Lateral behavior of a long pile with load application above ground: a case study

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Abstract. Large diameter piles are generally used to provide the foundation system for the elevated tanks. The behavior of the laterally loaded pile is influenced by the pile head conditions, position of load application, pile length and the soil resistance below ground. Understanding the load deflection behavior of the pile is an essential requirement for the consistent and reliable design of the tank. In this paper, performance of 1m diameter pile installed in layered soils and tested 2m above ground level is discussed. The pile is modelled by Finite Difference and Finite Element approaches to understand behavior of pile. This paper illustrates theoretical and actual behavior of laterally loaded long piles tested above ground level.

Keywords: Laterally loaded pile, load application above ground, finite difference, finite element.

1 Introduction

Pile foundations are typically used for providing stability for the structures subjected to high vertical and lateral loads. The lateral loads can be due to wind and seismic cases and the understanding of the load deflection behavior is an essential requirement for the design of the structures.

40m deep piles, 1m diameter was necessitated for an elevated tank in the West Coast of India. The project site is located in active Seismic Zone, subjected to high lateral forces. Behavior of the piles are studied by Finite Element and Finite Difference approaches. Lateral pile load test was performed at 2m above ground level.

This paper discusses theoretical and actual behavior of laterally loaded piles tested above ground level. The P-Y method proposed by Reese and Van Impe (2011) was used for the analysis. The governing differential equation is solved by the Finite Difference Techniques. The results obtained are compared with 3D Finite Element Models and the load test results. In addition, the diameter effect which needs to be considered while using P-Y curve method is also discussed.

2 Site and Subsoil Conditions

An elevated tank was proposed in the West Coast of India. Project specifications demand high lateral load requirement for the piles. The piles are 1m diameter, 40m deep and cut-off level is 2m above existing ground level.

Two boreholes were explored to 50m deep below the existing ground level (EGL). The subsoil consists of mixed soil strata (layers of sand and stiff to hard layers). Ground water table was observed to be 2 below EGL at the time of testing. The stratification along with the sub soil data is presented in Table 1.

Sl No	Type	Elevation, m	N	c_u kPa	ϕ' (°)
1	Silty Sand	0.0m-3.0m	8	-	31
2	Stiff clay	3.0m-7.5m	15	68	-
3	Silty Sand	7.5m-10.5m	46	-	34
4	Stiff clay	10.5-18.0m	27	122	-
5	Stiff clay	18.0-25.5m	38	171	-
6	Stiff clay	25.5-31.5m	26	117	-
s7	Stiff clay	31.5-36.0m	39	176	-
8	Silty Sand	36.0-50.0m	133	-	34

Table 1. Subsoil Stratification at the job site

3 Numerical Analysis

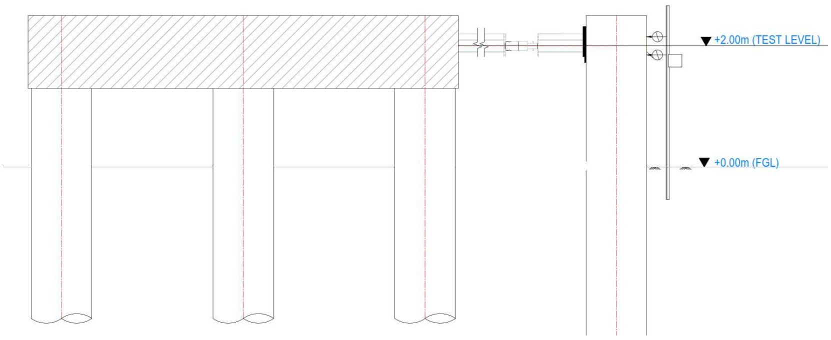


Fig. 1. Typical arrangement illustrating lateral pile load test

Figure 1 shows a typical arrangement of lateral pile load test. The pile is modelled by P-Y Method and 3D Finite Element method. P-Y curve analysis is performed using the method proposed by Reese and Matlock. The parameters used to develop P-Y curves in clay are undrained shear strength and the normal strain at 50% of the ultimate deviator stress in a triaxial test. The parameters used in sand are the angle of friction and the horizontal modulus of subgrade reaction. The governing differential equation is solved by the Finite Difference Techniques.

Embedded pile/beam option is considered for 3D Finite Element Method for pile and Mohr Coulomb model parameters are used for surrounding soil. The Clay layers are modelled as undrained soil whereas sand is modelled as drained type.

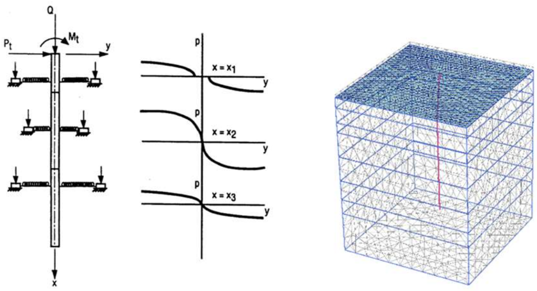


Fig. 2. P-Y Method and FEM Method

Influence of mesh coarseness in finite element method and diameter effect in the P-Y curve method is studied.

3.1 Effect of Mesh Coarseness on deflection pattern (FEM Analysis)

Four mesh types (fine, medium, coarse & very coarse) are considered to identify the influence on the deflection patterns in a finite element model. A typical load case of 920kN is considered in the analysis.

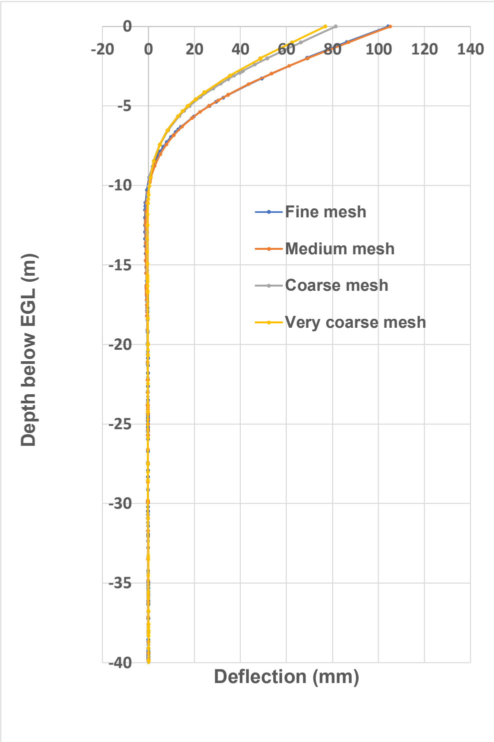


Fig. 3. Influence of Mesh on the deflection profiles (1m diameter)

It is observed that Load settlement behavior of an embedded pile is mesh dependent. Very coarse and coarse meshes underpredicted the deflection patterns while the medium and fine meshes yielded comparable results.

3.2 Diameter Effects (P-Y Method of analysis)

P-Y curves are originally developed based on the lateral load tests on the piles ranging between 0.30m to 1.20m diameters. An exercise is made to assess deflection of 1.0m, 1.5m and 2.0m dia piles for varying lateral loads in both P-Y & 3D FEM. The results are tabulated below:

Pile Dia (m)	Lateral Load (Tons)	Deflection (P-Y Model)	Deflection (3D FEM Model)
1.0m	31	25	27
	56	53	57
	76	86	85
	92	121	105
1.5m	100	37	42
	160	76	71
	200	110	99

	250	169	126
2.0m	100	18	24
	160	33	40
	200	43	52
	250	61	66

Table 2. Diameter effects of laterally loaded pile

The present analysis shows differences in the deflection patterns for large diameter piles at high loads, however, detailed studies are to be done on the same.

Data from experiments across the globe are insufficient to make a conclusion on the diameter influence and further extensive studies are required for the same. Hence it is opinioned that the assessment of big diameter piles through P-Y Analysis method shall be followed by additional checks such as FEM Analysis and load tests.

4 Field load Test

Pile was tested to maximum of 137 tons / 100mm deflection whichever comes first. Point of application of the load is kept 2.0m above ground level. Application of the loading was carried out by means of jacking the test pile against the reaction system. The readings were taken with the help of two calibrated dial gauges and the average readings were taken.

Fig. 4. Lateral Load Test Set Up

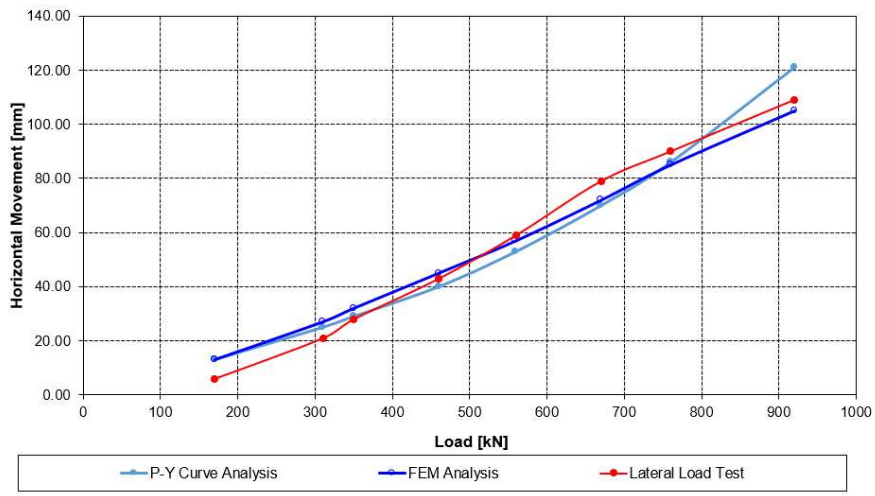
5 Comparison of Numerical Methods & Field Test Results

The results of the numerical analysis and the load test are plotted in the following table:

Sl No	Loading (kN)	Deflection, mm (P-Y Method)	Deflection, mm (FEM Method)	Deflection, mm (Load Test)
1	170	13	13	6
2	310	25	27	21
3	350	29	32	28
4	460	40	45	43
5	560	53	57	59
6	670	70	72	79
7	760	86	85	90
8	920	121	105	109

Table 3. Summary of results (Numerical Analysis Vs Load Test)

The deflections obtained from the numerical analysis are compared with the field records and are found to be in the order.



`**Fig.** 5. Comparison of Load Test results Vs Numerical methods

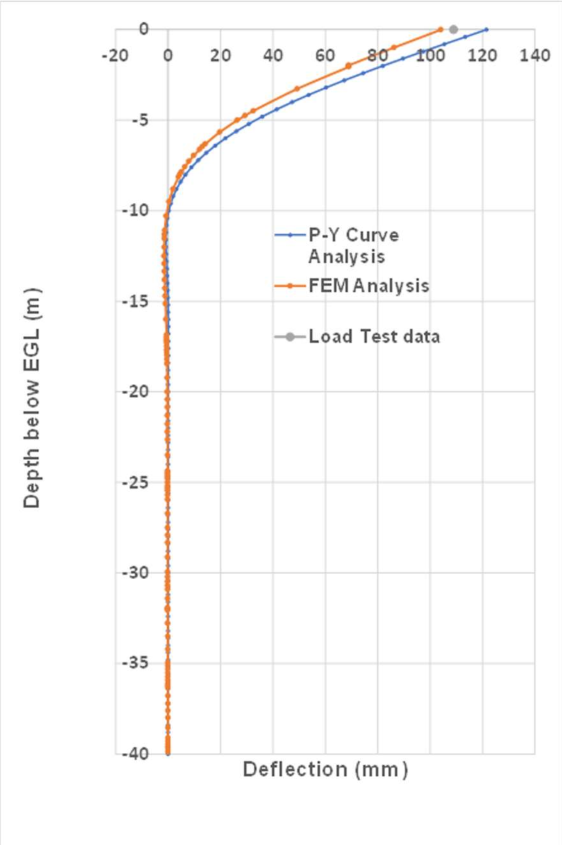


Fig. 6. Behavior of 1m diameter pile at 920 kN Test Load

It is observed that depth wise variation in deflection is following similar trends between the two numerical methods, the point of fixity is found to be the same in both the numerical methods.

6 Conclusion

Behavior of the laterally loaded pile is assessed by Finite Element Analysis and P-Y Method of analysis. It is observed that both methods follow similar trends and match with the load test results in most of the load cases. Programs using P-Y curves are originally developed for small diameter piles, application of it for larger diameter piles shall be used with caution. Additional checks such as FEM Analysis and load tests may be used to validate the performance.

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