Analysis and Design of Micro-Pile Foundation for an Extension of a Commercial Building

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Abstract. Foundations are classified as shallow and deep. They provide support for super structure by transferring load to layers of soil or rock that have sufficient bearing capacity. However, certain ground conditions and site constraints make it difficult to use these conventional foundations. In such situations, micro piles are seen as the only alternative. They can be used both as a ground improvement method and structural element designed as soil frictional piles and rock socketed piles either under tension or compression. They can be installed in restricted access sites making it very favorable. The present paper is a case study of use of micro pile for a commercial building at Chhattisgarh, India where the access to the construction site is restricted and the ground conditions are unfavourable for conventional foundations. The geotechnical design of micro pile are carried out. The present paper also discusses the design of group of six micro-piles with a pile-cap which were modelled in Plaxis 3D according to sub-strata conditions observed at a construction site and the deflection parameters were observed.

Keywords: Micro-pile, foundation, load carrying capacity, settlement

1 Introduction

Shallow foundations (0.5 m depth) are used for small, light buildings, while deep foundations (20-65 m depth) are for large, heavy buildings. Deep foundations may also be required in conditions where good hard strata are not available at shallow depth. For deep foundations, piles are used. A pile basically is a long cylinder of a strong material such as concrete that is pushed into the ground so that structures can be supported on top of it. Piles are used when there is a layer of weak soil at the surface, this layer cannot be support weight of the building, so the loads of the building have to bypass this layer and be transferred to the layer of stronger soil or rock that is below the weak layer. However, certain ground conditions and site constraints make it difficult to use these conventional foundations such as weak soil only present in shallow depths. In such situations, micro piles are the only alternative. A micro-pile is a pile having smaller diameter than conventional piles, typically less than 300mm. It is heavily reinforced and carries most of its loading on high capacity steel reinforcement. They can be used both as a ground improvement method and structural element designed as soil frictional piles and rock socketed piles either under tension or compression. They can be installed in restricted access sites making it very favorable. This paper is a case study of use of micro piles as foundation for a G+10 commercial building at Chhattisgarh, India, where the access to the construction site is restricted and the ground conditions are unfavorable for conventional foundations. Geotechnical design of micro-pile are carried out. Also, group of six micro-piles with a pile-cap were modelled in Plaxis 3D.

2 Site Investigation

The plan of G+10 building at Chhattisgarh site is shown in Fig 1. The site at Chhattisgarh having filling material up to 3 m then 3 to 4 m is fractured rock followed by soft rock up to 15 m. Ground water is acting at 1.1 m from ground level. The typical sub soil profile is as shown in the bore log Fig 2. The pile cap arrangement with micro-pile is shown in Fig 3. After referring to site investigation report and vicinity of the G+10 building, conventional foundation was found unfavourable. Therefore, feasibility of micro pile foundation was examined and found very convenient and suitable. Hence geotechnical aspect of micro-pile was studied, analysed and designed in the present study for the structural loads coming on the foundation.

2.1 Geotechnical Calculation

Assessment of vertical load of a single micro-pile based on geotechnical considerations:

- Diameter of pile = 300 mm
- Multiplication constant for socket length depending on rock strata = 4
- Socket length = 4 x 3 = 1.2 m (From IS 14593)
- Uniaxial compressive strength of rock = 730 t/m^2 (as per soil investigation report)
- Depth factor from formula =1.6 (From page 3 of IS 14593)
- Maximum value of depth factor = 2
- Actual depth factor = 1.6
- Area of pile toe = π/4 x 0.3 x 0.3 = 0.070686 m^2
- Rock socket slide resistance reduction factor, α =0.1 (From fig.1 of IS 14593)
- Rock socket correction factor, β=0.4 (From: fig. 2 of IS 14593)
- N_j, depending upon the discontinuity in rocks= 0.1 (From IS 12070)
- Total pile load capacity= 41.28t
- Safe load considering neglecting end bearing = 33.02t

Assessment of vertical load on micro-pile group based on geotechnical pile capacity:

- Allowable vertical load on pile group = number of piles x vertical load carry capacity of single micro- pile x efficiency factor

- Vertical load carry capacity of single micro-pile = safe load on single micro-pile = 33 t
- Minimum centre to centre distance between any two adjacent piles = 3 times diameter of pile = 3 x 0.3 = 0.9 m
- Group efficiency factor = 1

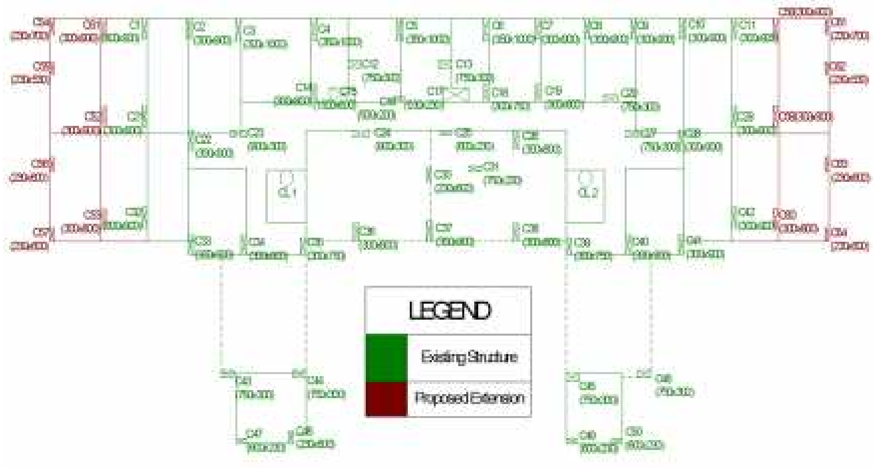

Fig. 1. Layout of proposed extension of existing structure of G+10 building at Chhattisgarh

Type of Boring	Rotary	Job No. : JSPL/SSA/005/14-15
Dia of Hole (mm):	150.00	Bore Hole No.: 03
Depth (M):	0.00-15.00	Co-ordinates :
Commenced on : 28 April 2014	Completed on : 29 April 2014	Ground Bed RL:
Water Struc :	Ground Water : 1.10	Location of Bore Hole :

Description of Strata	Symbol	Thk. (M)	From (M)	To (M)	Sample Depth (M)	Sample Type	Sample Ref. No.	SPT Record 0-150	150-300	300-450	N	Core Recovery (%)	R.Q.D.	SPT Curve
FILLING MATERIALS		0.00, 1.00, 2.00	0.00	2.90	1.50	P	SPT-1	12cm in 50 blows,N=50						
FRACTURED ROCK		3.00, 4.00												
SOFT ROCK			4.10		4.00	C	C-1					25.00	0.00	
		5.00, 6.00			5.50	C	C-2					30.00	0.00	
		7.00, 8.00			7.00	C	C-3					40.00	0.00	
		9.00			8.50	C	C-4					42.00	10.00	
		10.00, 11.00			10.00	C	C-5					44.00	12.00	
		12.00			11.50	C	C-6					50.00	10.00	
		13.00, 14.00			13.00	C	C-7					55.00	18.00	
		15.00		15.00	14.50	C	C-8					60.00	20.00	
Bore Hole Terminated at : 15.00														

D-Disturbed Sample, U-Undisturbed Sample, P-Standerd Penetration Test,C-Core, W-Water Sample, V-V

Fig. 2. Bore-log at the site of proposed extension of structure Chhattisgarh

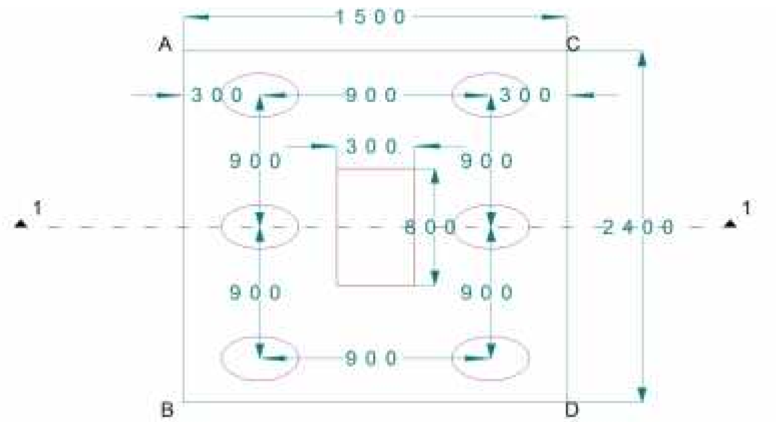

Fig. 3. Micro-pile arrangement at the site of proposed extension of structure

- Number of micro-piles in a group = 3, 4, 5, 6, 7, 8
  - 3 group micro-pile group capacity = 3 x 33 x 1 = 99 t
  - 4 group micro-pile group capacity = 4 x 33 x 1= 132 t
  - 5 group micro-pile group capacity = 5 x 33 x 1 = 165 t
  - 6 group micro-pile group capacity = 6 x 33 x 1 =198 t
  - 7 group micro-pile group capacity = 7 x 33 x 1 = 231 t
  - 8 group micro-pile group capacity = 8 x 33 x 1 = 264 t

The ultimate load acting on the foundation was 170 t (based on structural designer) which is less than the ultimate load carrying capacity of six-micro-pile group of 198 t and hence a six-micro-pile group was determined to be sufficient for the column extension. So future analysis six-micro-pile group is analyzed with Plaxis 3D software.

2.2 Numerical Analysis

It is necessary to review the estimated deflection of the pile under loading conditions and independently check for any geotechnical failure, before it is approved for construction, for this project Plaxis 3D has been used to independently review the design. The model prepared on Plaxis 3D must replicate the physical conditions at the site so that the simulation of the loading conditions give us the expected values of deflection and stresses that will be very close to the actual values that will be observed. For the purpose of this model a 50 m x 50 m space was considered and a six micro-pile group was modelled at the centre of the space; and 3 layers of the strata were modelled to replicate the conditions at the site namely the top layer (filling material) which was modelled as hardening soil, the intermediate layer (fractured rock) which was modelled as jointed rock and the bottom layer (soft rock) which was modelled as hoek-brown model. The hoek–brown failure criterion is an empirical stress surface that is used in rock mechanics to predict the failure of rock, for this model the hoek-brown parameters were modelled as uniform basaltic rock which was observed at the site. Table 1 shows the properties of the various layers used in the Plaxis 3D model. The pile was modelled (Fig. 4) as an embedded beam in soil of concrete with properties of M30 grade concrete grout.

Table 1. Properties of the various layers used in the model

Properties	Layers		
	Filling material	Fractured rock	Soft rock
Unit weight saturated (Υ_{sat}) kN/m^3	20	25	26
Unit weight unsaturated (Υ_{unsat}) kN/m^3	17	25	24
Secant stiffness in standard drained triaxial test ($E50^{ref}$) kN/m^2	35 x 10^3	-	-
Tangent stiffness for primary odometer loading ($E_{oed}{}^{ref}$) kN/m^2	35 x 10^3	-	-
Unloading/Reloading stiffness ($E_{ur}{}^{ref}$) kN/m^2	105 x 10^3	-	-
Young's modulus as continuum (E_1) kN/m^2	-	2 x 10^6	-
Young's modulus (E''_{rm}) kN/m^2	-	-	70x10^6
Young's modulus perpendicular on plane 1 direction (E_2) kN/m^2	-	2 x 10^6	-
Effective cohesion (C'_{ref}) kN/m^2	0	-	-
Effective angle of internal friction (ϕ)	33^o	-	-
Angle of dilitancy (ψ)	3^o	-	-
Drainage type	-	Non porous	-
Poisson ratio as continuum (V_1)	-	0.2	-
Poisson ratio perpendicular on Plane 1 direction (V_2)	-	0.2	-
Poisson ratio $(V)'$	-	-	0.18
Shear modulus perpendicular on plane 1 direction (G_2) kN/m^2	-	833 x 10^3	-
Uniaxial compressive strength $\|\sigma_{ci}\|$ kN/m^2	-	-	7300
Intact rock parameter (M_i)	-	-	25
Geological strength index (GSI)	-	-	80
Disturbance factor (D)	-	-	0
Undrained behaviour	-	-	Standard

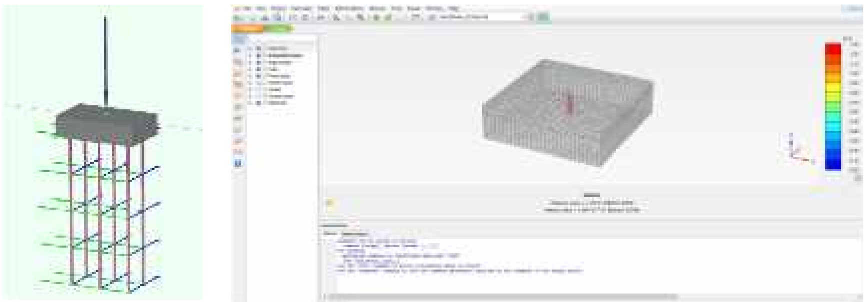

Fig. 4. Model of six micro-pile group and meshing

3 Concluding Remarks

The design of the micro-pile foundation needs to be independently reviewed, Plaxis 3D was used as a review mechanism. The proposed design was found to achieve the necessary geotechnical capacity without undergoing failure and the deformation of the proposed foundation was found to be 0.06599 mm (Fig. 5) which is very less, accordingly load at which failure occurs corresponding to 12mm settlement will be much higher than the anticipated load acting on the foundation, hence the proposed designed is deemed safe after the independent review by Plaxis 3D. For the proposed G+10 building micro pile was constructed as foundation with 6 bars of 25mm diameter and 8mm stirrups @ 100 c/c specifications.

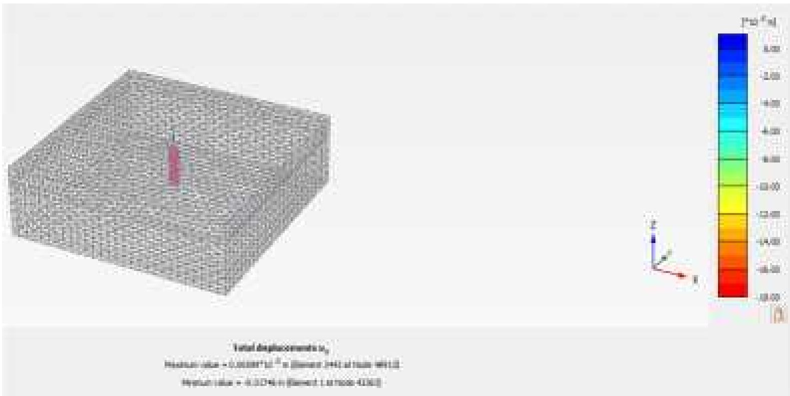

Fig. 5. Displacement analysis for six micro-pile group

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