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Driven cast in situ piles in sand - case history

La technique VIBREX des pieux battus -case history

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ABSTRACT
Vibrex piles - i.e. driven piles, cast through a steel “casing” with a lost shoe - in groups, were used for the Yakum “Industrial Park” project in Israel. Analysis of field static and dynamic testing of the piles was carried out. The piles 50-60 cm in diameter and 14-20 m deep, near existing buildings, were driven through clayey soils penetrating into a dense sand layer. Prior to the construction, the influence of vibrations due to the pile driving was measured on the existing buildings and found to be within acceptable limits, thus establishing the allowable penetration energy during the construction. Load tests were carried out on adjacent piles installed sequentially to investigate the densifying effects caused by the driving procedure. Static pile loading tests results were analyzed and used as a basis for the foundation design and for correlation between dynamic and static data. It was found that Standard Penetration Test results, as well as dynamic pile-driving formulas, could be used with caution, for evaluating the pile bearing capacity. Correlation of these testing methods with the static pile loading contributed to reducing the pile length in the project. Pile Dynamic Analysis with Blow Count when driving and CAPWAP results proved to be compatible with the static loading results.

RÉSUMÉ
La technique VIBREX des pieux battus avec un “couvercle perdu” a été utilisee recemment en Israel dans un projet realise au parc industriel de Yakum. L’exécution a été précédée par des essais statiques et dynamiques sur des pieux ayant des diamêtres de 50 - 60 cm et des longueurs de 14 – 20m, pres des batiments existants. Les pieux ont traverse des couches argileuses, en pénétrant dans une couche sableuse ayant une forte densité.
L’effet des vibrations accompagnant l’enfoncement des pieux a été vérifié en mesurant les vibrations des batiments.
On a effectué des essais afin d’établir l’effet des pieux sur la densité du sol. Les résultats de ces essais ont été utilisés dans le projet des fondations.
Ce procédé a permis de reduire la longueur des pieux choisie dans le projet préliminaire.
Les résultats des essais dynamiques (PDA, CAPWAP) ont été compatibles avec les resultats des essais statiques.

1 INTRODUCTION

At present, the use of pile foundations is a most common solution in densely built urban areas.

A relatively new technology of "Vibrex" driven piles is gaining popularity in Israel and this demanded a research of the pile behaviour regarding a single pile capacity as well as group interaction problems.

In this regard, pile loading test results were correlated to the soil investigation data. The analysis was aimed at finding out if the soil data was enough for prediction of the pile behavior, as well as to study aspects of behaviour of piles in groups.

Vibrex piling is a rather new technique in which a temporary steel casing pipe is driven with a lost shoe and the pile concrete is cast through the casing pipe after reaching the required depth.

The study was carried out in the site of Yakum "Industrial Park" where hundreds of Vibrex piles were installed adjacent to industrial and office buildings.

This study was aimed at interpreting the results of the static and the dynamic pile testing regarding the "Vibrex" technology.

2 SITE DESCRIPTION AND SOIL PROFILE

The site is situated in the coastal plain area, south of the town of Yakum, in a former agricultural area, and about 0.5 km from Rishpon stream. The ground surface at the site is at an elevation of about +9 m above sea level.

The design elevation of the basement floor was +1.7 m, so that an excavation up to 7.3 m was carried out. The site, 110x160 m in dimensions, was investigated by routine testing. Soil classification and SPT were performed in six borings to a depth of 20-25 m. An additional test boring was carried out at the location of the test piles.

The soil profile was composed of a lean brown clay layer (with some reddish-brown clayey sand lenses) to depth of about 15 m. The clay was underlain by a dense, clean, uniformly-graded fine sand, sometimes with some silty sand, to the bottom of the borings. The SPT results ranged in the clay layer $N_{SPT}=15\div34$ blows/foot and in the sand layer $N_{SPT}=25\div79$ blows/foot.

The ground water (GWT) was found at an absolute elevation +1, and perched water was found during the test boring at an absolute elevation of +3 (Fig. 1).

The proposed foundation for the design loads of 100-200 tons was 14-19 m long Vibrex piles, 0.5-0.6 m in diameter, driven through the clayey soils and penetrating well into the dense sand layer.

The butt level of the project piles was designed at absolute elevation of ~+1.7. The majority of the project piles were designed in groups including 2-4 piles.

3 PILE TESTING PROGRAM AND TEST PILES

Piles were tested as follows:
(1) Influence of the vibrations due to the pile driving on the adjacent buildings
(2) Static pile testing and study of interaction between adjacent piles
(3) Dynamic pile testing
(4) Statnamic pile testing

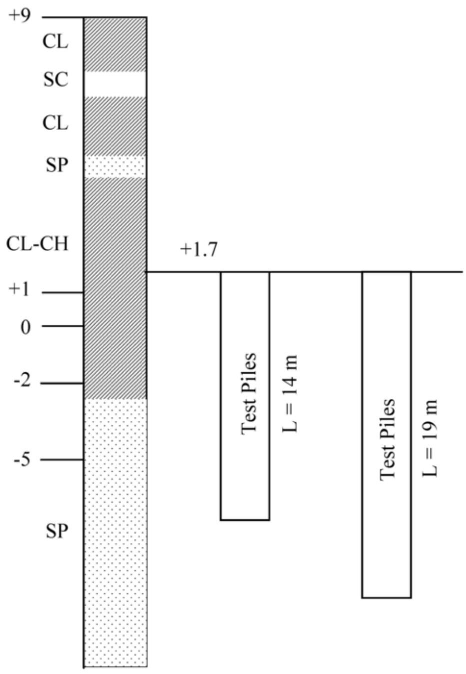


Fig. 1. Soil profile and test piles location

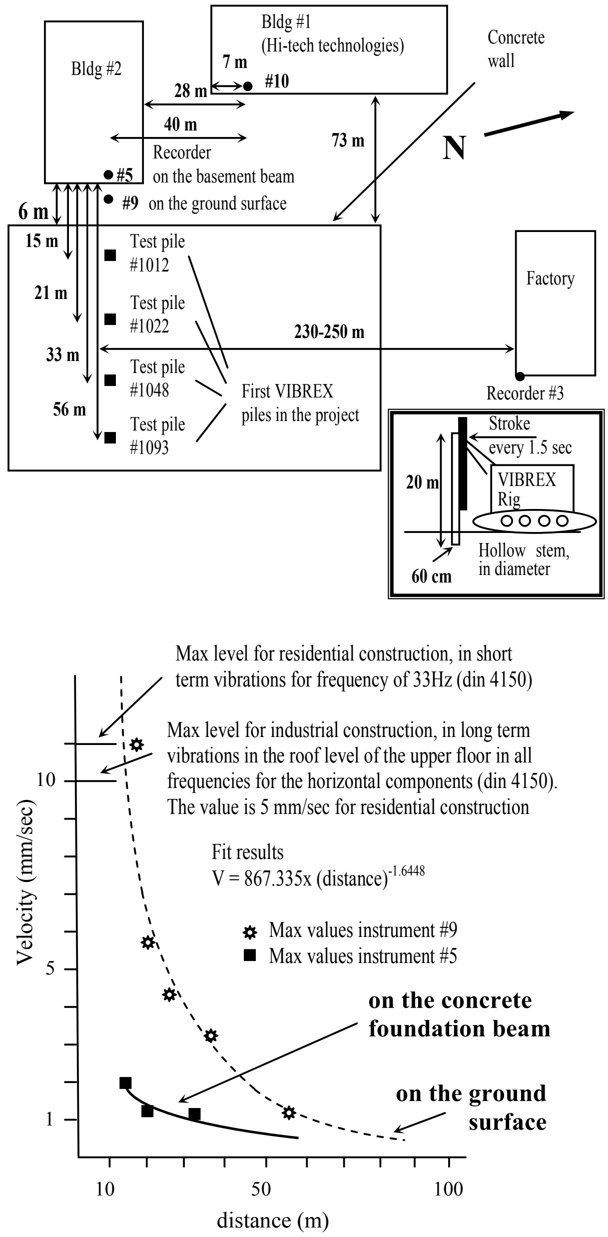
Test Piles:
Test piles were the working piles in the project, 14-20 m long. The pile pipe driving took 20-30 min and the total duration of one pile installation including casting was approximately one hour.

4 MONITORING OF VIBRATION PROPAGATION DUE TO PILE DRIVING

In order to approve or optimize the hammer parameters and driving energy prior to the intensive construction, it was decided to measure vibrations induced in the existing, near-by buildings. Five 61 cm diameter piles (nos. 1012, 1022, 1048, 1063 and 3013) were driven to a depth of 20 m in the site (the first piles in the project). Meanwhile, four geophones (particle velocity recorders) were installed on the foundation beams of the buildings (as marked at Fig. 2) and as well on the ground surface for the vibration monitoring.
The measured velocities on the concrete foundation beam due to pile driving were below a level of 2 mm/sec - these values provided full compliance with the requirements of the code requirements (the most severe code on vibration: DIN 4150 (part 3) for “sensitive” buildings and dwellings. Therefore, the parameters of the pile driving were approved as not interfering with the surrounding buildings (Fig. 3) and the allowable penetration energy was established for the construction.

5 STATIC PILE LOADING

The main objective of the static loading test (Jardine et al., 2001) was to establish the axial bearing capacity of a test pile "A" (50 cm diameter and 18 m long Vibrex pile) with two "interfering" adjacent Vibrex piles, installed sequentially, to investigate the densifying effects caused by the driving operation, in the groups Fang, 1999).



(2b)

Fig. 2. Location of the geophones (a) and results of velocity measurements (b)

Fig. 3 General view of the site and adjacent structures

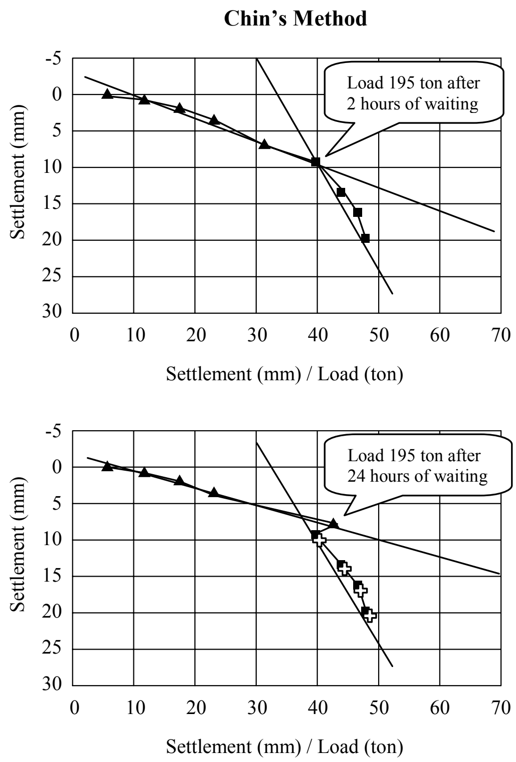


Fig. 4 "Interfering" piles' (C1 & C2) – static loading

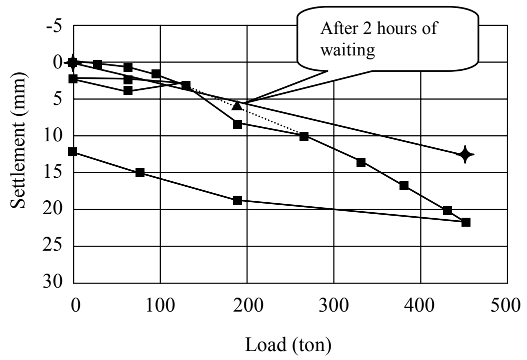


Fig. 5 Static loading of test pile A

The "interfering" piles were also 50 cm diameter and 18 m long:

- pile C1 – was driven one hour after the casting of pile A, with a spacing of 2 m (that is four diameters),
- pile C2 was driven 24 hours after the installation of pile A, with a spacing of 1.25 m (that is 2.5 diameters).

The requirement to carry out the pile testing with the "interfering" piles was dictated by the expected construction procedure and expected short time delays between installation and casting adjacent piles – the majority of the foundation piles were closely positioned in the design plans.

The results showed no significant influence due to the "interference" on the piles bearing capacity between these adjacent piles (Fig. 4) thus approving the future construction procedure in the site regarding the timing of pile driving in groups.

During the construction, densifying effects prevented the piles in the groups to reach an equal depth of penetration. In this regard, according to the approach of neutral plane ((after Fellenius, see in Winterkorn & Fang, 1975), the bearing capacity and settlements of the piles may be different, but owing to the same densifying effects, their design bearing capacity (up to 100 ton) was provided.

Test pile A showed good performance and a sufficient bearing capacity in static compression (Fig.5). The load distribution with pile depth, as well as skin friction distribution along the pile shaft may be seen at Fig. 6. It is demonstrated that at the pile ultimate load of 455 ton only 100 ton (approx. 22% of the total load) reached the pile tip level, while at the design load of ~200 ton, only 30 ton (approx. 15% of the total load) reached the pile tip.

6 DYNAMIC AND STATNAMIC PILE TESTING

A comparison of ultimate total pile capacity estimated from dynamic and statnamic tests is given in Table 1 and shows good compatibility of the results. It should be noted that the result of the static loading of test pile A (455 ton) lies in between the dynamic and statnamic estimates, with a deviation of 10-13%.

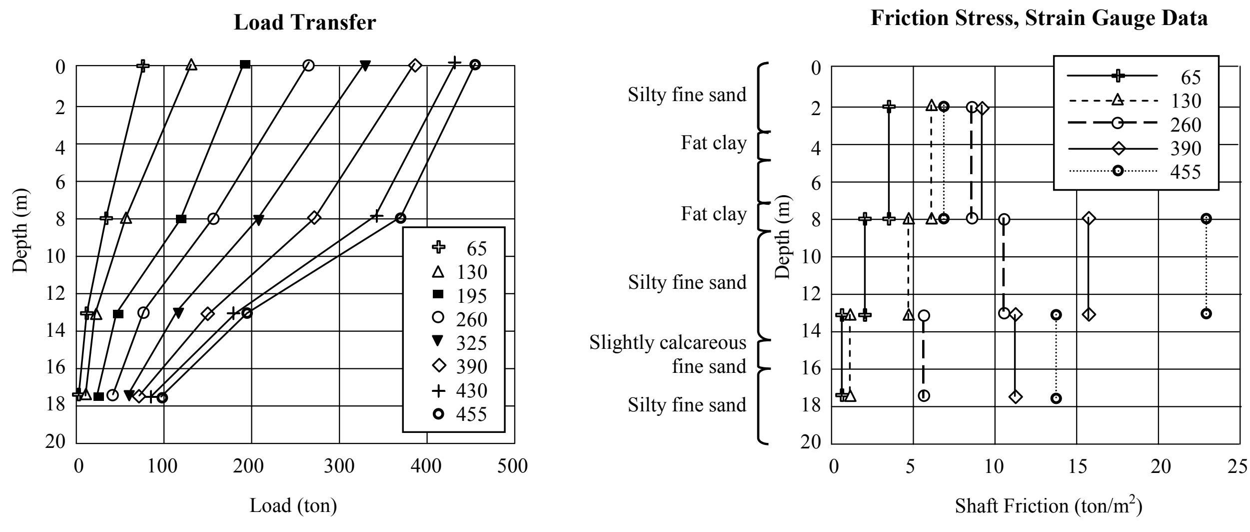


Fig. 6 Static loading response of test pile A

Table 1: Pile Driving Analysis (PDA) and Statnamic (TNO) results

Pile no.	A	1103	1191	1131
Length, m	18	15.8	13.5	13.8
PDA (total ultimate capacity), ton	513	593	448	384
Statnamic loading (total ultimate capacity), ton	411	432	403	380
Static loading (total ultimate capacity), ton	455			

As measured during statnamic testing, the tensile stress in the piles was very low (up to 8.1 KPa) during the driving thus assuring the piles' drivability without any damage.

7 PILE DYNAMIC ANALYSIS RESULTS

Five piles were constructed with a blow-count record versus the pile driving analysis (Table 2).

Table 2: Pile Driving Analysis (PDA) versus Blow-count

Pile No.	1043	1044	1045	1189	C1
PDA (total ultimate capacity, ton)	320	350	315	450	384
Blow-count (at the last meter)	74	64	77	150	180

The dynamic testing was carried out by the Case Method (Dunnicliff, 1988), involving analysis of the stress wave during driving (using a pile driving analyzer for measuring of strain and acceleration at the pile butt).
The movement of the pile into the sand layer was measured to be only 2-3 mm (being not at failure) indicating the effectiveness of the method and feasibility of pile driving without damaging the piles.

8 SPT RESULTS AND DYNAMIC PILE FORMULAS

Both analysis of SPT results, and the use of traditional pile driving formulas produced a large divergence of calculated pile capacities. The variation of estimated pile bearing capacity (for the statically loaded pile) obtained from the different pile formulas was 200-300%. Use of SPT results for bearing capacity calculations also led to divergent results, thus demonstrating that both pile driving formulas and SPT results should be used for Vibrex piles with great caution, and only after their calibration with a static pile loading test.

9 CONCLUSIONS

A reliable prediction of the bearing capacity of Vibrex driven cast in-situ piles is difficult if only dynamic testing is used. Therefore, multi-method testing is recommended for a large project.

Pile spacing of 2.5 x pile diameter – with a time delay of 24 hours, and spacing of 4 x pile diameter – with a time delay of 1 hour, were found not to lessen the pile bearing capacity. Based on this experience, the construction sequence time-table was established for the project.

The application of Vibrex piles, accompanied with PDA and Blow-count analyses, provided a good savings in the construction.

It was found that pile driving formulas should only be used with considerable caution (due to 300% divergence of their results) and cannot serve as the only guideline of the Vibrex driven pile bearing capacity.

The densifying effects which occur during driving prevented the piles in groups to reach an equal depth of penetration; however their bearing capacity was not decreased.

The Vibrex piling method, including pile groups, was proven to be reliable and cost effective pending soil investigation that should be accompanied by static and dynamic loading tests.

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