A Case Study of Deep Foundation Design Using MPT and Comparison with Instrumented Pile Load Tests

Une étude de conception de fondations profondes, en utilisant le pressiomètre Ménard et comparaison avec des essais de chargement de pieux instrumentés

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ABSTRACT: The pre bored Pressuremeter tests are widely used for design of foundations (either for shallow foundations or deep foundations) and shoring systems in European Practice. The method is widely used in Turkey as well in the last decade. The project subjected in this paper is a mass housing project, which consists of high rise blocks (up to 30 floors). The project site is located on a high seismic zone which additionally lies on ~150 m deep alluvial deposits (sand, silt and clay interbedded with high ground water table).

Due to the geological – hydrogeological conditions and high structural loads, deep foundation systems were proposed starting from the planning phase. This case study presents the comparison of pile design by means of in-situ tests (such as pressuremeter tests) with axial static pile load tests. The pressuremeter tests were used for estimating the friction of cast in-situ bored piles where E. U. design scheme was followed. A total of 114 pressuremeter tests conducted in 20 boreholes were used in the design of the deep foundation system. Afterwards, 13 Nos. of pile load tests were conducted at site to check the design assumptions. Among them, 4 Nos. were instrumented by strain-gauges, The elevations at which pressuremeter tests were conducted were chosen for the locations where the sister-bar strain-gauges were placed in order to achieve compatible data. All piles were loaded up to failure where skin resistances were fully mobilized. The results indicate that skin frictions found by in situ pressuremeter tests are almost in the same order with the ones obtained from pile loading tests.

RESUME : Dans la pratique européenne, les essais pressiométriques préforés sont largement utilisés pour la conception des fondations (pour les fondations soit superficielles soit profondes) et pour les écrans de reprise en sous-œuvre. La méthode a été largement utilisée en Turquie dans la dernière décennie. Le projet étudié dans le présent document est un vaste ensemble de logements, qui se compose de blocs de grande hauteur (jusqu'à 30 étages). Le site du projet est situé sur une zone sismique qui se trouve en outre sur environ 150 m d'alluvions profondes (sable, limon et argile interlités avec une nappe phréatique haute).

En raison des conditions géologiques et hydrogéologiques, ainsi que des charges de structure élevées, les systèmes de fondations profondes ont été proposés dès la phase de planification. Cette étude de cas présente la comparaison de la conception de pieux au moyen d'essais in-situ, les essais pressiométriques, avec des essais de chargement statique axial de pieux. Les essais pressiométriques ont été utilisés pour estimer la distribution du frottement le long des pieux forés coulés en place en suivant les règles de l'U.E. Un total de 114 essais pressiomètriques réalisés dans 20 forages ont été utilisés pour la conception de ces fondations profondes. Ensuite 13 essais statiques de chargement de pieux, dont 4 instrumentés par extensomètres, ont été menés sur le site pour vérifier les hypothèses de conception. Les cotes auxquelles les essais pressiométriques ont été réalisés avaient été choisies aux endroits où les extensomètres devaient être placés afin de parvenir à des données compatibles. Tous les pieux ont été chargés jusqu'à la rupture, le frottement latéra étant alors pleinement mobilisés. Les résultats indiquent que la résistance par frottement latéral calculée à partir des essais pressiométriques in-situ sont presque de même ordre de grandeur que ceux obtenus à partir des essais de chargement de pieux.

KEYWORDS: Deep Foundation Design, Pressuremeter Tests, Pile Load Tests

MOTS CLES : Conception de fondations profondes, essais pressiométriques, essais de chargement de pieux.

1 INTRODUCTION

This paper aims to present a comparison of a deep foundation design by means of in situ tests and pile static load tests in Turkey. For the last decade Pressuremeter Tests have been used in the foundation design in engineering practice.

A case study of Mass Housing Project in the Bursa Region was selected since the site condition from a geological point of view is very challenging in terms of engineering practice. The site is located in a high seismic region with thick alluvial sediments. In order to improve the foundations soil, deep foundations of cast in place concrete piles were projected. The design was done based on the information obtained from the in situ tests. A series of pile load tests were also executed to check the design and also the quality of the pile construction. In this sense, the results by in situ tests of soil investigations are compared with the site proof tests of axial pile load tests.

1.1 *Site Geology*

The geology of the site is mainly composed of Quaternary aged alluvial sediments. The depth of the bedrock is reported at a depth of 150-400 m in the valley by previous studies. During the site investigation which was performed specifically for this site, bedrock was not encountered in any of the boreholes. The stratigraphy of the sediments is interlacing and heterogeneous that silt, sand and clay particles were formed in different percentages through the depth. Groundwater level was approximately at -4.0 m level from existing ground.

1.2 *Project Data*

The foundation piles were designed for high rise buildings of up to 30 floors. Each structure had a base area of approximately 1000 m^2. The depth of the foundation is 4.0 m below the existing ground level. Since the site is almost a plain area, all the investigations and tests were executed from this level. 4 pilot piles with 30 m length were instrumented and load tests were conducted on them. Based on the information gained from these 4 pilot piles, working piles were designed and installed. 9 of the working piles which were 20 m long were proof tested.

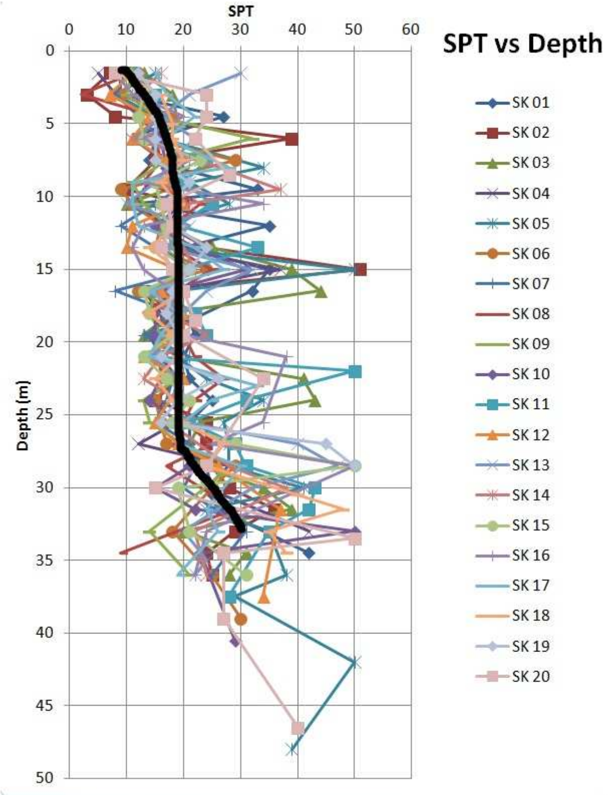

Figure 1. SPT's versus depth and average shown with thick line

1.3 *Site Investigations*

Continuous core drilling was executed at site with NX size sampler with rotary drilling technique. Since the groundwater level is close to the ground surface and the boreholes were not able to stand stable for a long time, casing was used to support the borehole walls. Twenty numbers of boreholes down to depths between 40-55 m were drilled and total 114 numbers of prebored Pressuremeter tests were conducted in these boreholes. NX sized Menard type Pressuremeter apparatus was used for the tests.

Beneath the locations of each pressuremeter test, SPT`s were conducted at every 1.5 m intervals down to the 30 m depth. The graph of SPT values vs. depth is given as Figure 1. The type of soil encountered in the boreholes was classified mainly as CL where some sand (SP) lenses were interbedded (Soil Investigation Report. 2012. ELC Group INC).

1.4 *Model Tests*

Cast in place concrete piles were designed to have 80 cm diameter and 30 m long for pilot load tests. Piles were drilled with casings of 82 cm. According to the pile load tests, new lengths of the piles were modeled and the proposed length of the piles was reduced to 20 m. Construction works were done according to this 20 m length. The working piles were drilled using 79 cm casings. After the installation of the piles, pile load tests were conducted on nine of these piles for quality control. Pile load tests on both the pilot piles and working piles were executed up to failure.

Instrumented piles were set up so that 6 levels of sister-bar strain gauges were placed in each pile. The result of the friction values between these strain gauge levels is given in Table 1.

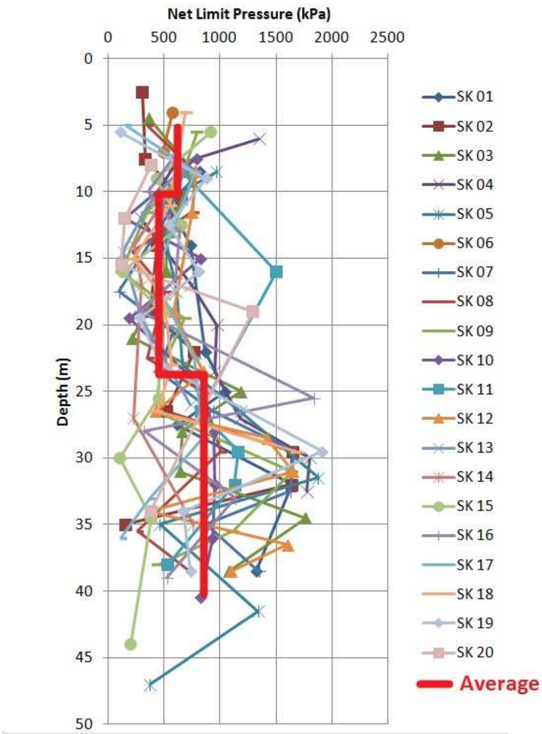

Figure 2. Net limit Pressures versus depth by MPT

Table 1. Adhesion values obtained from strain gauge measurements

Depth (m)	Adhesion(kPa)
1.0-7.5	72
7.5-13.0	74
13.0-18.0	91
18.0-24.0	85
24.0-30.0	61

2 DESIGN

Geotechnical design of the piles was conducted according to EN-1997-2:2007 Annex E. Average values of the net limit pressures were used to select the friction ratios.

Axial capacities of piles were calculated as a total of side friction + tip resistance. Piles were 80 cm in diameter and 20-30 m in length. Piles without strain gauges were 20 m, where piles with strain gauges were 30 m long.

Hence the soil was classified as Clay and the limit pressure is around 700 kPa, p_{LM} category was selected as “A-B” according to the net limit pressure of selected values as indicated in Figure 3. In order to use the table of friction values by Eurocode (see Figure 3) soil category was selected as “1-2” where it indicates a friction value of 40-60 kPa values according to Figure 4.

Soil category		Clay and silt			Sand and gravel			Chalk			Marl		Weathered rock
p_{LM} catagory		A	B	C	A	B	C	A	B	C	A	B	
Pile type													
Bored piles and caissons	No support	1	1/2	2/3	—		—	1	3	4/5	3	4/5	6
	Mud support	1	1/2	1/2	1	1/2	2/3	1	3	4/5	3	4/5	6
	Temporary casing	1	1/2	1/2	1	1/2	2/3	1	2	3/4	3	4	—
	Permanent casing	1	1	1	1	1	2				2	3	—
Hand-dug caisson		1	2	3	—	—	—	1	2	3	4	5	6
Displacement piles	Closed end steel tube	1	2	2	2	2	3				3	4	4
	Prefab. concrete	1	2	2	3	3	3				3	4	4
	Driven cast in-situ	1	2	2	2	2	3	1	2	3	3	4	—
	Coated shaft (concrete driven steel [a])	1	2	2	3	3	4				3	4	—
Grouted piles	Low pressure	1	2	2	3	3	3	2	3	4	5	5	—
	High pressure	1	4	5	5	5	6	—	5	6	6	6	7

a A preformed steel pile of tubular or H-section, with enlarged shoe, is driven with simultaneous pumping of concrete (or mortar) into the annular space.

Soil category	p_{LM} category	p_{LM} MPa	Bored piles and small displacement piles	Full displacement piles
Clay and silt	A	<0,7	1,1	1,4
	B	1,2–2,0	1,2	1,5
	C	>2,5	1,3	1,6
Sand and gravel	A	<0,5	1,0	4,2
	B	1,0 – 2,0	1,1	3,7
	C	>2,5	1,2	3,2
Chalk	A	<0,7	1,1	1,6
	B	1,0–2,5	1,4	2,2
	C	>3,0	1,8	2,6
Marl	A	1,5–4,0	1,8	2,6
	B	>4,5	1,8	2,6
Weathered rock	A	2,5–4,0	[a]	[a]
	B	>4,5		

a) Choose k for the closest soil category.

Figure 3. Tables for p_{LM} and soil categories (EN-1997-2:2007).

The adhesion values that were calculated from the strain gauge readings are given in Table 1. Similarly average adhesion values can be calculated from the nine pile load tests which were loaded up to failure.

As it can be seen from Figure 5, the pile fails when the applied vertical load reaches a value between 250-300 tons. The fact that the pile fails means that the side friction is fully mobilized. Based on these statements we can say that the average adhesion value can be calculated simply by means of formula 1.

$$F = (\text{Adhesion}) \times (\text{Side Area}) \quad (1)$$

When the average diameter is taken as 0.8 m, the side area shall be approximately 50 m^2. If the mean value of the external load causing a failure is taken as 275 ton (2750 kN), using formula 1, and considering that the adhesion is fully mobilized, the average value of skin resistance is back calculated as 55 kPa.

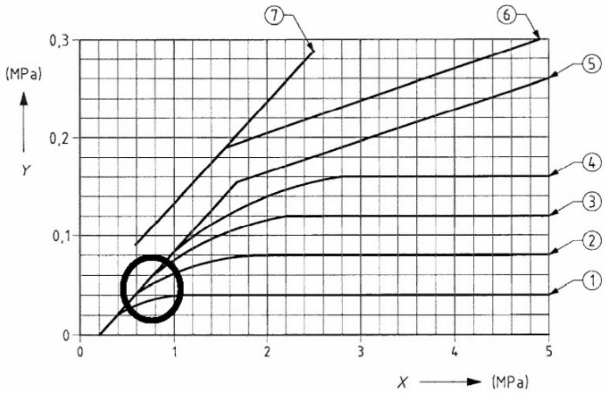

Figure 4. X axis: Limit Pressure from MPT, Y axis: Unit Shaft resistance. Circled area indicates relevant zone. (EN-1997-2:2007)

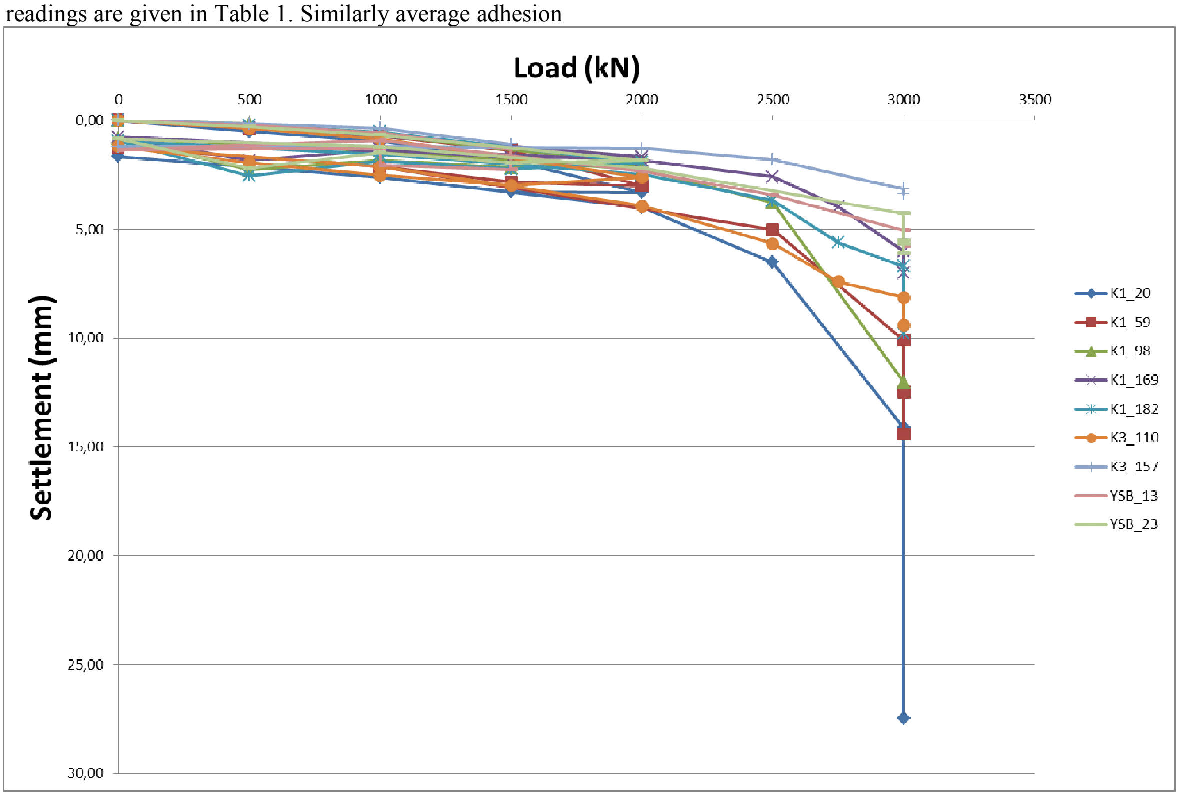

Figure 5. Load settlement graph of nine load tests (Pile Load Tests Evaluation Report, 2012. ELC Group INC.)

This simple approach can also be used for the instrumented pile load tests (see Figure 6). Here it is observed that the piles fail at an average external load of 600 ton (6000 kN). When we consider that the piles fail and as a consequence that all the skin resistance is activated, the average adhesion value can be back calculated as 80 kPa. It can be seen that this value is in very good agreement with the weighted average of the adhesion values given in Table 1, which is 76 kPa.

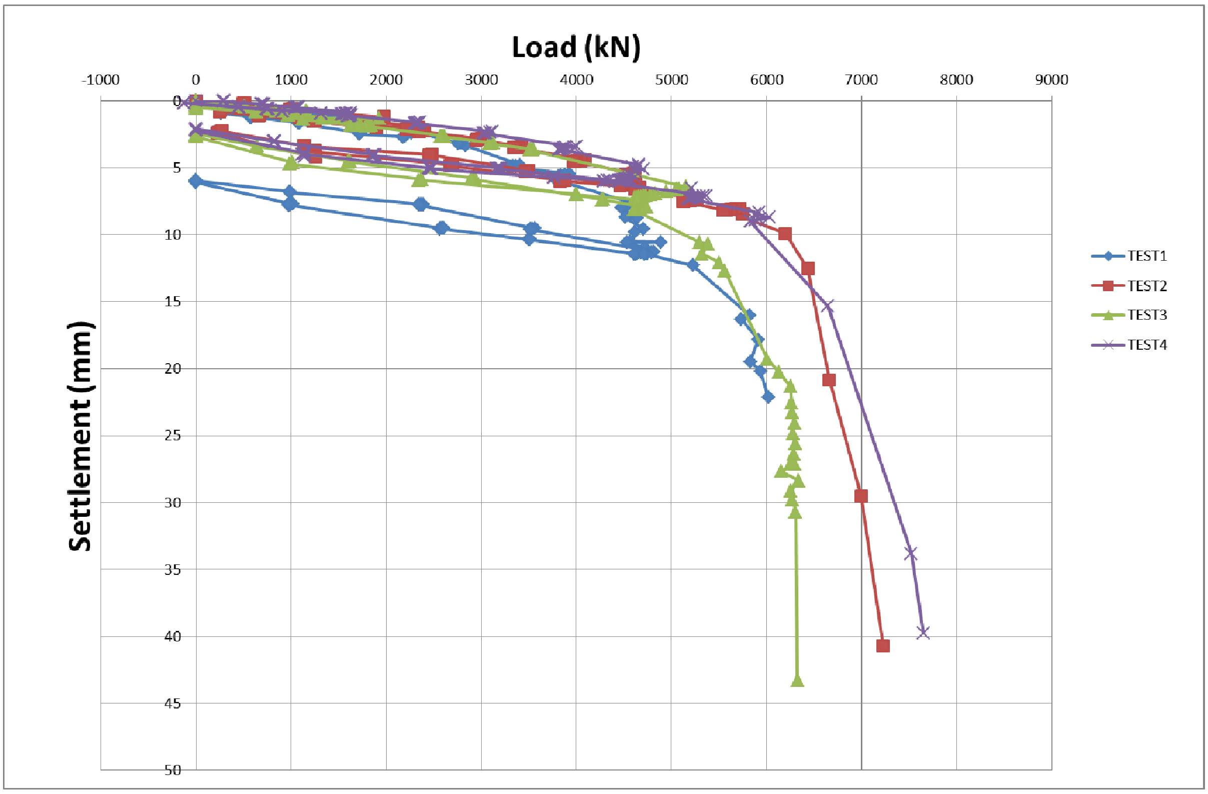

Figure 6. Load settlement graph of instrumented pile load tests (Pile Load Tests Evaluation Report, 2012. ELC Group INC.)

3 RESULTS

The design of the piles was conducted according to EN-1997-2:2007 Annex E. Average values of the net limit pressures were used to select the unit shaft resistance. Beyond this, instrumented pile load tests were also executed and unit adhesion values were measured. The magnitude of settlements recorded during these tests reveal that the settlements were not enough to mobilize the tip resistance and almost the entire test loads were dissipated through the shafts.

Resultantly, the value of the back calculation from the four instrumented pile load tests and additional nine load tests are in good agreement with each other and the proposed values by means of Eurocode informative tables which predict unit shaft resistance based on pressuremeter test results. The unit shaft resistance values obtained by instrumented pile load tests are slightly higher than the values calculated based on the pressuremeter test results. This is also as expected, because a theoretical design must remain on the safe side.

So as a general conclusion it can be stated that the Eurocode approach of predicting unit shaft resistance based on pressuremeter is a very good approach and that instrumented pile load tests are a must in piling engineering for an economical design.

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5 REFERENCES

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