Behaviour of Laterally Loaded Piles

Berrak Teymur
Istanbul Technical University, Turkey

Zeynep Şekerer
Reinforced Earth® İnşaat Project, Turkey

Commemorate the Legacy of Ralph B. Peck
Seventh International Conference on
Case Histories in Geotechnical Engineering
April 29 - May 4, 2013 CHICAGO
and Symposium in Honor of Clyde Baker

BEHAVIOUR OF LATERALLY LOADED PILES

Berrak Teymur
Istanbul Technical University
İstanbul, Turkey

Zeynep Şekerer
Reinforced Earth® İnşaat Proje
İstanbul, Turkey

ABSTRACT

Pile foundations are often subject to lateral loads and axial loads. Although design methods for axial loading are well developed, lateral loading cases have attracted more attention recently following reported case histories of piles damaged during earthquakes. In this work, pile design due to lateral loading in tuff soils is considered. Pile deflections, bending moment and rotation were analyzed with OpenSeesPL program, a 3D finite element tool. OpenSeesPL is used to model the properties of the piles which are embedded in tuff and laterally load tested in Izmir. The displacement calculated by OpenSeesPL of 2.25mm is close to the measured 2.5mm. In this study, influence of pile length was investigated. From the results, it was observed that as the pile length increased from 6m to 20.5m, the movement, displacement and the rotation of the pile has decreased. In addition, with the same program, lateral displacement of a single pile in sandy and clayey soil layers were also analyzed with the results summarized. In all types of soils, as the pile length has decreased, the pile displacement has increased.

INTRODUCTION

Pile foundations are often subject to lateral loads and axial loads. Although design methods for axial loading are well developed, lateral loading cases have attracted more attention recently following reported case histories of piles damaged during earthquakes. In this work, pile design due to lateral loading in tuff soils is considered. Pile deflections, bending moment, and rotation were analyzed with OpenSeesPL program, a 3D finite element tool.

Under lateral load, the pile is subjected to bending moment and shear, and the behavior of its cross section is a major component of the pile response. The design of piles for use against lateral loads is usually governed by the maximum tolerable deflection (Poulos and Davis 1990). Load-deflection responses of laterally loaded piles depend on many factors, such as pile dimensions, structural material properties, nearby soil conditions; lateral spreading, soil-structure interaction and type of loadings.

OpenSeesPL is used to model the properties of the piles which are embedded in tuff and laterally load tested in Izmir. The displacement calculated by OpenSeesPL of 2.25mm is close to the measured 2.5mm. In this study, influence of pile length was investigated. Lateral displacement of a single pile in sandy and clayey soil layers was also analyzed.

SITE CONDITION

A 140000 m^3 capacity tank was planned to be constructed in Izmir in 2001. Axial and lateral loading tests were conducted on the 120cm diameter bored piles proposed for use in supporting the tank. The soil investigation consisted of four boreholes. Two boreholes were drilled during the first exploration and two boreholes were drilled after the tank site was filled. The soil profile is shown in Fig. 1 and is as follows: (Sekerer, 2009):

Fill having a thickness of 7.5-9.0m N_{30}=3-50

Organic Mud (silt+sand) having a thickness 2.5-4.0m N_{30}=1-2 (before the construction of fill) N_{30}=4-16 (under the fill load)

Tuff

ANALYSIS AND NUMERICAL SIMULATION

In the OpenSeesPL program; pile geometry, material properties, boundary conditions and input excitation are defined. Representative soil properties are given for soils in Table 1.

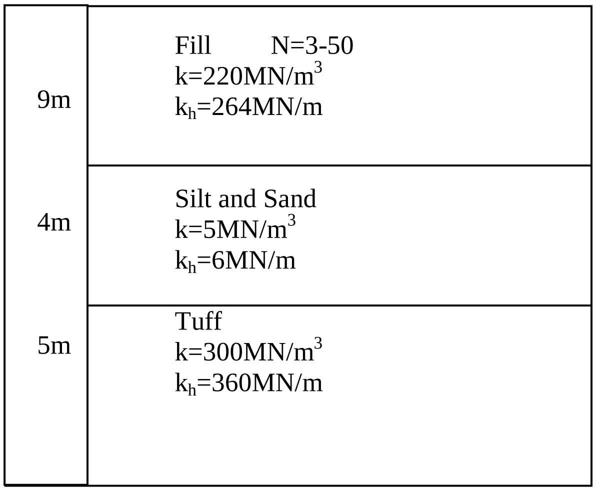

Fig. 1. Soil profile.

Table 1. Representative set of basic material parameters (data based on Seed and Idriss (1970), Holtz and Kovacs (1981), Das (1983), and Das (1995))

Cohensionless Soils	Shear wave velocity at 10m depth (m/s)	Friction angle (°)	Mass density (kg/m^3)
Loose	185	29	1.7x10^3
Medium	205	31.5	1.9x10^3
Medium-dense	225	35	2.0x10^3
Dense	255	40	2.1x10^3
Cohesive Soils	Shear wave velocity (m/s)	Undrained shear strength (kPa)	Mass density (kg/m^3)
Soft clay	100	18	1.3x10^3
Medium clay	200	37	1.5x10^3
Stiff clay	300	75	1.8x10^3

In the analysis, the bottom of the soil profile fixed in the horizontal (x), transverse (y), and vertical (z) directions. The mesh is fixed in x and y directions and free in z direction at the sides. The lateral load is applied at the pile head in x direction.

Test pile is located next to the tank foundation area. It was drilled with casing down to tuff formation. The pile is drilled through fill material and completed after pile was socketted 5m in tuff. Lateral load tests at two different locations were performed on previously constructed 120cm diameter piles. The test performed on piles minimum 30 days after the completion of test pile and reaction piles. The maximum load applied was 80 tons which is the design verification load (DVL) calculated. Total test load were applied by means of a hydraulic jack. Deformations were measured by dial gauges at three different points. The displacement of the pile relative to ground was measured by dial gauges. In addition, rotation of pile cap was controlled by a dial gauge.

Loading was in stages of 12.5% of DVL. Unloading was performed in stages of 25% of the DVL. Total test duration was 5 hours for time and load deformation curves. Test results are shown in Fig. 2 and Fig. 3. Deformation measured is 2.5mm under 80 ton loading as shown in Fig. 3.

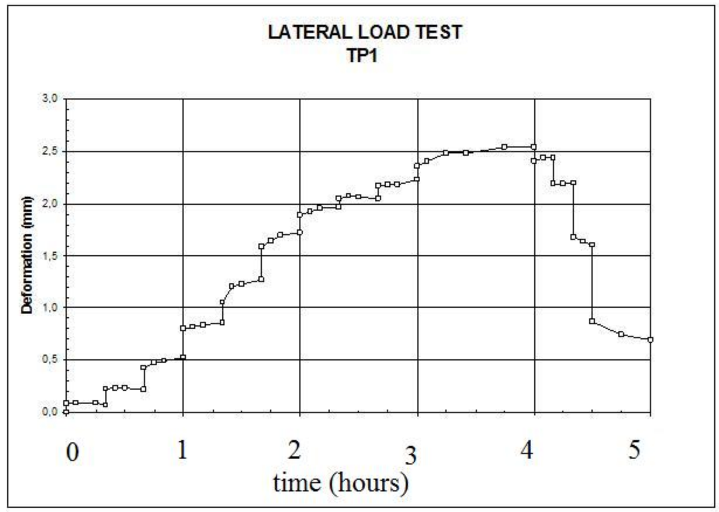

Fig. 2. Time- deformation graph (Sekerer, 2009)

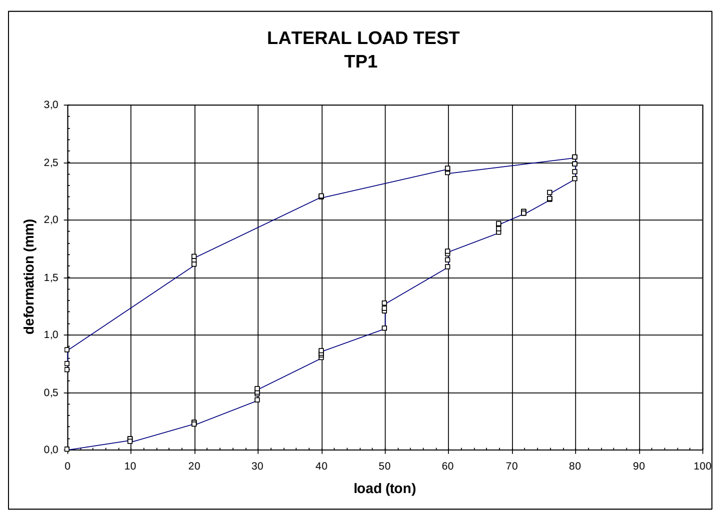

Fig. 3. Load-deformation graph (Sekerer, 2009)

In Fig. 4, the displacement of the pile found by OpenSees PL program is shown. The displacement calculated is 2.25mm and the measured one is 2.5 mm. The results are close. Sandy and clayey soils parameters are given in Table 1 are used in the analysis of piles with different lengths.

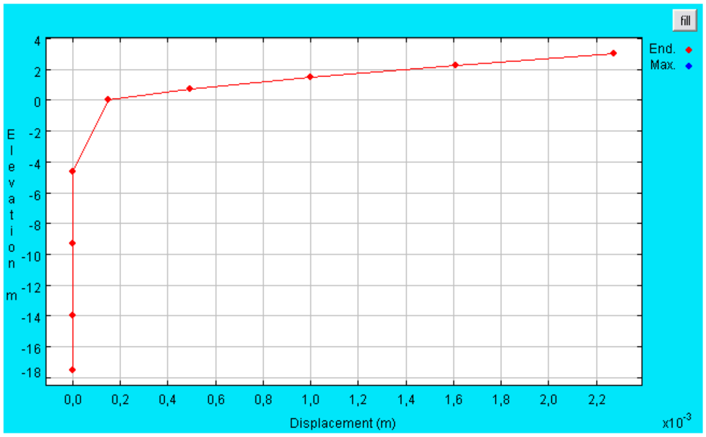

Fig. 4. Aliaga pile displacement result with OpenSees PL program.

Cohensionless Soils Analysis

The effect of pile length was investigated in the cases of loose and dense sand soil layers for 20.5m, 15m, 10m and 6m long piles. Under 80 ton lateral loading, the pile displacement observed at the pile head is 2.79mm for 20.5m long pile as seen in Figure 5. The 15m pile displacement is 2.81mm, 10m pile displacement is 3.25mm and the pile displacement for the 6m pile is 3.4 mm.

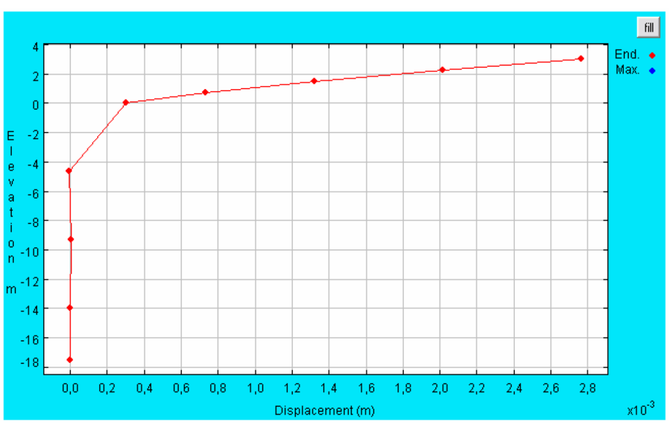

Fig. 5. Displacement for a 20.5m long pile in loose sandy soil.

The results for the various pile lengths of the pile in dense sands are shown in Figures 6. Under 80 ton lateral loading, the pile displacement observed at the pile head is 2.23mm for 20.5m long pile. The 15 m pile displacement is 2.22mm, 10m pile displacement is calculated 2.25mm and the pile displacement for the 6m pile is 2.7mm. It is observed that as the pile length decreases, the pile displacement increases as shown in Fig. 6.

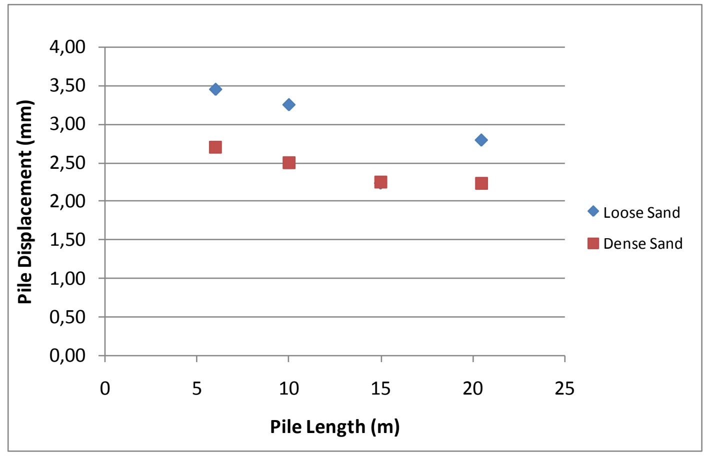

Fig. 6. Pile length, pile displacement for loose and dense sands.

Analysis of Piles in Clayey Soils

The effect of pile length was investigated in the cases of soft and stiff clay soil layers. Under 80 ton lateral loading, the pile displacement observed at the pile head is 2.23 mm for 20.5 m long pile as seen in Figure 7. The 15m pile displacement is seen 2.22mm, 10m pile displacement is 2.25mm and the pile displacement for the 6m pile is 2.7mm.

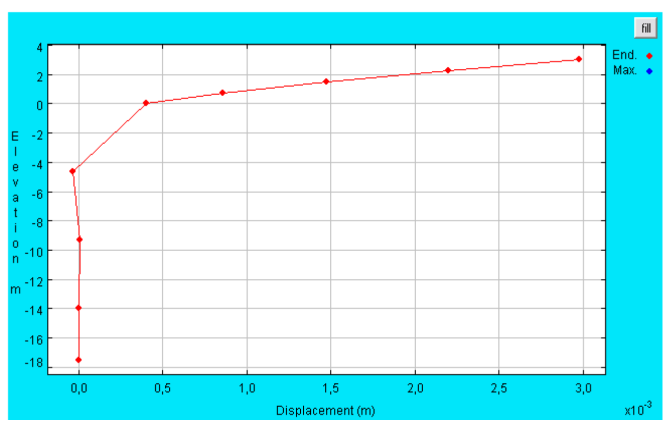

Fig. 7. Displacement for a 20.5m long pile in soft clay soil.

The results for the various pile lengths of the pile in stiff clay are shown in Fig. 8. Under 80 ton lateral loading, the pile displacement observed at the pile head is 1.70mm for 20.5m long pile, the 15m pile displacement seen is 1.71mm, 10m pile displacement is 1.72mm and the pile displacement for the 6m pile displacement is 1.73mm. It is seen that as the pile length decreases, the displacement increases as seen in Fig. 8.

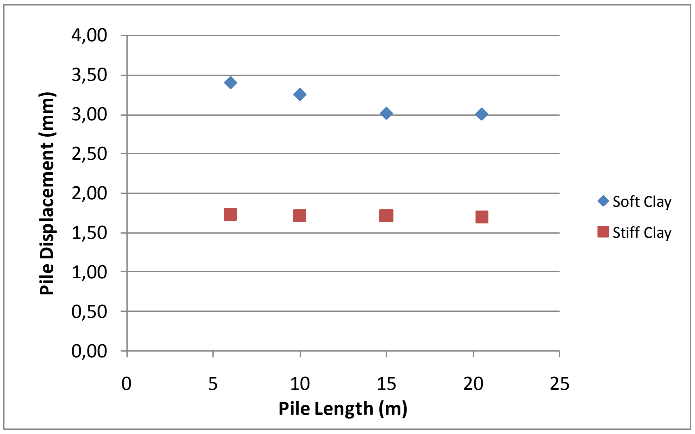

Fig. 8. Pile length, pile displacement for soft and stiff clays.

CONCLUSIONS

The aim of this paper is to analyze laterally loading deformation of piles due to loaded piles deformation in different soils. The example pile which was lateral loaded single piles has been analyzed for the case history in Izmir. A real field data obtained from the lateral loading test of a pile was used to validate the program used. The displacement calculated by OpenSeesPL program is 2.25mm and the measured one is 2.5mm. With the program lateral displacement of a single pile in sandy and clayey soil layers were analyzed. In all types of soils, as the pile length decreases, the pile displacement increases. This could be due to the length of the pile resistance in soils. Long piles have more advantages than short piles. Therefore, pile must be socketted to stiffer or denser soil structures. In long piles, displacements are less than the shorter piles due to the frictional forces around the piles. From the results, it was observed that as the pile length increased, the movement, displacement and the rotation of the pile has decreased. Tables 2 and 3 show the pile rotation at the pile head in four different soil type and four different pile length obtained from the analysis. In all type of soils as the pile length decreases, the pile rotation increases.

Table 2. Sandy soils rotation results

Pile length (m)	Pile rotation (10^{-3})	
	Loose sand	Dense sand
20.5	1.01	0.89
15	1.01	0.89
10	1.06	0.91
6	1.40	0.99

Table 3. Clayey soils rotation results

Pile length (m)	Pile rotation (10^{-3})	
	Soft clay	Stiff clay
20.5	1.05	0.74
15	1.05	0.74
10	1.07	0.72
6	1.20	0.72

REFERENCES

Poulos H.G and Davis, E.H, [1990]: *Series in geotecnical Engineering, Pile Foundation Analysis and Design*,

Sekerer Z. [2009] *Behaviour of laterrally loadded piles in soils*, MSc Thesis, ITU Institute of Science, Engineering and Technology.

Das [1983] *Fundamentals of soil dynamics*, Elsevier, NY

Das [1995] *Principles of foundation engineering*, PWS Publication

Holtz and Kovacs [1981] *An introduction to geotechnical engineering*, Prentice Hall, NJ.