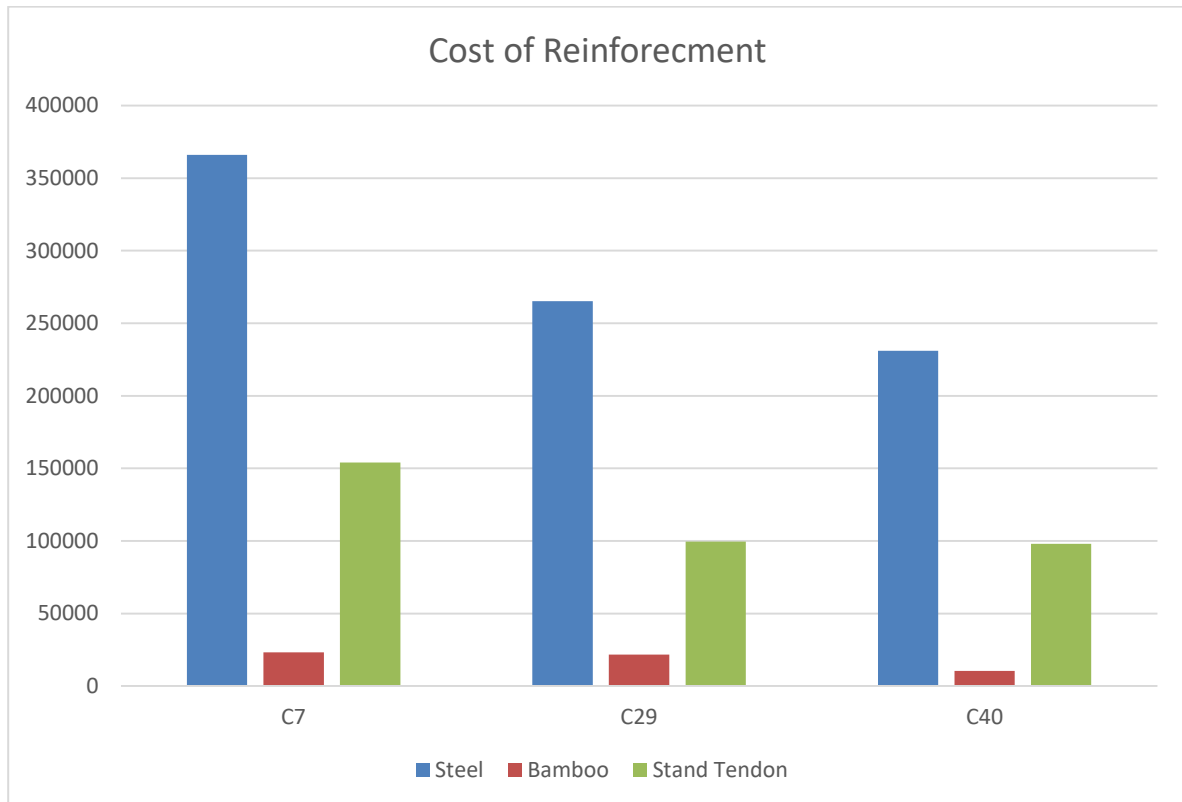


Figure 4.12: Comparison of Cost of reinforcement

V. CONCLUSIONS

After analyzing the building in ETABS and estimating the pile configuration and loads on pile in RCDC, design of pile has been done in ETABS with different types of reinforcement materials, the following conclusions have been drawn.



- Steel reinforcement may be the most general type of reinforcement in practice but for pile with greater depth it has certain limitations such as buckling failure, construction difficulties etc.
- • Strand cables are one of the substitute of steel rebar as they don't have any buckling problem for greater length piles. But it can increase the cost of the project significantly as manufacturing and installation cost is high as compared to steel reinforcement.
- • Bamboo reinforcement is an ideal solution for piles with greater length as it is cheaper and also easily available. Although area of reinforcement required is more but total quantity of reinforcement for bamboo is very less as compared to other reinforcement.
- • Bamboo reinforcement can withstand buckling as well as tensile forces similar to strand cables and very efficient in construction similar to steel reinforcement.
- • Bamboo reinforcement can be a useful substitute to steel rebar with cheap and ecofriendly option but use of bamboo is limited to structures with less heights upto G+2 structures resting on black cotton soil or filled up soil due to low tensile strength of bamboo, for higher loading it is difficult to accommodate bamboo reinforcement required in pile foundation.

VI. FUTURE SCOPE

Following are the some points for future scope of this study:

1. Depth of foundation can be increased for further analysis.
2. Ultra high rise building can be considered for analysis.
3. Bamboo reinforcement can be used in columns and walls for further studies.
4. Bamboo reinforcement can be used for raft foundation for further studies.

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