A Case Study on Determination of Pile Capacity Using CPT

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SYNOPSIS : The detailed site study using CPT in design of the foundations for a major housing development with 500.000 square meters floor area in İzmir, Turkey are presented in this paper. CPTs and pile load tests are performed to obtain an optimum pile design. Due to the presence of soft clay deposits to large depths, 65 cm diameter vibrex piles with lengths between 35.0 and 40.0 m in different zones are installed. At early stage, various test piles are constructed and loaded up to failure to estimate the ultimate pile capacity and to have a comparison basis with relevant CPT tests. The pile lengths for various zones of the construction area are optimized with the evaluation of the load test results and final pile lengths in the field are determined based on the driving criteria which was developed as a result of wave propagation analysis. Subsoil conditions at the site are improved by means of preloading. The settlement under the fill is monitored by settlement columns and lateral load capacity of piles are estimated using the shear strength parameters of the improved subsoil conditions using the results of the CPT testing after the realization of settlement under the fill.

1. INTRODUCTION

Geotechnical problems and utilized solutions for the foundations of the second phase of a major housing development with a total three thousand units exceeding 500.000 square meters floor area are investigated. The housing development consists of high rise towers up to 22 stories. The project is divided into five zones each constructed by a different contractor. The building types for each zone are summarized in Table 1.

The site is situated on the shoreline at the estuary of a major river flowing into the Aegean Sea which has recently been diverted to open the area for housing construction. Deep alluvial deposits govern the subsoil conditions. Soil borings and CPT testings have been performed for the determination of initial subsoil conditions. Driven cast-in-situ vibrex piles in 65 cm diameter with lengths between 35 m and 40 m have been selected based on the determined subsoil conditions.

Vibrex piling was very fast compared to other methods, consequently great number of piles were able to be installed in a relatively short period of time.

Optimum pile capacity for different zones of the construction area is achieved with the evaluation of pile load tests performed up to failure on test piles constructed at the design stage of construction. Wave equation analyses have been performed to determine the driving criteria of the vibrex piles. The final lengths of the piles are determined at the site during construction according to the given criteria.

Table 1. Layout of Buildings (ZETAŞ, 1994a)

Contractor/ Zone	Site Area (m^2)	Number of Stories	Number of Buildings
A	21500	22	5
B	21500	22	5
C	45000	8	21
	60000	13	15
	60000	22	12
D	74000	8	29
E	45000	8	21

A certain number of piles among the constructed ones are randomly selected and these piles are loaded to 1.5 times the design load as a part of the quality control process.

Subsoil conditions at the site are improved by means of preloading. The settlement under the fill is monitored by settlement columns and lateral load capacity of piles are estimated using the shear strength parameters of the improved subsoil conditions and the results of the CPT testing after the realization of settlement under the fill.

2. SUBSOIL CONDITIONS

Total of thirty nine borings were performed at the initial stage of investigations. The scale of the project, erratic subsoil conditions and variety of structural loads made it necessary to utilize comprehensive CPT testing to be performed within limited time of the construction schedule.

At the initial stage total of forty CPT's up to bearing strata have been performed to determine subsoil conditions and pile capacity. Five typical CPT soundings for different zones of the construction area are given in Figure 1. The subsoil stratification present in the site with consequent foundation behavior is outlined below (ZETAŞ, 1994a).

- A preloading embankment of 3.0 m was constructed at early stages in order to improve the soft subsoil.
- The topmost layer below the fill is soft clay with thickness up to 18.0 m. This clay layer creates the major problems in terms of the pile foundations. The settlements that are expected to occur in this strata under fill create negative skin friction on the pile shaft and reduce the pile capacity considerably.
- Below the clay layer exists a sand layer with varying thickness. The presence of the sand layer helps in the dissipation of the excess pore pressure occurring due to the fill. Negative skin friction depth will be limited with the upper clay layer and will not extend to deeper strata because of such a dissipation.
- Stiff hard clay and dense gravel are present below 30.0 m depths which contribute to most of the pile capacity.

3. PILE DESIGN

Vertical pile capacity is determined utilizing CPT soundings and the soil stratification determined from soil borings. A summary of the results for pile capacity for each zone is given in Table 2. The pile capacities calculated are for the depths of the CPT's performed, final pile capacities are determined from evaluation of the above results based on pile load tests.

3.1. Pile driving criteria

Vibrex piles with 65 cm diameter are installed as the foundation of the residential buildings. Pile lengths for different zones of the construction area range between 35.0 m to 40.0 m. A minimum pile length is specified for each zone to guarantee that the pile is socketed to the bearing stiff clay or gravel strata.

The pile driving procedure is modeled and analyzed by means of wave equation analysis. The number of blows per 25 cm penetration representing a certain energy is specified as pile driving criteria. It is stated in the criteria that the pile is driven a minimum length specified and it

Table 2. Summary of Pile Capacities from CPT

Contractor / Zone	Pile Capacity-ϕ65 cm Vibrex			Pile Length (m)	Negative Skin Friction		Allowable Capacity (kN)
	Total (kN)	Skin (kN)	Tip (kN)		Depth (m)	for ϕ65 cm (kN)	
A	2750	2010	740	36.5	12.0	604	593
B	3400	2370	1030	35.0	13.4	680	738
C	3500	2460	1040	36.0	6.0	328	1278
D	3380	2270	1110	35.5	5.3	400	1029
E	3720	2670	1050	36.0	2.0	61	1604

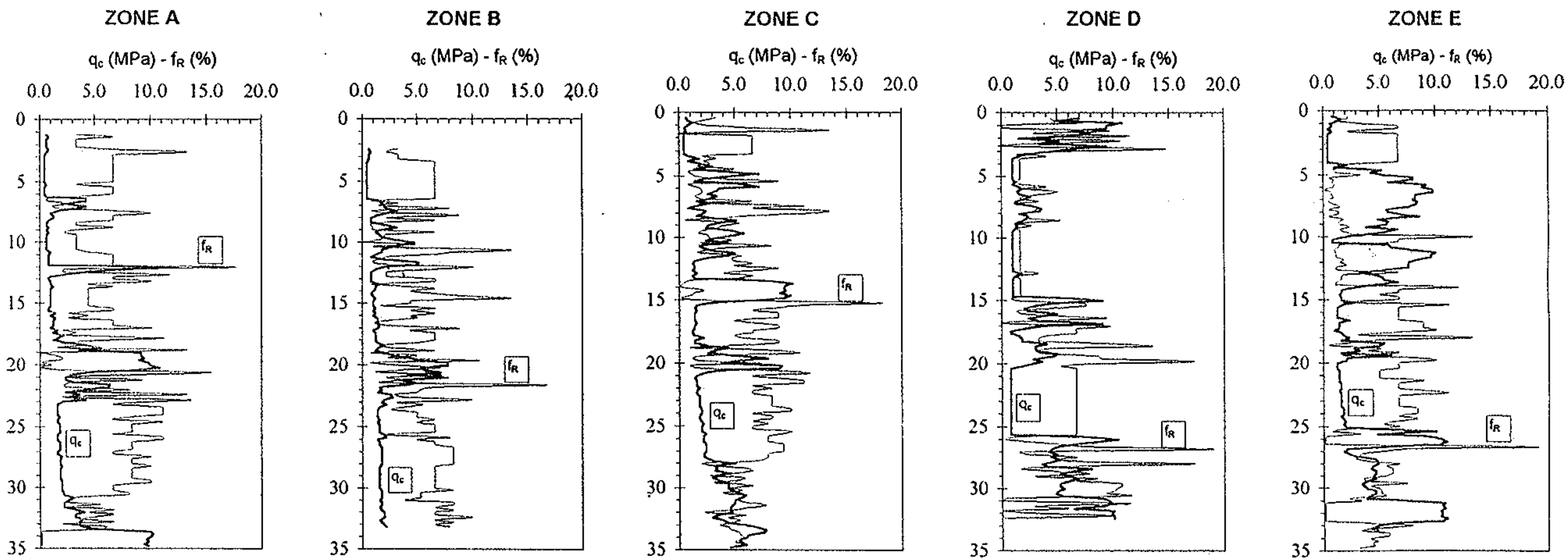

Figure 1. Typical CPT Soundings for the Zones of the Construction Area

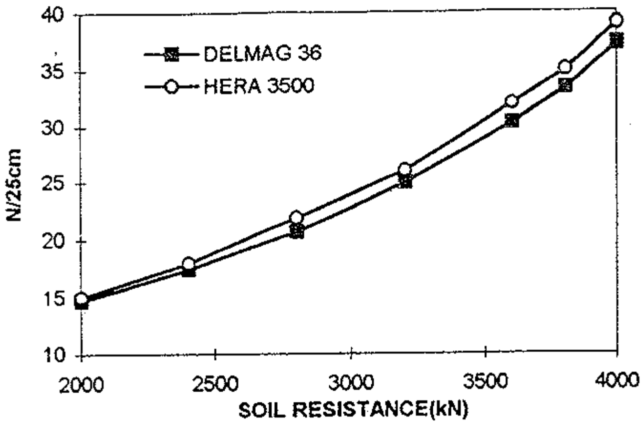

Figure 2. Variation of Soil Resistance with Blows / 25 cm Driving

is driven after this depth until the criteria for 25 cm penetration is achieved.

The results of pile driving analysis for two types of hammers used in the site is shown in Figure 2. The results of the wave equation analyses are presented as number of blows for corresponding soil resistance for 65 cm diameter pile (ZETAŞ 1994b).

3.2. Pile load tests

Test piles are produced at different locations in the construction area at the design phase of the project. Pile load tests are performed up to failure on test piles to evaluate the design assumptions.

The load settlement curve for pile load tests performed at various zones of the site are shown in Figure 3.

Two unloading runs are made to see the plastic settlement behavior of the pile and the pile is loaded up to failure to determine the maximum capacity. The load settlement curves are divided into two parts, first a flatter section which is considered to be the range of settlements where skin friction governs. The second section of the curve after the break until failure is a measure of the developed tip resistance (Fellenius, 1980).

The negative skin friction that is likely to develop on the piles is used in the determination of allowable pile load from pile load tests. The depth of the soft clay layer that causes negative skin friction for the piles is estimated from the soil stratification determined from borings. The estimated negative skin friction will result in a reduction in the capacity of the pile and the same amount will act as a load on the pile shaft. The safe capacity of the piles are calculated with a factor of safety against bearing capacity FS = 2. The results of the pile load tests for different zones of the construction area are summarized in Table 3.

3.3. Quality control tests

The quality of the piles are monitored at construction stage with several procedures. A

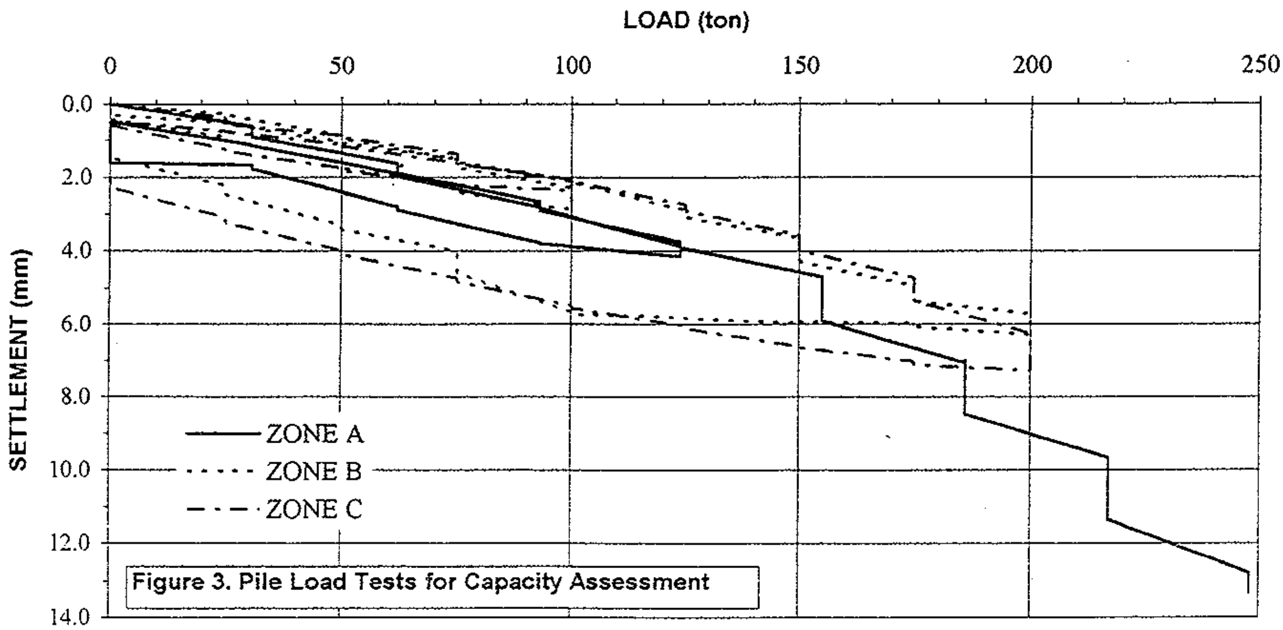

Figure 3. Pile Load Tests for Capacity Assessment

Table 3. Summary of Pile Load Tests

CONTRACTOR ZONE	PLT	L (m)	Q_{skin} (kN)	Q_{tip} (kN)	CPT no.	NSFD (m)	NSF (kN)	Q_{all} (kN)
A	MES3	34.0	1550	900	16	8.0	296	745
B	AKF1	33.0	1300	>700	14	15.5	550	>145
C	CEY3	37.0	1500	>500	1	7.5	243	>605
D	OTK1	34.0	2100	>900	8-9	3.0	95	>1310
E	GK1	36.5	1250	>1250	5	3.0	50	>1145

NSFD : Negative Skin friction Depth NSF : Negative Skin Friction

certain number of piles (1 out of 100) are randomly selected among the constructed ones and these are loaded to 1.5 times the design load and the results of the tests are evaluated to check the settlement and vertical load capacity of the constructed piles.

The load settlement curves for three zones of the area under construction are given in Figure 5. The evaluations of the test are given below.

- The tested piles safely carries the applied load which is 1.5 times the design capacity.
- The settlements of the piles under the applied maximum load is are in the range of 2.2 mm to 4.2 mm and the plastic settlements of the piles when it is unloaded are in the range 0.6 mm to 1.6 mm. Such settlements are within tolerable limits for the safety of the upper structure.

4. SOIL IMPROVEMENT AND MONITORING

The site is situated at a seimically active zone and this makes it very critical in terms of lateral pile capacity. The initial subsoil conditions resulted in inadequate lateral pile capacity and the construction area is loaded with a preloading embankment of 3.0 m height at the design stage to improve the subsoil conditions.

It has been compulsory to utilize the improved geotechnical parameters in the lateral pile capacity analyses and settlement columns are installed to assess the amount and rate of settlement. Settlements are measured with the vertical movement of magnetic rings within the settling layer.

A typical result of settlement monitoring is shown in Figure 5. Unfortunately the contractor was late in the installation of the instruments and the first readings were obtained 9 months after the construction of the fill. It is observed from the shown data that the settlement in the subsoil is about to stop and some heave is observed at the rigs close to the surface due to piling activity at a nearby location.

The settlement monitoring results have indicated that the settlement under the weight of the fill had been realized. The settlements have been monitored to be realized under the weight of the fill. Therefore, strength parameters of the improved subsoil conditions are used in the lateral pile capacity calculations (ZETAŞ, 1995).

5. SUMMARY AND CONCLUSIONS

The detailed site study using CPT in design of the foundations for a major housing development with 500.000 square meters floor

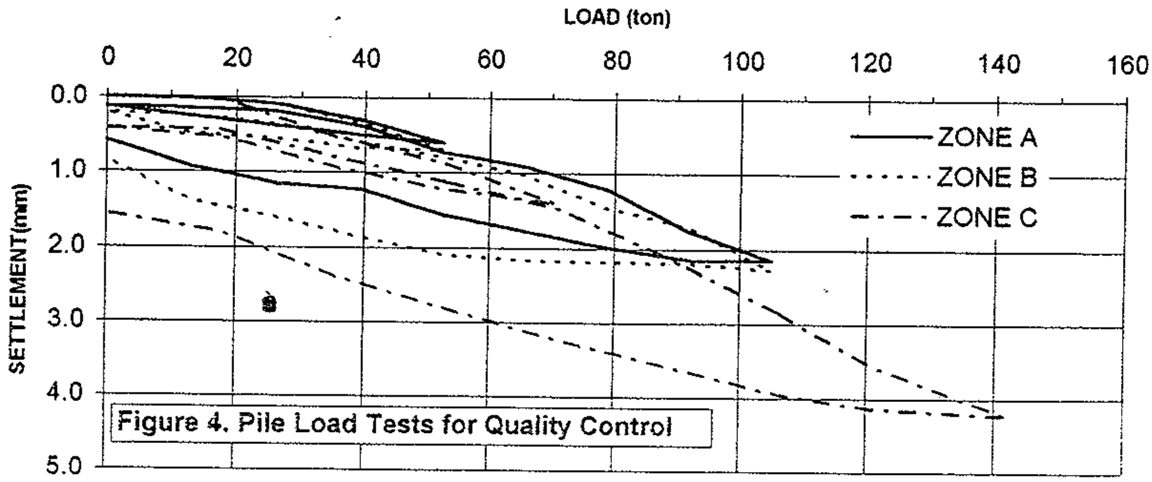

Figure 4. Pile Load Tests for Quality Control

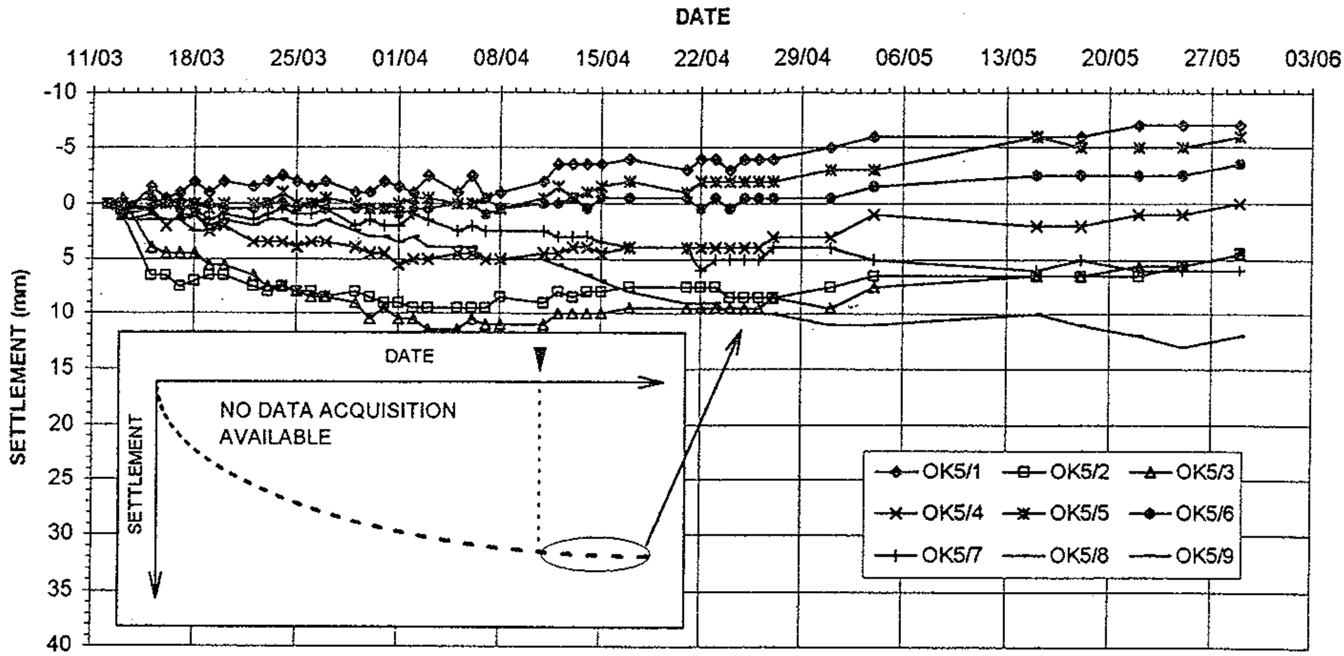

Figure 5. Settlement Column Monitoring Data

area in İzmir, Turkey are presented in this paper. Deep alluvial deposits govern the subsoil conditions. CPT soundings have been utilized in the determination of initial subsoil conditions and related pile design. At early stages various test piles are produced and loaded up to failure to estimate the ultimate pile capacity.

Vibrex piles in 65 cm diameter with lengths between 35 m and 40 m have been chosen for different zones of the construction area. Wave equation analyses have been performed to determine the driving criteria for the vibrex piles.

Subsoil conditions at the site are improved by means of preloading. The settlement under the fill is monitored by settlement columns and lateral load capacity of piles are estimated using the shear strength parameters of the improved subsoil conditions and the results of the CPT testing after the realization of settlement under the fill.

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