Static 2,100 ton load test for pile design at the Azrieli Center, Tel Aviv

Essai statique de pieux pour une charge de 2,100 t au center Azrieli, Tel Aviv

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ABSTRACT: This paper presents the results and analysis of a loading test carried out on large diameter bored piles at the Azrieli Center, Tel Aviv. The project includes three towers up to 186 m above street level, with column loads of up to 4,500 ton founded on load bearing elements and large diameter piles. The test was carried out on two cast-in-situ piles 0.7 and 1.5 m in diameter and 20 m and 24 m deep. The soil profile along the pile shaft consisted of an upper 10 m of clay covering partially cemented sand locally known as Kurkar. A correlation between the skin friction and the SPT is proposed. The skin friction recommended for the pile design (6 t/m^2) is considerably higher than any other known precedent in Tel Aviv. Level readings during the construction were in good compliance with the parameters used in the foundation design. The load test analysis was carried out together with the late Prof. G.A.Leonards.

RÉSUMÉ: On présente la conception et les résultats d'un essai statique de deux pieux, effectués dans le but de déterminer les paramètres nécessaires pour le profet des fondations des bâtiments du Centre Azrieli de Tel Aviv. Ce centre comprend trois tours d'une hauteur de 186 m, destinées à des bureaux et des espaces commerciaux. Les charges des éléments verticax de la structure atteigment 4,500 t. Les essais ont été effectués sur deux pieux de 0.70 et 1.5 m diamètre à des profondeurs de 20 et 24 m, forés à l'aide de bentonite. Le profil géotechnique du sol comprnd une couche supurieure d'argile de 10 m qui couvre une couche cimentée de sable calcaire (Kurkar). On propose une relation entre le frottement latéral et le SPT. On a recommandé un coefficient de frottement latéral 6 t/m^2 pour le calcul des pieux de, ce qui dépasse largement les valeurs couramment admises pour les sols de Tel Aviv. Les essais qu'on a decrit et la méthode de calcul des fondations ont été conçus en collaboration avec feu Prof. G.A.Leonards.

1 INTRODUCTION

The common practice of pile design in the Tel Aviv Kurkar was usually based on a skin friction of up to 3-4.5 ton/m^2 and an end bearing of about 200 t/m^2 depending on the pile depth. Kurkar is a local name for partially cemented sand: the quartz grains of the sand are cemented by carbonates into thin plates of sandstone mixing erratically with non-cohesive sand, thus producing a kind of "reinforced" earth. Large loads at the Azrieli Center in the tower columns made it necessary to evaluate more precisely the pile behavior under the relevant loading. Therefore it was decided to carry out static loading tests on two representative piles. An additional purpose for the tests was to rule out a possibility of collapse (as mentioned by J.Angemeer et al. (1975) and B.McClelland (1974) for driven piles) in the cemented sand thus weakening of the friction resistance.

2 GENERAL DATA

2.1 *Brief description of the project*

The Azrieli Center in Tel Aviv includes four underground parking lots for 3,400 cars, three mall floors of 50,000 m^2 and three towers of up to 50 residential and commercial floors, rising 186 m above the street level (Fig. 1).

The total area of the project reaches 345,000 m^2 located on a terrain of about 33,000 m^2.

The column of the three towers carry up to 4,500 ton and are founded on a combination of "H" and cross-shaped load bearing elements made by 3.4 m long and 1m wide grab (Fig. 10). A raft solution was ruled out because of the existence of a top saturated clay layer.

Parking areas were supported on bored piles 0.7 m to 1.8 m in diameter depending on the loads. The structural design was done by Eng.R.Balas – "Ben-Avraham Engineers".

2.1.1 *Location*

The site is located in the central part of Tel Aviv adjacent to the Ayalon highway.

2.1.2 *The soil profile*

The soil profile is composed of a top 10 m of clay of medium plasticity (with an SPT blow count ranging from 15 to 40) overlying Kurkar sand.

The Kurkar sand consists of sheets of calcareously cemented sand, typically 1-2 cm thick, and in-between non-cohesive sand lenses, typically 5-50 cm thick. The cemented sheets are of different sizes and are erratically located (Fig. 2). The Kurkar originates in sands that have undergone a carbonate cementation through water percolation.

The SPT blow count was 30-50 blows at the upper 8 m and 50 blows with nil to 13 cm penetration in the lower part.

The ground water table was found at the elevation of the lower floor (Fig. 3).

Figure 1 General view of the project

3 PILE LOAD TESTS

3.1 *General*

Only one large-scale load test (to 800 ton) was done in Israel in the past (1966), on bored pile using the Bentonite technique under the guidance of A.Komornik & G.Wiseman (1967) and Prof. G.Zeitlen; it was aimed to test the structural quality as well as the soil bearing parameters. A limit stress of 50 kg/cm^2 in the pile cross-section was recommended. The present pile load tests at the Azrieli Center were designed to more accurately evaluate the skin friction. The experience gained from these load tests resulted in a saving of about 30% of the originally estimated foundation budget.

3.2 *The load test arrangement*

The test counterweight set-up comprised 24 ground anchors installed in a ring configuration around the pile and pretensioned via a head unit by four 650 t hydraulic jacks.

The loading system was built, by Cementcal Co. Pressure cells were custom-made by German manufacturer Eberspacher and controlled by a system capable of loading each jack simultaneously but independently so that the pile head could be kept vertical if the pile started to tilt, or of loading equally in each of the four jacks.

The ground anchors, each 28 m long and inclined at 26°, were bonded over the bottom 15 m only. This provided a sufficient distance – as set out by the American standard test procedures followed for the test – between the ground stressed by the anchors and the test pile. According to Prof. G. A. Leonards, the actual influence of the anchor system on the test pile behavior was about 1% of the measured results.

Although nominally designed with a capacity of 150 t, anchors were made to limit extension under the load. After installation, each anchor was prestressed to 90 t, to verify performance and confirm the anchor extension under the test load.

Figure 2. Kurkar at the part of the site.

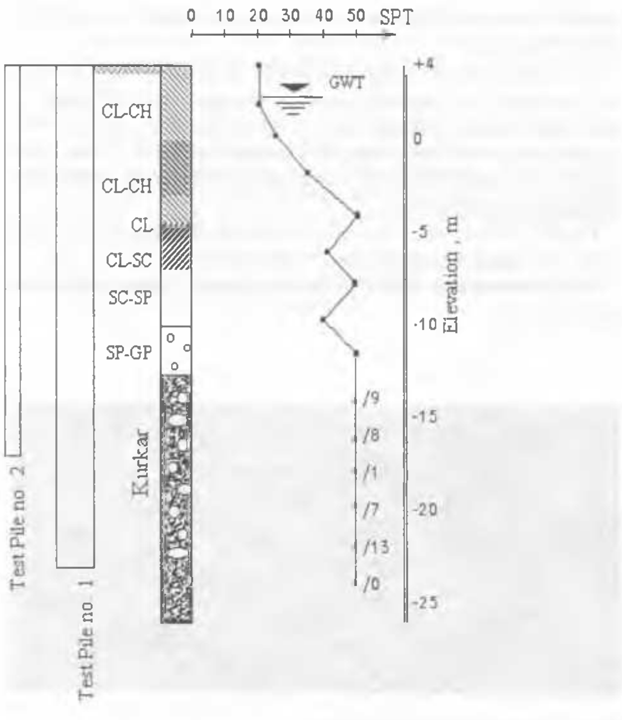

Figure 3. Soil profile.

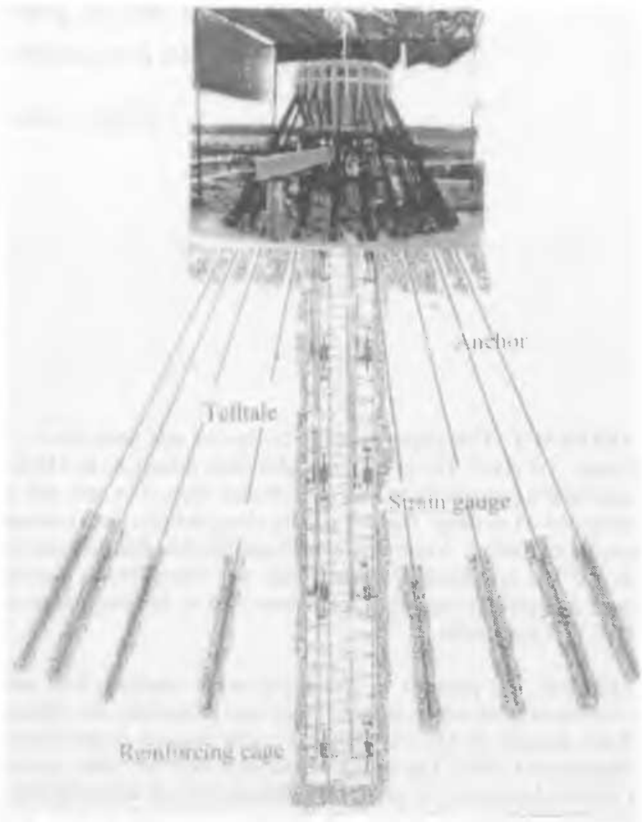

Figure 4. Scheme of load test arrangement.

3.3 *Test piles data and results*

The testing was carried out on two cast-in-situ piles, 0.7 m and 1.5 m in diameter and 20-24 m deep respectively, bored under Bentonite slurry. Pile instrumentation included sets of load cells, strain gauges and telltales at 5 m intervals down the pile shaft:

- Pile no. 1:1.5 m in diameter and 24 m long was loaded up to 2,100 ton.
- Pile no. 2 :0.7 m in diameter and 20 m deep was loaded up to 700 ton.

The load settlement curves obtained for the two piles are presented in Figure 5 - it may be seen that failure has been reached in both tests. The ultimate values of pile load were established according to different criteria as listed in Table 1:

Table 1. Ultimate load in the test piles.

Ultimate load, ton, according to	Pile No 1	Pile No 2
Kulhawy	2250	700
Davisson	1800	600
Chin	2400	802
NY Code	>2100	>800

The skin friction distribution obtained from the strain measurements (pile no. 1) is presented in Figure 6. The measure-

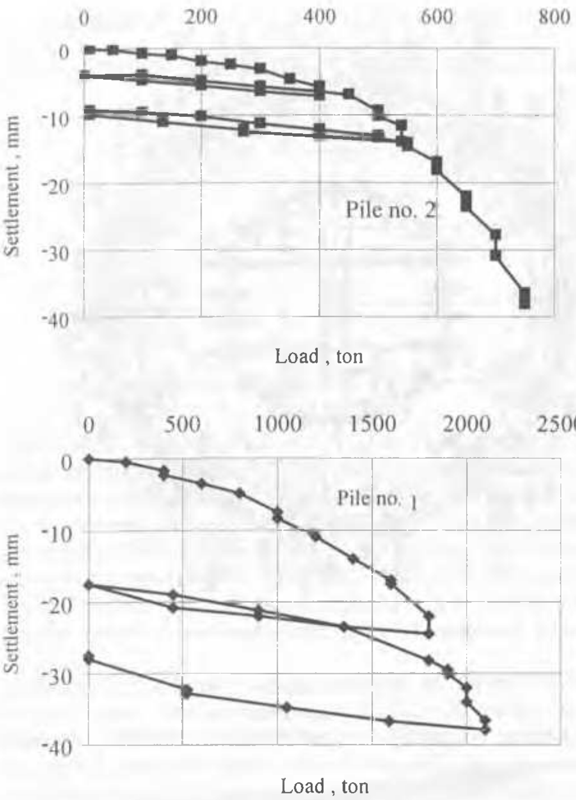

Figure 5. Load-settlement curves for pile no. 1 and 2.

ments of strain gauges at different load stages were compared with telltale readings and the comparison showed a satisfactory compliance of the results (Fig. 7), therefore confirming the validity of the measurement system.

From the curve in Figure 8 (the ratio between the tip pressure and the tip settlement) Kv value was found to be about 14,000 t/m^3 (or 14 kg/cm^3). This is a reasonable value for dense sand but a low one for cemented sand, showing that any end bearing parameter in the Kurkar should be taken with caution due to the potential occurrence of cohesionless sand interlayer. On the other hand, the cemented layers increase the average skin friction along the shaft.

The curve in Figure 9 demonstrates that the friction approaches the ultimate value where the butt load increment approaches the tip load increment.

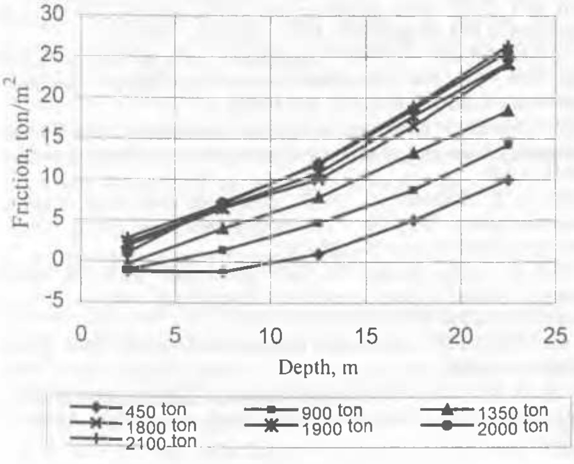

Figure 6. Distribution of friction along the pile shaft.

4 DISCUSSION OF THE RESULTS OF TEST LOADING

4.1 *Using results of the pile tests for Load Bearing Elements*

The problem of load transfer by Load Bearing Elements was analyzed by H.Kienberger (1975). The average skin friction along the pile shaft and the load bearing element differed by only 2% and could therefore be reckoned as practically the same at the

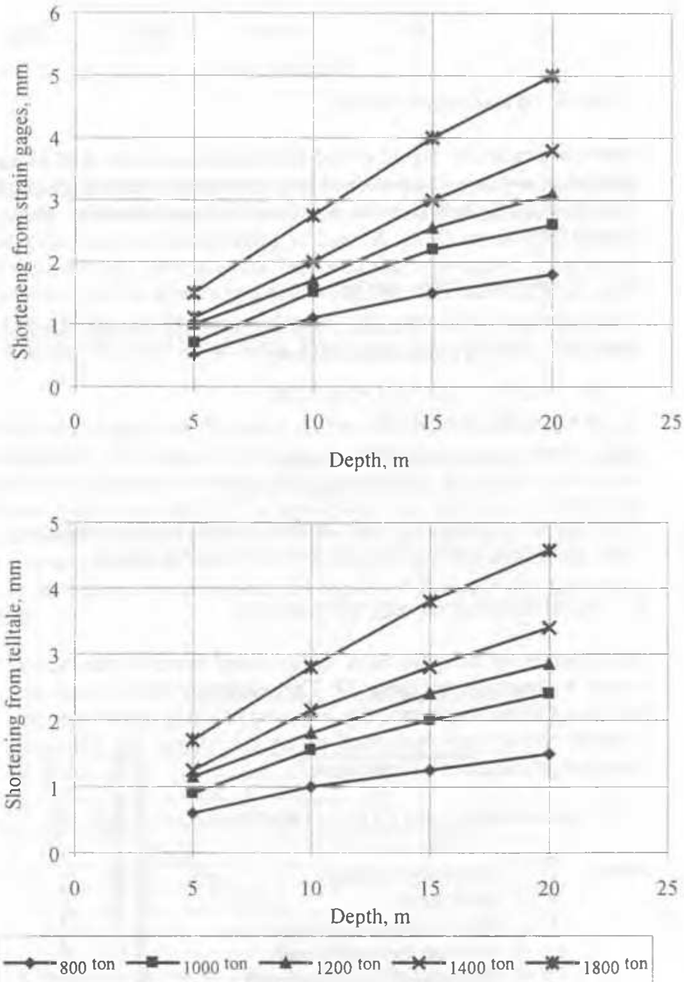

Figure 7. Pile shortening based on strain gauges and telltale measurements.

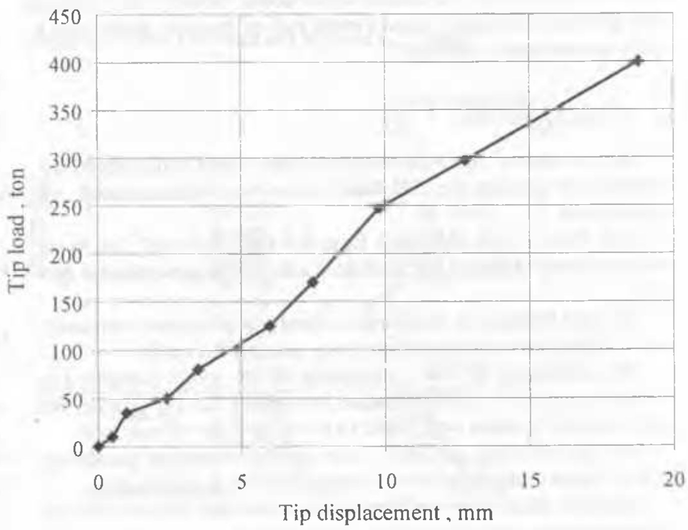

Figure 8. Tip load versus tip displacement.

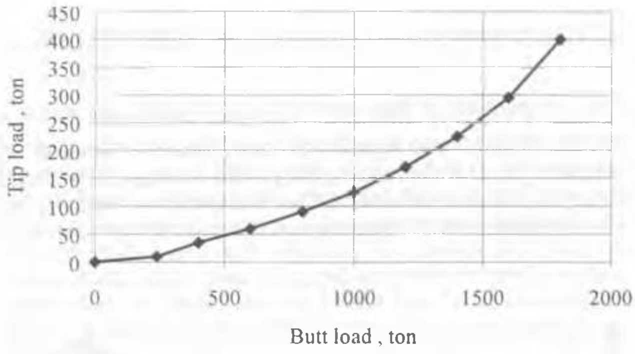

Figure 9. Tip load versus butt load.

same base pressure. Based on the above conclusions as well as on general experience, the results obtained in the pile tests were used for the design of both piles and load bearing elements in the Azrieli Center.

4.2 *Prediction of skin friction*

A correlation for the ultimate friction, as found through the test piles, with SPT, is proposed as follows:

for $N \geq 50$ $f_S = 10\,(1 + \log N/50)$
for $N \geq 50$ $f_S = 0.2N$,

where N - uncorrected SPT results,
f_S - ultimate skin friction in ton/m^2

For allowable values of skin friction where no test loading is done, a factor of safety FS=3 is recommended for design.

5 MONITORING OF SETTLEMENTS

The observation of settlements in the round tower of the Azrieli Center is presented in Figure 11. The settlement at the maximum load was 1.4 cm. Analyzing the behavior of a pile group acting as a virtual raft at the lower third of the pile depth, the following "modulus of elasticity" is obtained:

$$E = I\sigma B/\delta = 0.88 \times 55 \times 44 \,/\, 0.014 = 150{,}000\ t/m^2\ (15{,}000\ kg/m^2)$$

where E - elasticity modulus
δ - settlement
I - shape influence factor
σ - pressure below the raft
B - diameter of the virtual raft

This result might be compared to the raft of Aviv Tower on top of a similar Kurkar in Tel Aviv where the observed settlement showed an elasticity modulus, E, of about 70,000 t/m^2. Taking into account the depth of the virtual raft of the pile group, the E value is reasonably doubled.

6 CONCLUSIONS

The increase of the routine pile design values could not be accomplished without the full-scale extensively instrumented pile loading test.

Skin friction was increased from 4.5 t/m^2 to 6 t/m^2 due to the reinforcement effect of the Kurkar sheets on the general sand profile.

The end bearing in the Kurkar should be designed cautiously as a cohesionless sand inter layer may govern the result.

The settlement of pile foundations in the group compared to the settlement of a raft foundation on similar Kurkar ground and under similar loading was found to be in the order of one half.

No signs of either collapse of the cemented sand or weakening of the friction resistance were found under the design loading.

Geodetic monitoring of the tower settlement verified the design parameters and showed no indication of any significant difference of bearing capacity between piles and Load Bearing Elements.

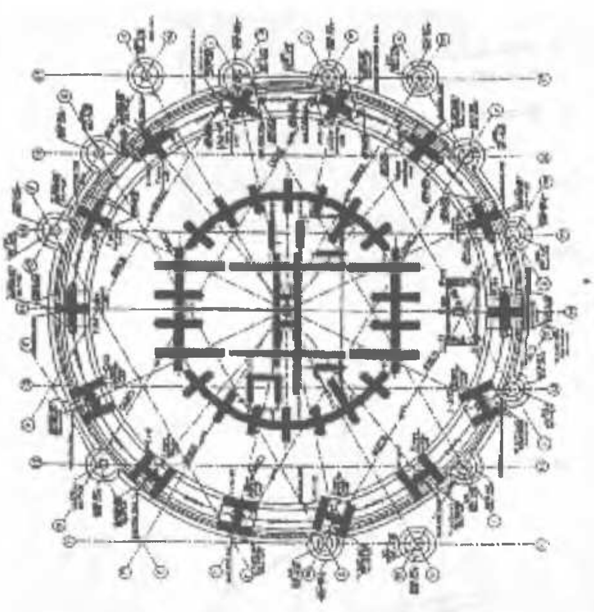
Figure 10. Foundation layout.

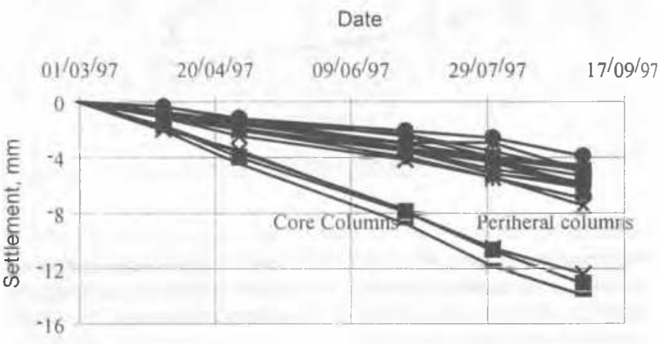

Figure 11 Settlements of the round tower upon construction.

The distortion between the core of the tower and its peripheral columns was no more than 1:1350, while the in-between floors obviously showed no distress – thus leaving a margin of safety for some future additional settlement.

7 LIST OF REFENCENCE

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