Loading tests on closed and open ended pure piles

Essais de chargement de pieux tubulaires à pointe ouverte et fermée

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SYNOPSIS The results of extensive dynamic and static tests on steel pipe piles are described. The piles tested were open ended, close ended, equipped with an enlargement of the pile section (vanes) and with a plate with a circular opening inside the tube. The favorable effect of the soil plug was ascertained and the parameters influencing the bearing capacity calculation by the wave equation method are discussed.

INTRODUCTION

The main aim of the investigations, described in this paper, was to estimate the driving resistancy and the bearing capacity of steel pipe piles, driven through 30 m thick layer of very soft marine clay into the bearing gravely and sandy soils. The pipe piles investigated were open ended, partially or fully close ended, equipped with an enlargement of the pile section (vanes) or ordinary pipes without lagging.

The tests were performed at a site of grain silo situated on a pier at one of the Adriatic ports. The very close spaced driven displacement piles could damage the existing storage foundations or even threaten the stability of the quay wall constructions, and the underwater slopes. Therefore the most of the tests on driving and bearing capacity were performed on open ended pipe piles to prevent the lateral displacements and the heave of more than 5 000 m^3 of the soil at the site area of 2 200 m^2.

SOIL CONDITIONS AT THE SITE OF THE TEST PILES

The soil profile at the site of the test piles is shown in Figs. 1 and 2. In this report only some test results will be reproduced for the typical soil layers.

Layer a- silty sand: average angle of internal friction and cohesion intercept in terms of effective stress

$\varphi' = 26^{o}\ 40'$ Translatory and rotatory
$c' = 7.5$ kPa direct shear tests

Layer b- marine clay: average cohesion in terms of total stress

$c_u = 21$ kPa ... In situ vane tests

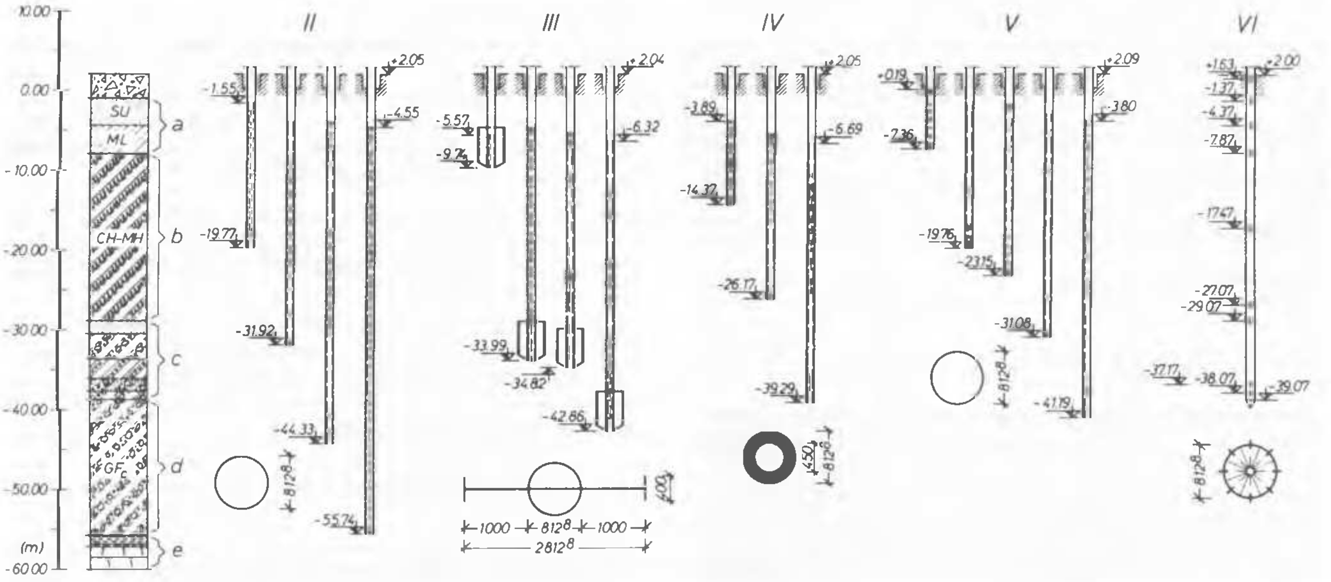

Fig. 1 Geometry of the test piles and heights of the soil plug inside the piles II, III, IV and V during driving

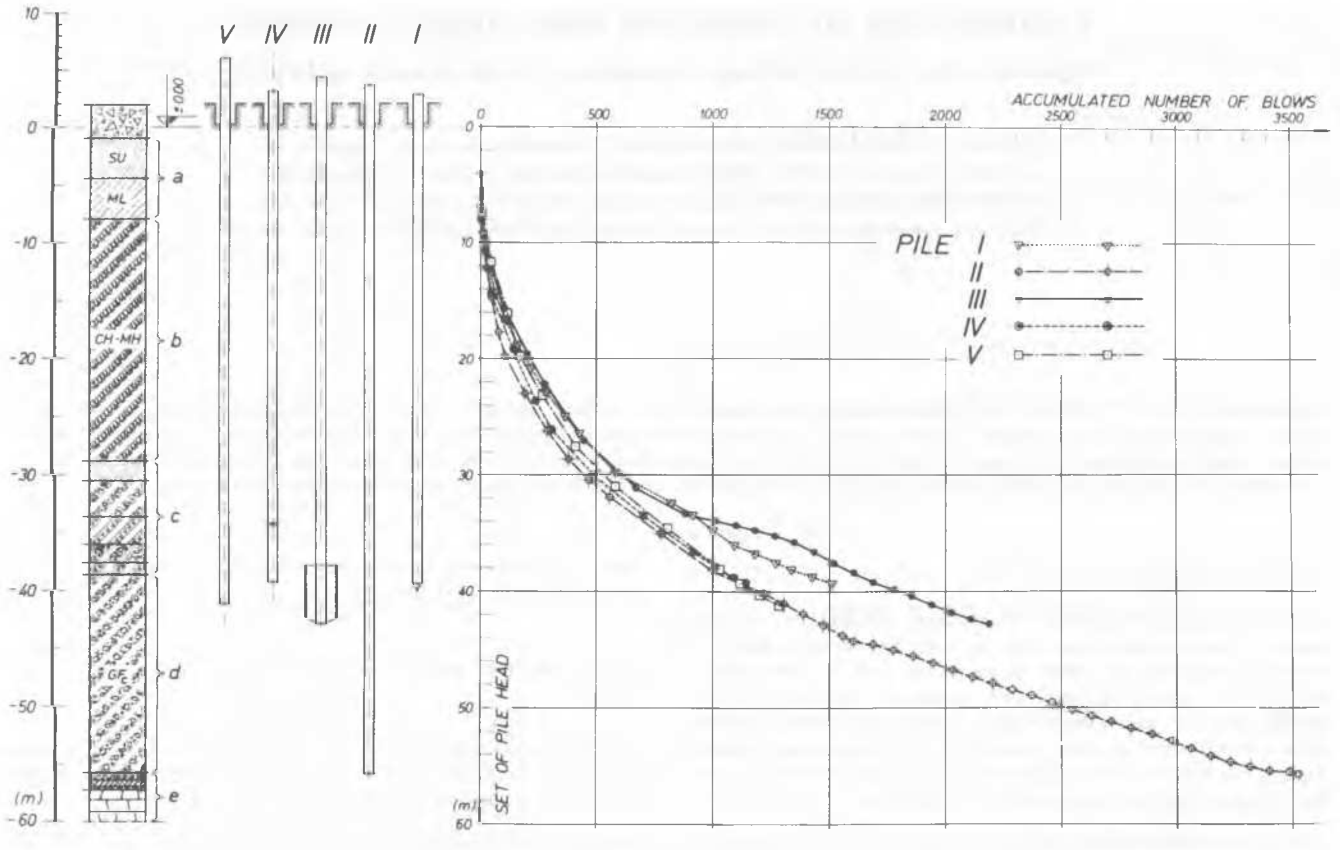

Fig.2 Scheme of the test piles and plots of accumulated number of blows versus depth

$\varphi' = 19^{o}$
$c' = 20$ kPa ... Triaxial shear tests

Layers c and d- silty and clayey gravel and sand intercepted in section c by thin layers of clay:

TABLE I

Layer	El. (m)	SPT N	Grain size distribution (mm) > 20	20/6	6/2	< 2
c	- 28	33	9	22	20	49
	- 33		9	11	7	73
d	- 43	34	18	11	13	58
	- 53	45	20	17	11	52

Layer e- Eocene flysh

DESCRIPTION OF THE TEST PILES

The schemes of the six test piles are shown in the Figs.1 and 2. Piles are steel tubes with the outside diameter of 812.8 mm and the wall thickness of 12 mm. Piles I to V were driven with a single acting Diesel hammer with the theoretical maximum energy of 146 kN m/blow. The pile VI, located about 45 m apart from the group of piles I to V, was driven with a single acting Diesel hammer with theoretical maximum energy of 115 kN m/blow.

Pile I and Pile VI are closed at the bottom with a metal cone. The pile I was driven to the el. of -39.34 m (0.74 m underneath the upper face of the bearing gravely layer d) and the pile VI to the el. of -39.07 m (1.90 m underneath the upper face of the bearing gravely layer d).

Pile II and Pile V are open ended tubes. The pile II was driven to the el. of -55.74 m (17.14 m underneath the upper face of the bearing gravely layer d) and reached the base of the firm eocene flysh. The pile V was driven to the el. of -41.19 m (2.59 m underneath the surface of the gravely layer d).

Pile III is an open ended tube with vanes, located 5 m above the base level. The pile was driven to the el. of -42.86 m (4.26 m underneath of the upper face of the bearing layer d).

Pile IV is an open ended tube with a plate with a circular opening, located 5 m above the base level and has the inside diameter of 450 mm. The pile was driven to the el. of -39.29 m (0.69 m underneath the surface of the gravely layer d).

MEASUREMENTS DURING DRIVING AND TEST LOADING

The following measurements were carried out during driving and test loading on piles I to V:
a) the settlement of the pile head during driving

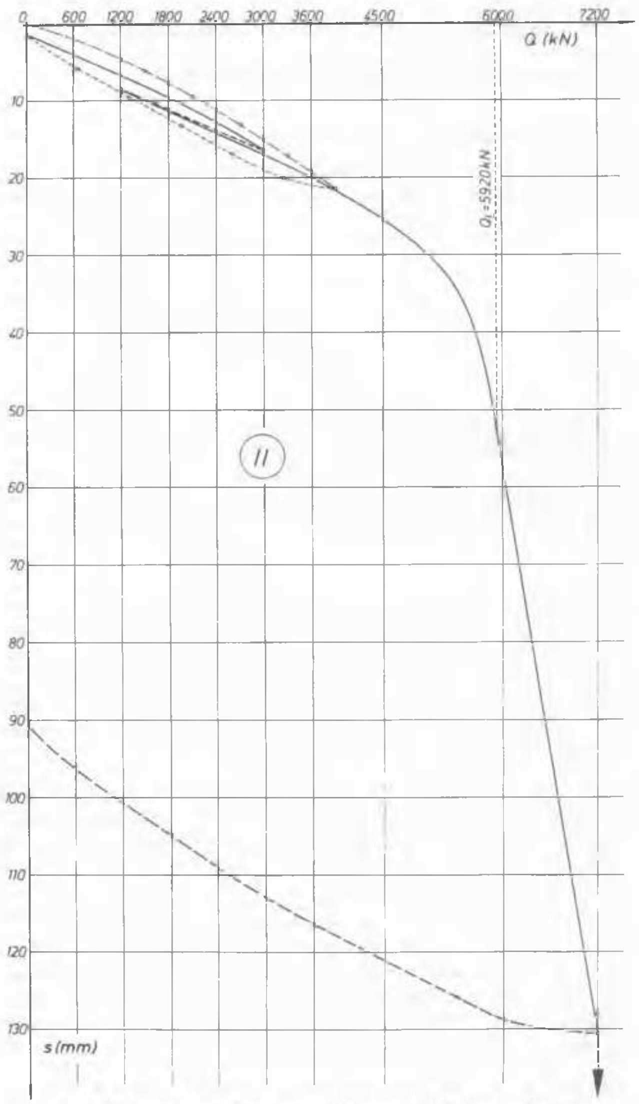

Fig. 3 Load settlement diagram of the pile II

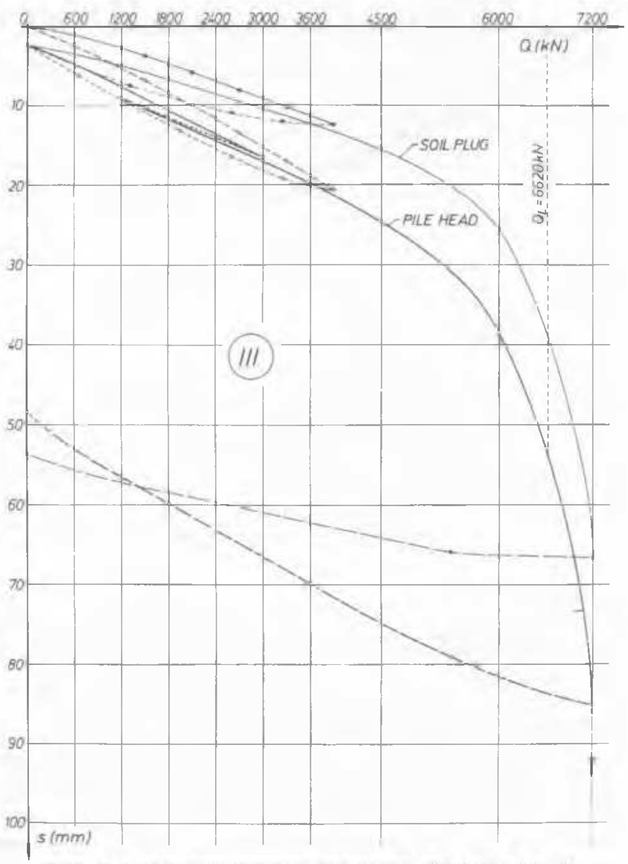

Fig. 4 Load settlement diagram of the pile III

b) the settlement of the pile head during loading by axial compressive and cycling load on piles II, III and IV
c) the upwards movement of the pile head during pulling of the piles I, II, III, IV and V
d) the movement of the upper part of the pile during horizontal loading of piles I and II
e) the upper face of the soil plug inside of the open ended piles III and IV
f) the heave of the surrounding soil during driving of the pile I.

Pile VI was instrumented with strain gauges for measurements of driving stresses in the pile shaft as well as the transfer of the axial load in the pile during test loading.

Due to the scarcity of space available not all of the test results will be given and discussed in this paper. They will be published elsewhere.

Results of measurements during driving

The settlements of the pile head during driving versus the accumulated number of blows for piles I to V are given in Fig. 2. In order to measure the driving stresses in the pile VI at 9 levels A to I strain gauges were fitted on the pile shaft (see Figs. 1 and 7). The maximum tensile stresses in the pile shaft were registered during driving through less resisting soil when the compressive wave reflected in the upwards direction (as tensile). The maximum tensile stresses of 76 MPa were observed at the level G, located 7 m from the head of the pile. The maximum impact (compressive stress 194 MPa) was measured at the level H, 4 m from the pile head. By using the wave equation and Smith´s damping parameters the maximum stresses at the last set of blows would be 135.5 MPa in tension at the level 6.70 m underneath the pile head and 162.5 MPa in compression 4 m under the pile head.

Results of the measurements of the height of the soil plug inside the pile during driving

The upper face of the soil plug formed inside the open ended piles II. to V during driving was measured by using a metal disk connected to a measuring device located near the pile head. The results of measurements (the base level of the pile and the height of the soil plug inside the pile) are shown in Fig. 1.

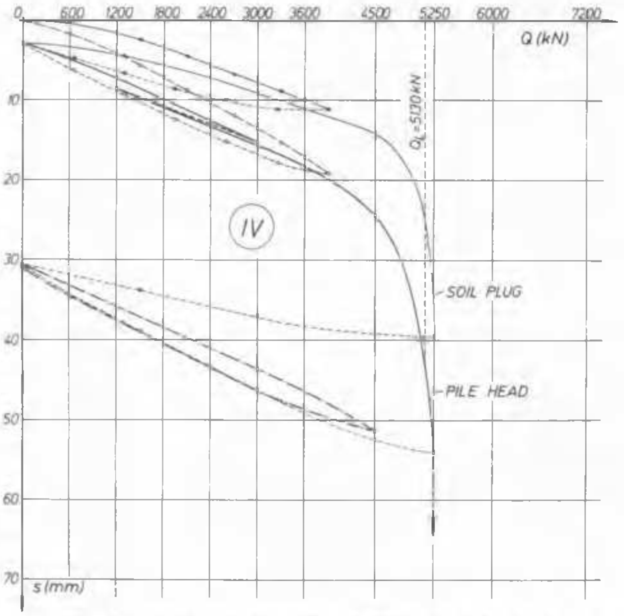

Fig. 5 Load settlement diagram of the pile IV

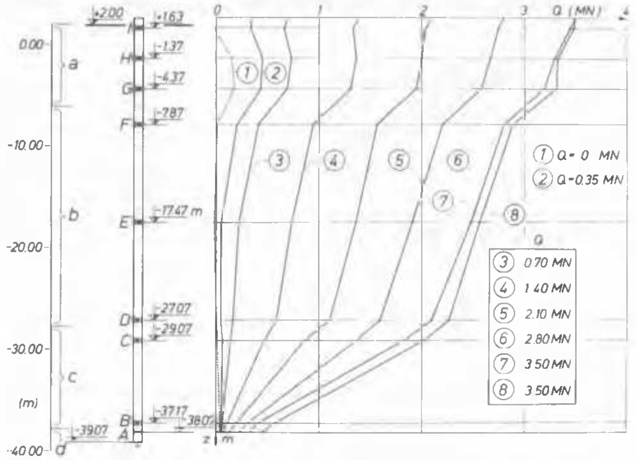

Fig. 7 Measured load distribution curve of the pile VI (No 8 ... after 27 hours)

The load on test piles was realized by using 4 hydraulic jacks (4 x 1 800 kN). The reaction of the jacks was taken by a steel beam supported by two tension piles. The piles I and III, II and IV, and III and V were used as tension piles for the piles II, III, and IV, respectively. A platform weighted with concrete blocks was used for the pile VI.

The load settlement diagrams of the test piles II, III, IV and VI are shown in Figs. 3 to 6. For the determination of the limit load Q_L the criterium of the German DIN 4026 was chosen.

The results of the measurements of the upper face of the soil plug inside the open ended piles III and IV during test loading are shown in Figs. 4 and 5. It is evident that inside the piles a plug was formed and therefore the bearing capacity of the piles increased (especially for the pile IV) considerably.

By using the results of measurements during driving and the test loading of the pile VI, the static bearing capacity was evaluated by means of the wave equation and Smith's damping parameters. For skin friction and toe damping factors 0.16 s/m and 0.49 s/m were introduced, respectively. Limit load of 5 450 kN is probably very close to the load test results. To get a satisfactory agreement for measured and calculated limit load for pile IV the Smith's damping factors need to be changed to 0.03 s/m for the skin friction and to 0.10 s/m for the toe damping.

Heave of the surrounding soil

The measurements were made by very precise surveying in a square area 10 m x 10 m around the close ended pile I. It was stated that the most of the displaced volume of the soil was in the lateral direction.

Measurements during test loading of the piles

The test piles were subjected to a stress controlled loading test 35 to 44 days after driving. In the first phase the load was increased to 3 900 kN in 5 loading steps. The vertical movements were observed at each step 2 hours or until the increment of settlements of the pile head in 20 minutes became equal or less than 0.1 mm. After reloading, in the second phase, the load was increased again in steps until the failure load was reached. In this way all the piles except the pile VI were loaded. The full instrumented pile VI was tested according to a different procedure.

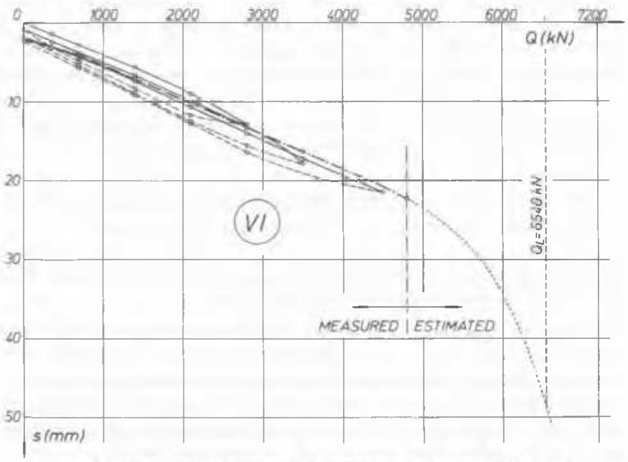

Fig. 6 Load settlement diagram of the pile VI

CONCLUSIONS

- The bearing capacity of open ended pipe piles, provided with an enlargement of the outside cross section (vanes) or with a plate with a circular opening inside the tube, can be increased considerably.

- In predicting the static bearing capacity by means of the wave equation the Smith's damping parameters should be reduced for the piles with the soil plug inside in comparison to the close ended empty pipe piles.