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RAFT FOUNDATION WITH GROUND IMPROVEMENT

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Abstract **–Raft foundations are popularly used on erratic marshy ground. This is a case study based on raft foundation for a multipurpose Cyclone Shed, situated in Siolim village, Goa. Ground improvement was done using wooden piles, with an objective to reduce the settlement. The superstructure is a two storeyed building supported on the concrete raft foundation. The top soil at the site was silty sand underlain by clayey soil. The soil model was analysed and designed by using PLAXIS 2D and SAFE 2012. The results showed the reduction in settlement and improvement in bearing capacity with the introduction of micropiles beneath the raft-foundation.**

***Keywords* - Bearing Capacity, Inclined-Micropiles, PLAXIS 2D, Raft-Foundation, SAFE 2012 and Settlement.**

I. INTRODUCTION

Geotechnical engineers often encounter problems in designing foundations of structures on soft clayey soil with water table within shallow depth below ground surface. The raft foundation is considered for soft ground containing erratic patches, and these erratic patches are bridged over by the raft, thereby reducing the settlements. When the soil on which raft to be rested is weak, ground improvement is considered. Ground improvement changes soil characteristics like; shear strength, swelling and shrinkage characteristics and bearing capacity.

When raft footing is utilized on soft soil, the soft soil sustains from excessive settlement and low shear strength. Thus excessive consolidation settlement causes partial or full damage in the raft footing or in the building. The alternative solution is to use deep foundation as reinforced concrete piles or raft footing with reinforced concrete piles. But both solutions are expensive. The other solution is to improve the soft soil effectively under raft footing.

In Kolkata, a common practice has been to provide closely spaced 150–200 mm diameter timber piles of 5–6 m length. These timber piles have helped the structures to stand on soft clayey soil with little or negligible distress over the years. (Ghosh et.al. 2018). There have been studies on improving ground using timber piles and analysing the effect of length, spacing of timber piles on the settlement of ground. Micro piles have been used effectively in many applications of ground improvement to increase the bearing capacity and reduce the settlements particularly in strengthening the existing foundations (Griffin, 2016). Many research studies have been done in recent times on the raft foundation resting on improved soil (Han and Ye, 1991; Lee and Pande, 1998; Elsawy, 2013). Logs of wood about 1.5 m length were placed in the weak ground with a view to stabilize the ground (Ghosh et al. 2016). This method involves driving closely-spaced sand columns into the soft seabed to form a grid of sand columns, which imparts higher strength and stiffness to the improved ground. Piles bring about significant changes in the strength and stiffness of the soft clay around piles. When used under water table, these materials are durable. Mini concrete pile raft has emerged to replace bamboo pile raft to carry bigger load and overcome the limitation of bamboo or timber piles (Rahardjo, 2005). If ground improvement is not done excessive consolidation settlement causes partial or full damage in the raft footing or in the building. The alternative solution is to use deep foundation as reinforced concrete piles or raft footing with reinforced concrete piles. But both solutions are expensive. The other solution is to improve the soft soil effectively under raft footing. Several researchers also studied the improvement efficiency of floating granular piles which depends on pile length, area replacement ratio and pile stiffness (Kirsch; 2006, 2009). As more and more land becomes subject to urban or industrial development, good construction sites and borrow areas are difficult to find and the soil improvement alternatives becomes the best option, technically and economically. Use of micro piles was carried out, to increase the bearing capacity and reduce the settlement of footing in the soil by Babu., et al. (2002), Dr. Pusadkar S. and Bhatkar T. (2013), PLAXIS 2D was used for the analysis of the mat foundation. Manjareakar, et al. (2018) have used SAFE-2014for static and dynamic The study presented here is a partial case study, wherein the soil properties and site investigation details were studied and a analysis of raft foundation was done using Plaxis 2D. The soil model and raft model were created. The soil investigation revealed presence of sand underlain by clay and also water table was encountered. Further the analysis of footing performance on improved ground under structural load is analysed using Plaxis 2D and SAFE-2014 software and the total settlement was determined. Ground improvement was considered using timber micro piles placed with an inclination into the clay soil layer and the foundation analysis as carried out. The results show improvement in the values of safe bearing capacity of soil and reduction in the total settlement of the soil due to the placement of piles.

II. SITE INVESTIGATION DATA

The site is based in the Siolim Village, North Goa. For site investigation soil samples were collected from two pits of size 2.0 x 2.5 x 1.7 m deep. Ground water was encountered at a average depth of 1.8 m.. Undisturbed soil sample were recovered using SPT tests. Top soil at the site was silty sand and as observed for the tests pits the sand was underlain by clayey soil. Figure 1 shows the location of borehole on the site.

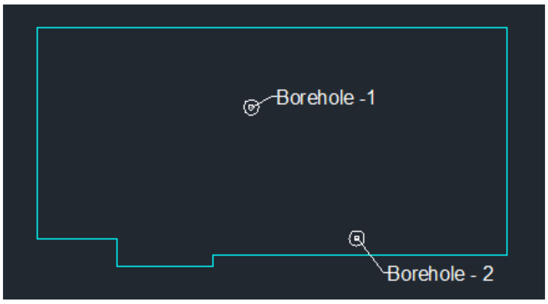

Figure 1. Location of boreholes on plot

The properties of soil samples as obtained after conducting relevant laboratory tests are given in Table

Table 1
GEOTECHNICAL PROPERTIES OF SOIL SAMPLE COLLECTED FROM SITE

Pit No.	Pit-1	Pit-2
Specific Gravity	2.68	2.65
Natural Moisture Content	37.81 %	38.01%
Bulk Density kN/m³	20.40	18.30
Dry Density kN/m³	14.81	13.26
Cohesion t/m²	1.09	1.12
Friction Angle ϕ	28°	31°
Average Safe Bearing Capacity kN/m²	110	110
Liquid Limit	11 % to 15 %	
Plasticity index	1 % to 5 %.	

The chemical tests shows that it is closer to neutral with pH = 7.21 to 7.22. The chlorides (0.0195 % to 0.0208 %) and sulphates (0.0321 % to 0.0456 %) are within the permissible limits as per I.S:456-2000.

Table 2
SAFE BEARING CAPACITY BY DIFFERENT METHODS

Sr. No.	Method	Safe Bearing Capacity t/m²
1	IS:6403-1981	6.85
2	Mayerhof's approach	6.00
3	Cole and Stroud's (1976)	6.17

To be on safer side assuming safe bearing capacity of 5.00 t/m² for footing design is proposed at 2 m depth.

Table 3
VALUES OF ENGINEERING PARAMETER AT VARIOUS DEPTHS FOR 15 MM SETTLEMENT.

Sr. No.	Depth Below G.L (m)	SBC (t/m²)	Settlement (mm)	Modulus of Sub-Grade Reaction (t/m²/m)
1	2.00	5.0	15	333
2	3.00	9.0	15	600
3	4.00	12	15	800

III. NUMERICAL MODELING

1) SOIL STRATUM

Analysis of structure, ground improvement, and design of raft are carried out by using STAAD PRO, PLAXIS 2D and SAFE 2012. The significant properties of structural materials are given in Table 4. Properties of foundation soil are presented in Table 1. and the material properties of Raft slab are provided in Table 6.

STAAD PRO ANALYSIS

Table 4
DESIGN PARAMETERS FOR STAAD PRO ANALYSIS

Design Parameter
$E = 2.17 \times 10^7$
Poison ratio = 0.17
Density of concrete = 24 kN/m³
Damping ratio = 0.05
Grade of concrete = M35
Steel = Fe500
Zone III = 0.16g
Beam size = 300 x 600 mm
Height of each storey is assumed as 3.5m
Total unfactored weight of super structure = 4163.84 kN

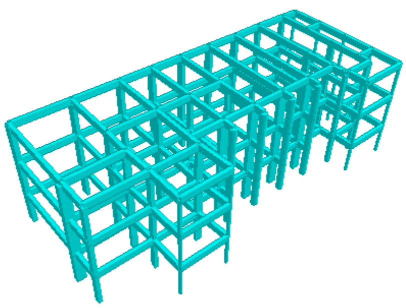

Figure 2: Analysed model in STAAD PRO

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PLAXIS 2D ANALYSIS

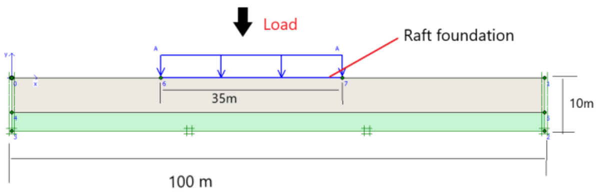

Figure 3: Geometry of the soil model under loading

Table 5
PROPERTIES OF SUBSOIL

Parameter	Value
Type of material	Fine clayey sandy silt
Material Model	Mohr-coulomb
Material type	Drained
E (kN/m^2)	1300
Dry density (kN/m^3)	13.260
Bulk density (kN/m^3)	18.300
Cohesion (kN/m^2)	10.900
Friction angle(ϕ)	31°
Interface reduction factor R_{inter}	1.0

SAFE 2012 ANALYSIS

Table 6
MATERIAL PROPERTIES OF RAFT SLAB

Parameter	Values
Mat Thickness	600 mm
Grade of Concrete	M35
Grade of Steel	Fe500
Bearing Capacity of Soil	50 kN/m^2

Based on the drawings and layout, raft is created using the SAFE-2014 software. Axial loads from each column were taken from STAAD PRO output and accordingly it has been designed. The analysed model of the superstructure which was done using STAD PRO is shown in Figure 2. The geometry of soil model created using Plaxis 2D is shown in Figure 3. The raft is divided into number of strips in both directions. The safe bearing capacity of soil was 110 kN/m^2 but the mat has been designed for 50 kN/m^2 considering factor of safety of 2.

IV. STATIC ANALYSIS OF FOUNDATION SOIL

Using finite element modelling and soil properties, static analysis was carried out in PLAXIS 2D for raft foundation considering Mohr-coulomb model. The dimension of the raft foundation was 35 m x 17 m and thickness was 0.6 m. The numerical model dimension was chosen as 100 m x 10 m to avoid the effect of boundary condition on the results. Soil layer was idealized as Mohr-Coulomb model. Drained behaviour was assumed for soil analysis. The soil model was subjected to uniformly distributed load of 500 kN/m^2 and boundary conditions were applied as shown in the Figure 4.

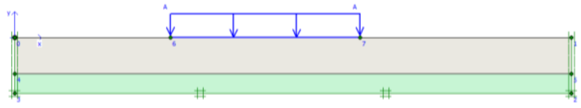

Figure 4: Normal loading on soil model

1) Soil and micro piles

The timber micro piles under the raft were placed inclined at 70° to the horizontal as shown in Figure 5. The micro piles 3 m long and 150 mm diameter were placed inclined at 70° to the horizontal. Twelve such micro piles were used, out of which, five piles were placed at the edges and two piles were placed at the mid span. The model was discretized using 15-nodded element considering accuracy.

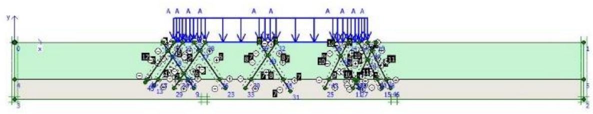

Figure 7: Loading with inclined piles

2) Raft foundation

The foundation is the most important element in the structure, which carries out any type of superstructure and transmits the loads including its self-weight to the underlying soil strata. Foundation does the work of spreading the load from the superstructure to the soil so that the load or pressure transmitted to the underlying soil without causing excessive shear in the ground to fail or settlement that leads to the distortion and failure of the structure. The mat foundation is analysis and designed for G+2 building resting on soil having bearing capacity of soil as 110 kN/m^2 using SAFE software. In this software, the soil is modelled as per IS: 456-2000.

V. RESULTS AND DISCUSSION

The numerical model of soil analysed without any ground condition reported a total settlement of ------ mm. To satisfy the initial conditions of water level, the phreatic level was considered at 1.1 m from the ground level. After analysis the displacement was observed to be 2.9 m under a loading of 500 kN/m^2. This settlement generated slight bulging of soil around the edges of raft, as shown in the deformed soil model, Figure 5.

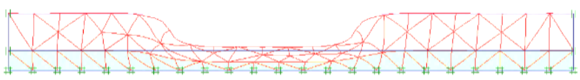

Figure 5: Deformed mesh

As per IS: 1904-1986, the permissible total settlement for raft foundation in sandy soil is 75 mm. As per the analysis of the soil model generated, the total settlement of the soil was found to be beyond the permissible limit of 75 mm; hence the need was felt for improving the ground. Micro piles of wooden

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material were considered as they were available in the vicinity at low rates and hence raft foundation would be the most effective and economical foundation for the given site conditions. Figure 6 shows the load-settlement curve for the plain soil model analysis

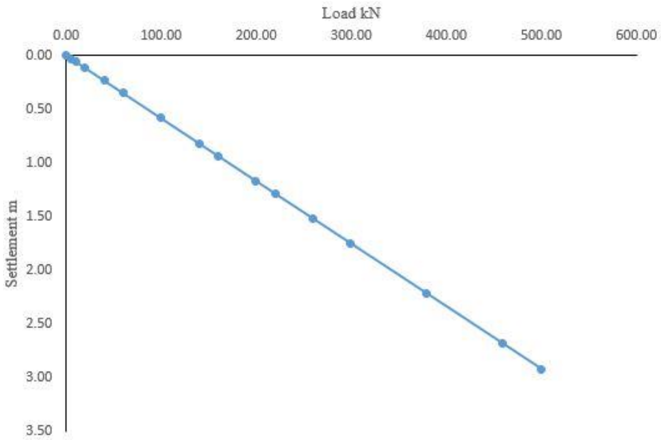

Figure 6: Load – Settlement Curve for 35 m Raft Foundation

Here the loading increases the settlement also increases excessively and raft sinks in the soil. For the next analysis case, inclined micro piles were modelled in the same soil and a load 500 kN/m^2 was applied. Analysis was carried out to check the improvement in results with respect to settlement values. The result of the soil model analysis with micro piles is shown in Figure 8.

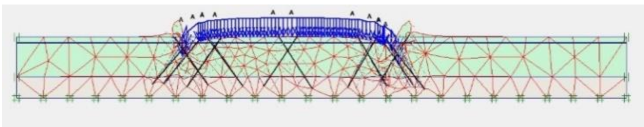

Figure 8: Deformed soil model with inclined piles

The Table 7 gives the details of arrangement and spacing of inclined piles.

Table 7
ARRANGEMENT AND SPACING OF PILES

Placement of piles	Inclined Piles		
	Nos.	Angle	Spacing
At the edges	5	70	2 m
At the mid span	2	70	3 m

The soil at the edges was observed to have undergone a settlement of 34 mm, which is less than permissible settlement as prescribed by IS. The central portion of the soil also experienced a settlement of 34 mm, which satisfies the permissible settlement criteria. Hence 12 timber micro piles inclined at 70° to the horizontal were considered for ground improvement. Figure 9 represents the relation between load and settlement for the soil model provided with inclined micro piles with maximum load corresponding to 34 mm settlement.

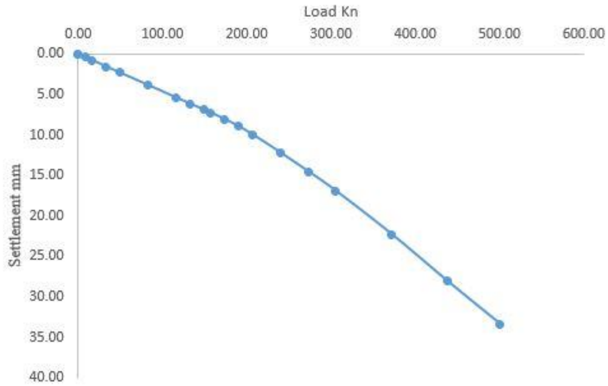

Figure 9: Load settlement curve for soil model provided with inclined piles

Figure 10 presents the effect of placing inclined micro piles on the safe bearing capacity of soil. The results indicate that bearing capacity has increased to 200 kN/m^2 corresponding to a settlement of 25 mm. This may be attributed to improved stiffness of the soil in the presence of inclined piles. It may be also be due to the pile soil interaction

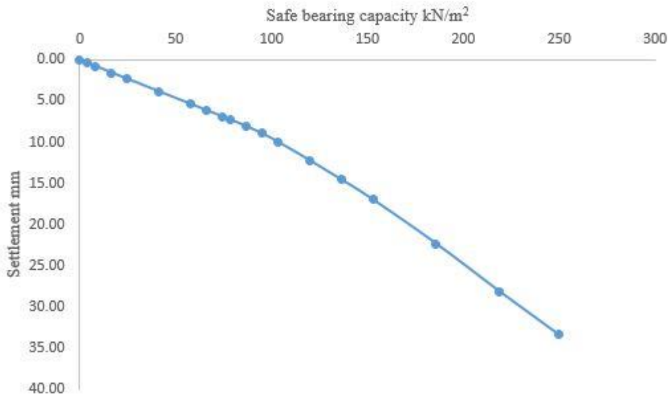

Figure 10: Effect of placing inclined micro piles on the safe bearing capacity of soil

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VI. RAFT FOUNDATION

When the mat foundation is subjected to axial loads, soil pressure is exerted on the mat at the interface of soil and mat in upward direction. The mat undergoes displacement. The pressure generated at the two extreme ends was 25 kN/m^2 minimum and soil pressure of 134.21 kN/m^2 maximum. Figure 11(a) shows the results of soil pressure generated at the extreme ends of the raft slab and Figure 11(b) shows the displacement values of the deformed raft.

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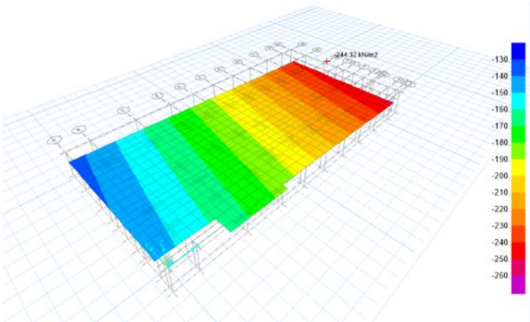
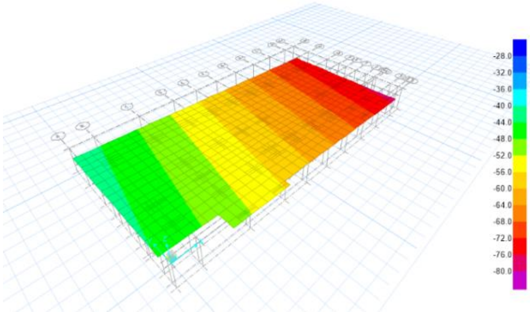


(a)



(b)

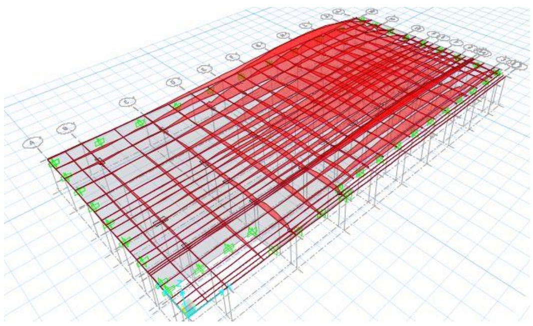
Figure 11: Results for (a) Soil pressure on raft slab, (b) Displacements of deformed raft

Table 8 presents the displacement values of the raft slab due to dead load and live load.

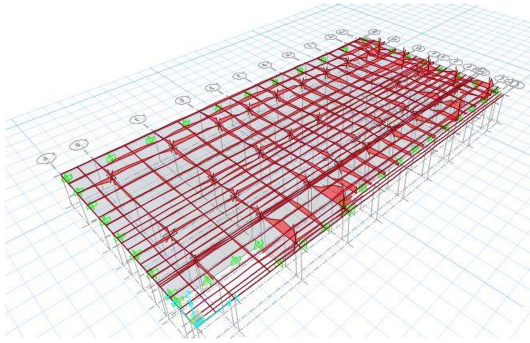
Table 8
DISPLACEMENTS DUE TO DEAD LOAD AND LIVE LOAD

Displacement (mm)	Due to	
	Dead Load	Live Load
Corner Panel	-40 mm	-68 mm
Edge Panel	-26 mm	-43 mm
Middle Panel	-22 mm	-32 mm

Figures 12(a) and (b) shows the results corresponding to bending moments and shear force respectively for the raft slab.



(a) Bending moments



(b) Shear force

Figure 12: Bending moments and Shear force due to Live loads in both layers

Table 9 gives the detail of bending moments and shear forces in the strips of the raft slab.

Table 9
STRIP FORCES

	Dead Load		Live Loads	
	Max. Bending Moments kN-m	Max. Shear Force kN/m²	Max. Bending Moments kN-m	Max. Shear Force kN/m²
Layer A	2064.0	716.12	-3039.45	386.09
Layer B	934.15	680.91	-1090.52	522.07

The mat has been designed as per IS 456-2000 using SAFE software and the ductile detailing along section-A and B as shown in figure 13.

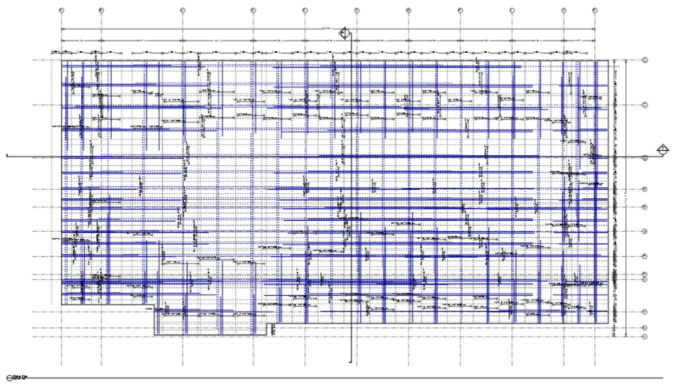


Figure 13: Reinforcement detailing

VII. CONCLUSIONS

This case study considers the ground improvement of the soft clay layer using timber micro piles. A two storeyed structure is supported on this ground through a raft foundation. The numerical analysis of this case study was performed by considering numerical model of soil with piles further model for soil with piles supporting raft foundation. The results obtained based on the numerical analysis revealed that:

1. Ground consisting of sand underlain by clay at the foundation level and also water table at 1.1m depth was a weak soil
2. The clay soil model analysis without timber micro piles, failed with large settlement of soil
3. The soil when provided with inclined piles at the edges and mid span portion showed considerable improvement in the soil response to structural loading in terms of settlement. The settlement obtained was well within the permissible value.
4. The study of relation between safe bearing capacity and the settlement indicated a marked improvement in the value of safe bearing capacity of soil as 200 kN/m^2 for soil with inclined micro piles. This indicates that the soil properties improved with the provision of micro piles in the clay layer.

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