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An integrated CPT approach for a major housing development project

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ABSTRACT : Extensive site investigations and office studies have been performed for the subsoil characterization and geoenvironmental evaluations of a major housing development project with 500.000 square meters floor area in İzmir, Turkey. The performed investigations, covering detailed and complete studies from preliminary investigations at the initial stage of construction to final design and construction performance are presented. The investigations consist of two parts, the first part being the subsoil characterization and foundation design of the housing project. The second part of this integrated study is the contamination assessment and remediation studies performed for the closed municipal solid waste disposal site of the city, which is located near the extension area of the housing development. CPT has been performed both in the housing development site for subsoil characterization and in the solid waste disposal site for determination of the extent of contamination. Water and gas samples have been taken from various depths with a special device connected to the CPT penetration device. The results of the performed field and laboratory tests have been evaluated in the development of the remedial design project.

1. INTRODUCTION

Extensive site investigations and office studies have been performed for the subsoil characterization and geoenvironmental evaluations of a large scale housing development with a total of three thousand units exceeding 500.000 square meters floor area. The site is situated in İzmir, Turkey 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 development due to increasing value of land. Deep alluvial deposits govern the subsoil conditions. Soil borings and CPT testings have been performed for the determination of subsoil conditions.

The investigations consist of two parts, the first part being the subsoil characterization and foundation design of the housing project. Due to the presence of soft clay deposits to large depths and considerably large structural loads of 22 storey high buildings, 65 cm diameter cast in-situ driven piles with lengths between 35.0 and 40.0 m are installed. At early stages, 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.

The second part of this integrated investigation is the contamination assessment and remediation studies performed for the closed municipal solid waste disposal site of the metropolitan city of İzmir, which is located near the extension area of the housing development. The disposal site is located within one of the main extensions of the city towards north and partially occupies the extension zone of the housing development project, locally known as Mavişehir. The site has been used over the years for waste disposal by the municipality of İzmir. No precautions such as impermeable base liner and cover have been taken to isolate the waste and contamination from the environment. Although the site is closed to waste disposal, the storage area is a source of contamination and presents major environmental problems.

Now with the development of the city towards north, near the site, remedial measures have to be taken to prevent the major problems related with contamination. Integrated field and laboratory studies have been conducted to enable the solution of the existing environmental problem with determination and assessment of geometrical geotechnical and contamination parameters of the disposal site.

Cone Penetration Testing has been performed in the solid waste disposal site and the depth of contamination has been determined with the obtained conductivity measurements. Water and gas samples have been taken from various specific depths with a special device connected to the tip of penetration device. The degree of contamination has been systematically assessed with the laboratory testing of the retrieved samples. The results of the performed field and laboratory tests have been evaluated in the development of the remedial design project and it is expected that the geoenvironmental effects of the solid waste disposal site will be eliminated upon the implementation of the proposed design.

2. FIELD AND LABORATORY INVESTIGATIONS

2.1. Housing development site

Total of thirty nine borings were performed at the initial stage of investigations of the housing development area. 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 40 CPT's up to bearing strata have been performed to determine subsoil conditions and estimate pile capacity. The subsoil stratification present in the site with consequent foundation behavior is outlined below (ZETAŞ, 1994).

- A recent fill of 3.0 m is present which was constructed in order to establish working platform and reclaim land from the sea.
- 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 the recent 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.

2.2. Solid waste disposal site

The extent and geometry of the irregularly stored solid waste have been determined with topographical investigations performed at the initial stage of the studies. CPT has been conducted at 17 locations within the storage area, in order to determine the depth of the waste, subsoil stratification, corresponding geotechnical properties and parameters. The volume of the waste has been estimated to be 817,000 m^3.

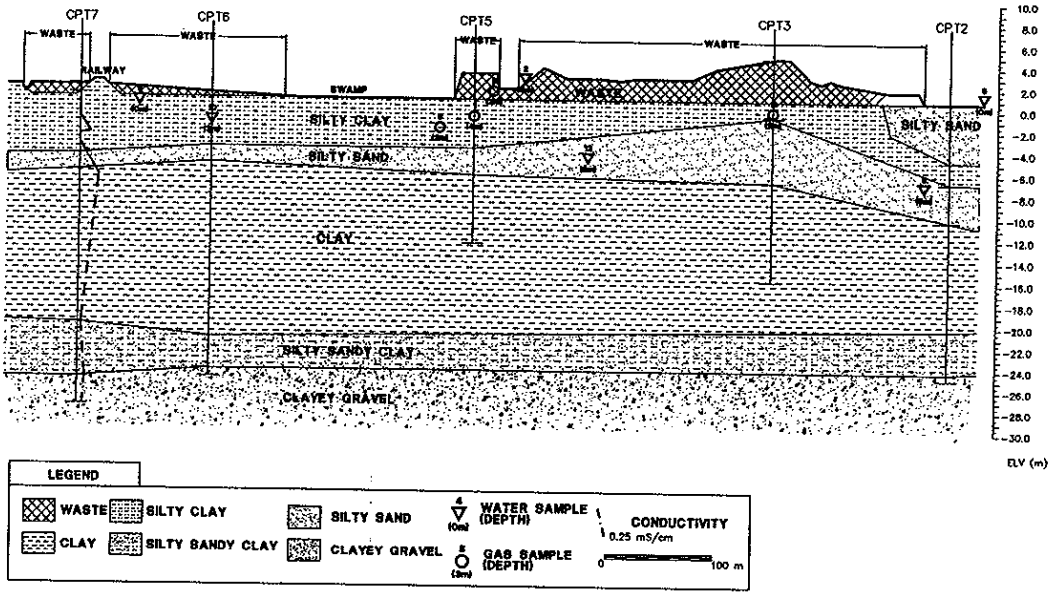

Figure 1. Typical geotechnical cross section

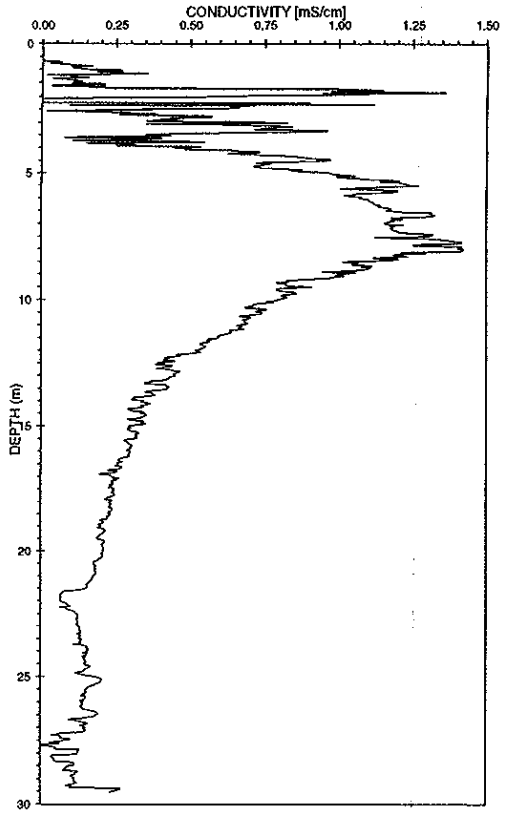

Figure 2. Conductivity measurement from a CPT sounding

A typical cross section of the waste and the subsoil is shown in Figure 1. The subsoil formation of the disposal site is similar to the subsoil of housing development area in terms of general characteristics. The average thickness of the waste is determined to be 3.0 meters, in some regions reaching the maximum thickness of 5.0 meters. Silty clay is located at the top on a continuous sublayer of silty sand. Below these a considerably thick clay layer and sandy clay overlying the bearing layer of clayey gravel located at a depth of 27.0-30.0 meters from surface is present, as seen in the cross section.

Erratically distributed sand and gravel lenses are present within the subsoil, creating vertical and horizontal connection between soil layers and increasing the rate of seepage within the subsoil. Such a geological formation is typical of the area, i.e., alluvial deposits of Gediz River.

In addition to conventional measurement of cone resistance and sleeve friction, conductivity of the soil has been measured with the CPT device to determine the extent of contamination within the subsoil. The presence of ions in the contaminated soil increases the electrical conductivity of the soil. Therefore the increase in the electrical conductivity in such areas is a measure of the extent of contamination within the subsoil.

A typical conductivity measurement at a CPT test is given in Figure 2. It is seen from the conductivity measurement that the first eight meters of the soil exhibits a relatively high electrical conductivity indicating the zone of contamination which extends to the clay strata within the subsoil.

Water and gas samples have been taken at test locations from various specific depths with a special sampling equipment connected to the cone penetration device (Durgunoğlu and Toğrol, 1995). The sampler is driven into the soil with the penetrometer, the filter is opened and with the aid of a peristaltic pump located at the ground surface the waste or gas (whichever is present at that location) is transferred into proper storage units.

The advantage of such sampling procedure over the methods associated with drilling is that the water or gas sample is characteristic of the certain depth at which the sampler is located. Therefore with the aid of such an equipment, the variation of contamination with depth can be determined with only one penetration. The degree of contamination within the subsoil and groundwater has been systematically assessed with the laboratory testing of the samples.

Chemical analyses have been performed on 12 water samples taken from various locations and depths in the area. The results of the analyses have been summarized in Table 1. Some criteria are also given for comparative purposes.

Concentrations measured in water samples are within the range and above the values given in column (b) which shows the concentration ranges measured in leachate from solid waste disposal sites in Wisconsin (Avcı et al., 1994). Especially, the chloride concentration is very high and reaches to 34000 mg/l in average. Such a concentration is an important measure of contamination in the subsoil and ground water.

Chemical oxygen demand (COD) has been measured to be 3450 mg/l in average. This value is far above the value 600 mg/l given in column (a) as waste water standard and is within the range given in column (b) as an example of leachate water.

It is seen from the comparison of the listed values of certain chemicals that groundwater has been contaminated with the leachate generation. Such a contamination makes it impossible to provide the drinking and domestic water from groundwater sources in the area which is planned to be developed for housing purposes. The high concentration of sulfate in the groundwater makes it necessary to take precautions against corrosive effects of the groundwater for the safety of underground concrete

Table 1. Analyses of Water Samples and Comparison with Available Criteria

Parameters	Various Criteria			Average of Samples
	a	b	c	
pH	6.5-10	5.4-7.2		7.93
Chloride mg/l	100	180-2651		33800
Total Phosphorus mg/l	15	0.1-117		1.40
Cadmium mg/l	2	B*-0.07	0.001	0.496
Total Cyanide mg/l	10			0.252
Total Chrome mg/l	5	B-1.0	0.05	0.313
Zinc mg/l	10	B-54	5	0.283
Chemical Oxygen Demand mg/l	600	1120-50450		3450
Total Nitrogen mg/l	75	4.7-1470		72
Sulfate mg/l	1000	8.4-500		2410
Lead mg/l	3	B-1.11	0.05	0.41
Oil mg/l	50			1780
Total Precipitating Solids mg/l				27.3
Total Solids in Suspension mg/l	350	2180-25873		755
Total Dissolved Solids mg/l		28-2835		105450

* B : below measurement limit
a : Waste water standards for storage units discharging to sea
b : Content range of chemicals present in solid waste disposal sites in Wisconsin, USA, (Avcı et al., 1994)
c : Standards for drinking water in Turkey

structures (foundation, piles, culverts) planned to be built near the area. Observation wells have been installed at CPT locations to monitor the groundwater. These may also be used for future sampling purposes.

The content of H_2S, CO_2 and CH_4 have been investigated in 11 gas samples taken from various locations of the site, especially from the waste itself. Carbondioxide (CO_2) is present in all samples. Except for 4 samples, the ratio of CO_2 is determined to be approximately 100%. Methane (CH_4) has been measured in 6 samples. The concentrations measured exceed 80% in 4 of the samples tested.

In addition, the organic content of the waste has been determined to be 23-37%, indicating that although decomposed to a great extent, the waste is still a possible source of gas generation in anaerobic conditions. Therefore, a gas collection and removal system has to be constructed for the removal of generated gas to eliminate possible problems on nearby housing and units.

3. DESIGN CONSIDERATIONS

Vertical pile capacity is estimated utilizing CPT soundings and final pile capacities are determined from evaluation of the results based on pile load tests.

Subsoil conditions at the site are improved by means of preloading. The settlement under the 3.0m 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.

A remedial project has been designed with the evaluation of the geotechnical model and contamination data to eliminate the present and future complications related to waste storage. The solid waste distributed over a large region within the storage space is planned to be compacted and stored in a limited area. A new storage geometry has been proposed to minimize the area of storage.

3.1. Pile design and load tests

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 cast in-situ driven piles. The final length of the piles are determined at the site during construction with the comparison of measured driving resistance and given criteria.

Cast in-situ driven 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.

Table 2. Summary of Pile Capacities from CPT

	Pile Capacity-ϕ65 cm			Pile	Neg. Skin Frict.		Allowable
Zone	Total (kN)	Skin (kN)	Tip (kN)	Length (m)	Depth (m)	ϕ65 cm (kN)	Capacity (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

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 is driven after this depth until the criteria for 25 cm penetration is achieved (Durgunoğlu et. al., 1995).

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. 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 as outlined in Table 2.

The load-settlement behavior of the piles are monitored during construction stage with pile load tests performed on a certain number of piles randomly selected among the constructed ones (1 out of 100). 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 3. 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.

3.2. Solid waste disposal site

With the evaluation of the geotechnical model and contamination data, an appropriate remedial project has been designed which will eliminate the present and future complications related to waste disposal.

The solid waste distributed over a large region within the storage area and approximated to be 817,000 m^3 in volume, is planned to be compacted and stored in a smaller area. The solid waste disposal site partially occupying the extension zone of Mavişehir Housing Development will be limited in extent and the remaining portions will be opened to housing development gaining extensive amount of land.

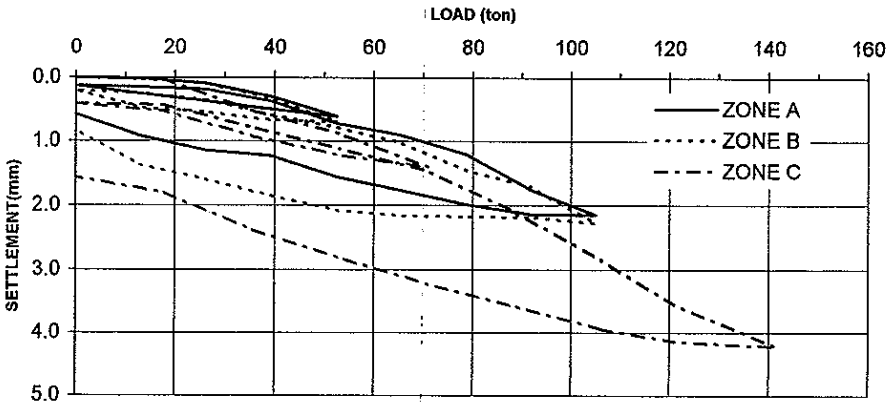

Figure 3. Pile load tests for quality control

The gas generation in solid waste disposal sites is divided into four stages. In the first stage named 'aerobic media' O_2 decreases to zero from 20% and N_2 starts to decrease from 80%, whereas the amount of CO_2 starts to increase. In the second stage taking place in anaerobic media the amount of CO_2 rises to 70-75% and H_2 rises to 20%, whereas N_2 drops to 10%. In the following stage (anaerobic media - formation of instable methane) CO_2 decreases to 45% and CH_4 rises from zero to 55%, whereas N_2 and H_2 diminish to zero. In the last stage (Anaerobic media - formation of stable methane) the CO_2 and CH_4 balance in 45% and 55% while no other primary components are present except these.

High amount of methane (CH_4) and carbondioxide (CO_2) has been measured in the solid waste disposal site. This condition corresponds to the fourth stage mentioned above as 'anaerobic media - formation of stable methane'. A proper leachate and gas collection system has been developed to eliminate the problems associated with the leachate and gas generation.

Stability and settlement analyses have been performed to eliminate the problems foreseen to be associated with the compacted waste disposal site. The geometrical configuration and height for the waste are optimized with the evaluation of these analyses.

4. SUMMARY AND CONCLUSIONS

Integrated studies including CPT and pile load tests have been performed in design of the foundations for a major housing development in İzmir, Turkey.

Cast in-situ driven 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 housing development 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.

CPT has also been utilized in the investigations performed for the assessment of the degree and extent of contamination of a solid waste disposal site which partially occupies the extension of the housing development. Water and gas samples have been taken from the waste and subsoil with a special device connected to the cone penetrometer. Laboratory tests have been performed on the samples and the extent of contamination has been assessed.

A remedial project has been designed with the evaluation of the geotechnical model and contamination data to eliminate the present and future complications related to waste storage. The solid waste distributed over a large region within the storage space is planned to be compacted and stored in a limited area.

A new storage geometry has been proposed to minimize the area of storage and the proposed design has been checked in terms of stability and settlement. The final storage scheme has been optimized with the evaluation of these analyses. A monitoring system consisting of settlement columns and piezometers has been proposed in the design to monitor the settlements and pore water pressures expected to occur during the construction of the compacted waste and are critical in terms of stability.

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