QUALITY CONTROL AT PIER NB-2

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A. Komornik, Faculty of Civil Engineering, Technion, Israel Institute of Technology
J.M.Amir, Foundation Control Institute, Ramat Hasharon, Israel

ABSTRACT
The paper describes the chain of events related to the construction of the piles carrying pier NB-2 of the Ayalon Highway over the period April to September 1992. From the start, construction of the piles was accompanied by various difficulties. As a result the integrity testing programme was extended to include practically all the methods presently available: Sonic echo testing, cross-hole utlrasonic logging, gamma-ray scattering, open excavation and core drilling. After serious defects were found in six of the nine piles, the client decided on remedial measures. These consisted of pressure grouting through holes that were specially drilled, as well as through the same steel tubes previously installed for testing. Subsequent integrity testing showed little effect, but Statnamic load testing, carried out on all the piles, demonstrated their capacity.

INTRODUCTION

The Northbound (NB) bridge is part of the Ayalon Highway which crosses Tel Aviv in the North-South direction. The foundation for Pier NB-2 of the bridge includes nine bored piles, cast in-situ with bentonite slurry. A field laboratory ensured compliance of both concrete and slurry with the specifications, and work was supervised by qualified personnel. The original integrity testing methods included both sonic method and cross-hole ultrasonic testing, the latter carried in tubes specially installed for this purpose.

In the following sections the paper describes the piles and the soil profile, summarizes the integrity testing findings, outlines the repair works and then comments on the results of the final acceptance tests.

SOIL PROFILE

The soil profile at the site, as obtained by rotary drilling (Figure 1), consists of alternating layers of hard highly plastic clay and Kurkar (Calcareous slightly cemented sandstone, typical to the eastern Mediterranean coast). Ground-water level was found in the upper Kurkar layer, at a depth of 11 metres.

DESCRIPTION OF FOUNDATION

Design

Pier NB-2 consists of two concrete columns (A and B). According to the original design, each column was to be supported by four bored piles with a 7 m square concrete cap. The piles were designed for uniform diameter of 1.5 m and a length of approximately 23 m. The maximum design load per pile is 3.5 MN.

The piling specifications prescribed boring with bentonite slurry and 30 MPa concrete to be cast with a tremie pipe.

Construction

The piles were constructed inside an excavation, with rather limited working space, during the first half of April 1992. Four steel tubes, each 63 mm in diameter, were concreted in each pile. The tubes were closed at both ends with steel plates and tied at equal spacing inside the spiral reinforcement. After construction problems plagued the first pile bored in group B, the structural engineer decided to abort this pile, enlarge the cap and reinforce the group by adding a fifth pile (No. B5) under the column (Figure 2).

INTEGRITY TESTING

Due to space constraints and the construction method, the pile heads were covered with drilling mud which made them inaccessible to testing equipment. As a result, the integrity testing programme had to be carried out in stages. Altogether, the following techniques were used:

Sonic Echo Testing

A few days after completion, the head of pile B4 was exposed and the pile was tested by the sonic echo method. The resulting reflectogram (Figure 3) indicated no irregularities.

Ultrasonic Cross-hole logging

Towards the end of April, as soon as the debris and the drilling mud were removed and the steel tubes opened and straightened, all piles were tested by analog ultrasonic equipment. The existence of four tubes in each of the piles enabled altogether the testing of six sections per pile, with almost full coverage of the pile volume. As testing operations progressed, it became obvious that pier NB-2 is afflicted by irregularities, with serious defects, sometimes at two or three distinct levels, observed in six of the piles (Table 1). Since defects were found in both the sides and the diagonals of the tube layout, it was concluded that defects exist not only close to the skin, but also inside the piles.

Open Excavation

The decisive (and most convincing) proof for the existence of defects in the piles was obtained when early in May the upper part of pile B2 was exposed by open excavation to an approximate depth of 3.5 metres. In the Northern side of the shaft, where the test indicated the existence of a defect, a large cavity was found, having a surface area of approximately 0.5 m2 and penetrating between 200 and 300 mm into the pile (Figure 4).

Gamma Ray Scattering

Although largely replaced by ultrasonic techniques and rarely used, gamma ray scattering was ordered by the engineer as a supplementary test. Essentially these tests, performed towards the end of May, gave results which independently corroborated the findings of the ultrasonic cross-hole logging.

Core Drilling

In the beginning of July, the contractor was ordered to drill and obtain a core through pile A1. Except for a minor defect at a depth of seven metres, the concrete core was fairly continuous. Below the bottom of the pile a 300 mm layer of sand mixed with bentonite was discovered, in which the split-spoon sampler sank under the weight of the rods. Subsequently, a Standard Penetration Resistance of more than 50 blows was obtained.

REPAIR WORK

After thorough preparations, repair work using neat cement grout, started in the beginning of July and took about two weeks to complete. The grouting operations included three categories:

Repair of the Pile Stem

To reach any cavities that are totally included in the pile, a system of holes was drilled in the piles to various depths. Drilling techniques included NX core drilling which enabled visual examination of the concrete, and 63 mm dia. percussion drilling which combined high speed with low cost. In addition, the contractor also utilized the steel tubes that served for cross-hole logging, making use of a special tool to pierce the tubes at any desired level (Figure 5). Initially all holes were flushed with water under high pressure and then a water-cement mix was pumped under pressures of up to 1 MPa. In many cases the extent of the defects caused the grout pumped to a given hole to exit from other holes.

Repair of the Pile Skin

To repair the cavities on the pile skin, 76 mm dia. holes were drilled in the soil surrounding the pile using a spiral auger. The holes, which did not reach below the ground water level, were filled with gravel, except for the upper two metres in which a steel pipe was concreted. Again, channels were found between these holes and the holes drilled inside the pile.

Repair of the Toe

The results of the Standard Penetration Tests carried out under the base of pile A1 proved that for the piles on the given site there is no reason to expect any toe resistance without some remedial measures. For this purpose the bottoms of the steel tubes were pierced, and the toe pressure-grouted.
A summary of the grouting operations is presented in Table 2.

REPEAT INTEGRITY TESTING

In an attempt to evaluate the effectiveness of the repairs, the treated piles were subject to both sonic and ultrasonic testing.

The sonic tests produced fairly normal reflectograms, showing no irregularities and giving no evidence to the extensive treatment to which the piles were subjected.

As to the cross-hole logging, direct before-after comparison was difficult since in the meantime the old analog equipment was replaced by a new computerized unit. Nevertheless, the test results (Figure 6) again showed little effect of the repair.

STATNAMIC LOAD TESTING

To verify the capacity of the repaired piles, the owner decided to subject the piles to a loading test. Due to time and space constraints, the Statnamic loading test appeared the only feasible alternative. All nine piles were tested during one week in September, with output ultimately reaching three tests per day. The applied loads reached a maximum of between 5.5 and 6.1 MN, with resulting deflections between 2.2 and 3.5 mm. All piles behaved elastically, with a net remnant settlement (Figure 7). The only exception was pile A2: Although considered free of defects, it showed a residual settlement of 1.5 mm.

CONCLUSIONS

From the construction history of pier NB-2 one may draw a few useful conclusions regarding quality control of piles and piling in general:

1. In bored piles defects will occur, even in simple soil conditions and under strict supervision.
2. Certain defects may escape detection by sonic integrity testing.
3. Core drilling inside piles has a good chance of missing defects, therefore its' results are at best inconclusive.
4. Cross-hole ultrasonic logging will detect even minor defects, and the tubes used for it may also be used for remedial work if such is deemed necessary.
5. The acceptance of pile repair work should not be based on stress-wave-based integrity testing.
6. The Statnamic loading test is an effective proposition when a considerable number of piles have to be tested in a short time.
7. Without pressure grouting of the toe, end-bearing in piles bored with bentonite slurry is at best questionable

Table 1: Ultrasonic logging — Summary of Defects

Pile No.	Depth of Defects (m)		
	Top	Intermediate	Lower
A1	+	2.4-2.6	7.2-7.5
A3			7.7-8.0
B1		2.0-2.7	7.2-7.8
B2		0.8-3.6	
B4		2.0-2.4	
B5			6.8-7.9

Table 2: Summary of Grout volumes

Pile No.	Grout Volume (m^3)
A1	0.29
A3	0.32
B1	0.40
B2	0.70
B4	0.16
B5	0.43
Total	**2.30**

Figure 1: Soil Profile

BOREHOLE LOG

FOUNDATION CONTROL INSTITUTE

Borehole number:	**NB-2**	Project name:	NORTHBOUND BRIDGE
Job number:		Site location:	Tel Aviv
Client:	Ayalon Highways Ltd.	Vertical scale:	1:250
Co-ords (x,y):		Elevation [m]:	13.34
G.W. Table [m]:	11.00	Date:	92-04-16
Date started:		Date finished:	
Total depth [m]:	34.00	Logged by:	
Type of sampler:		Type of boring:	Rotary
Remarks:			

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Depth[m]	DESCRIPTION	Symbol	Color	Plasticity
0.00	Hard CLAY, N = 6-22 blows		Brownish grey	High
7.00	Clayey SAND		Reddish brown	
8.00	KURKAR, N = 33->100		Yellowish	
15.00	Hard CLAY, N = 17-20			
20.50	Sandy SILT-Sandy CLAY, N = 22		Light brown	Low
23.00	KURKAR, N > 100		Yellowish	
26.70	Hard CLAY, somewhat silty, N = 22-27		Dark grey	High
34.00				

Figure 2: Pile Layout

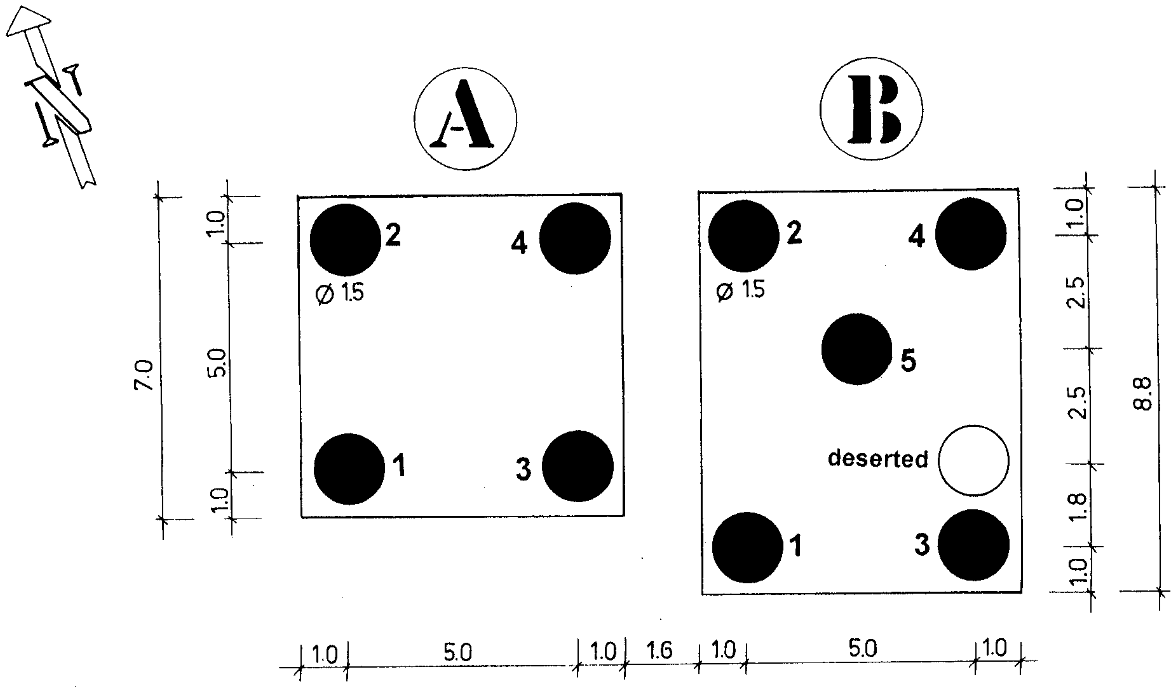


Figure 3: Result of Sonic Test - Pile B4

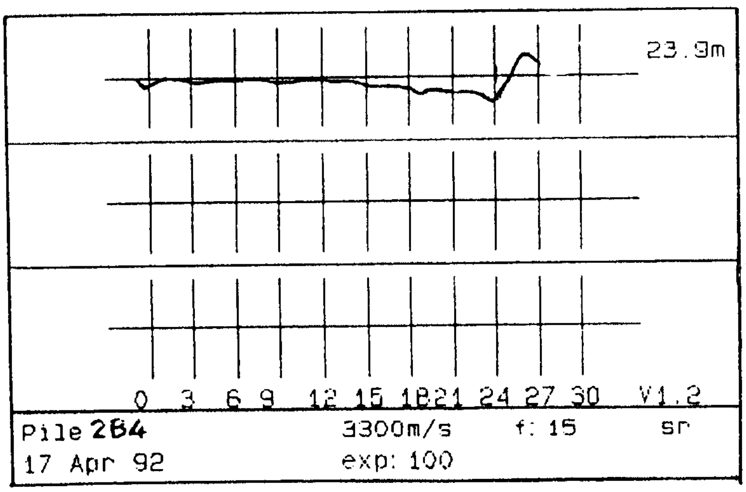


Figure 4: Typical Defect in Pile B2

Figure 5: Mechanical Device for Piercing Steel Tubes (Courtesy A. Mastboim Ltd.)

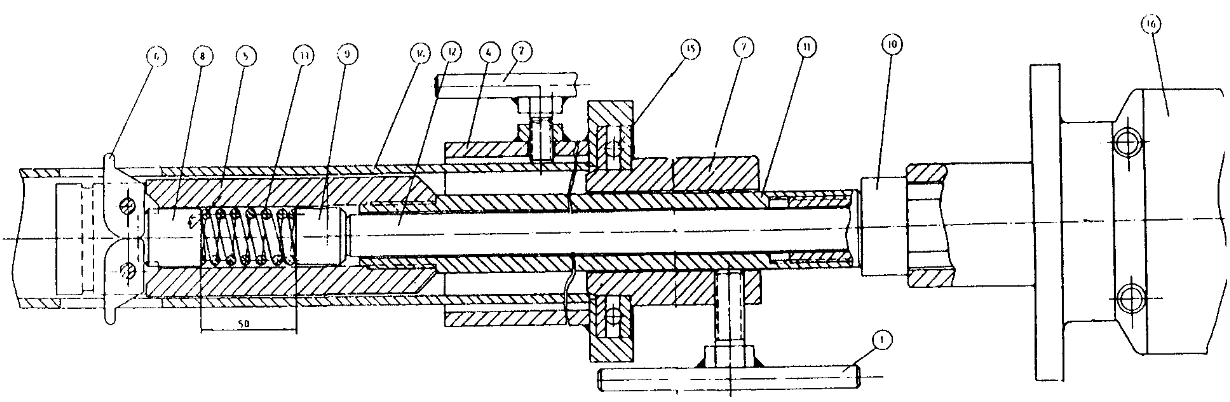
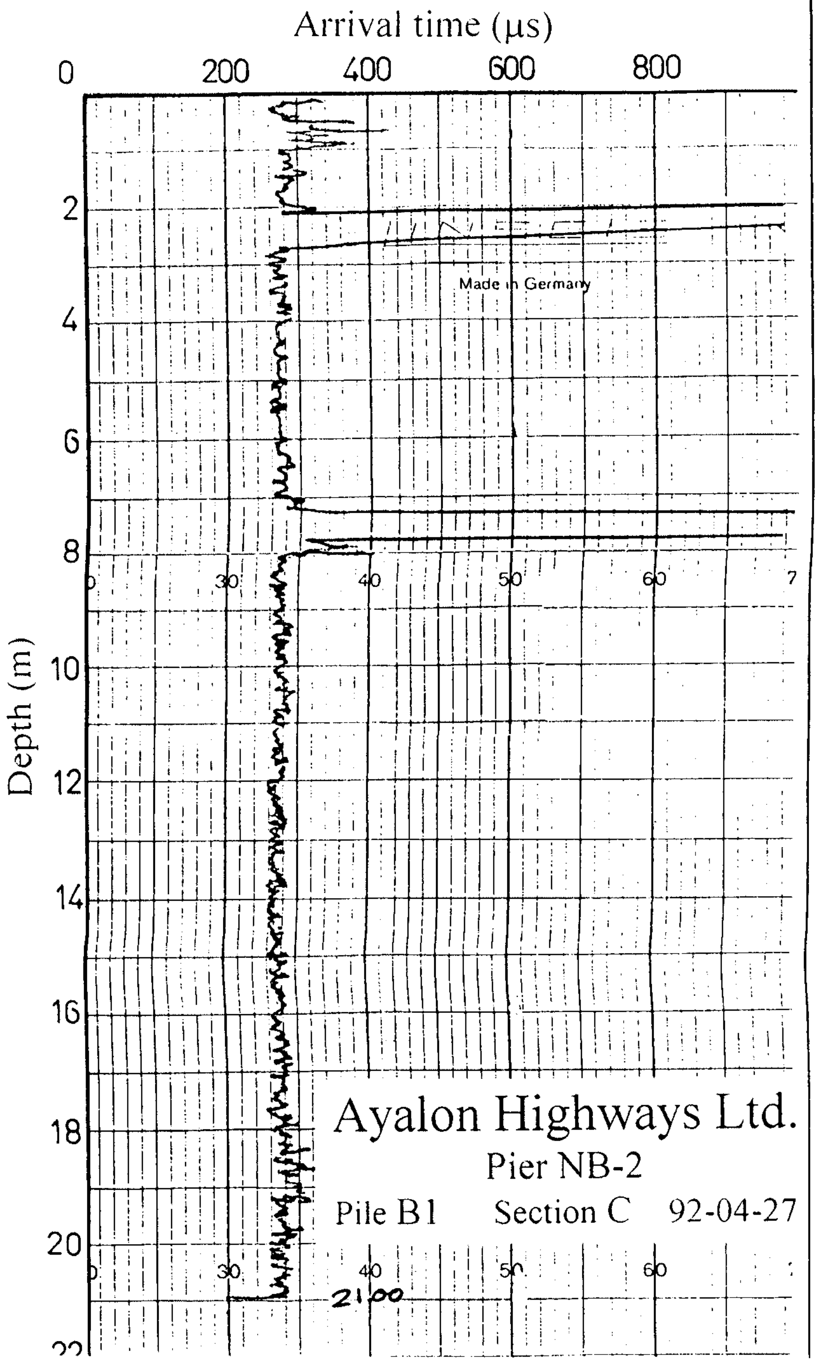


Figure 6: Result of Ultrasonic Testing Before Repair (Left) and After Repair (Right)



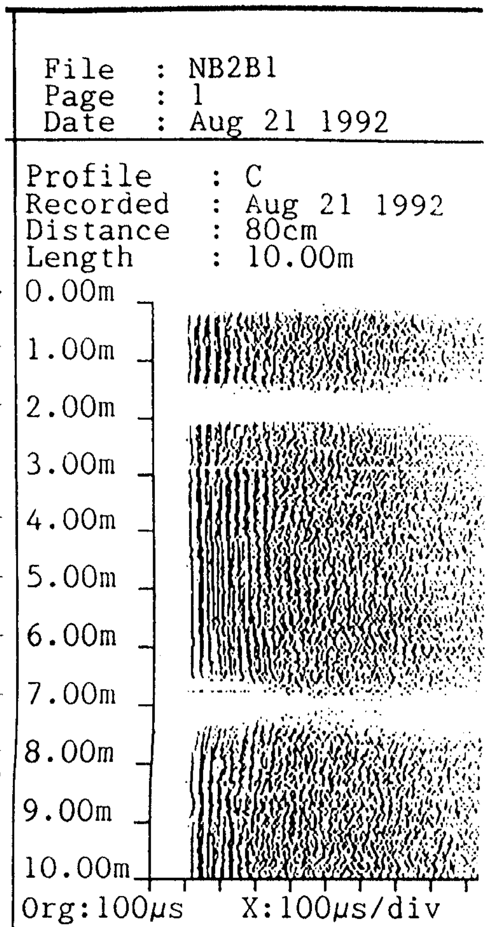


Figure 7: Results of Statnamic Loading Test on Pile A1