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SYNOPSIS Based on dynamic and static formulas and loading tests analysis of bearing capacity of type Vibro-Fundex driven piles is presented. The piles were embeded into noncohesive soils of various origin and degree of compaction. Using this analysis and performed investigations, the lengths of piles designed on the basis of static formulae have been corrected for safety transfering of loads into subsoil.

INTRODUCTION

In this paper an analysis of bearing capacity of type Vibro-Fundex piles used under a crane foundation in the Merchant Harbour in Gdynia is presented.

The subsoil consisted mainly of uniform, wet sand, of defree of compaction I_D = 0.4 - 0.6 until about 13 m depth, and below of dense sandy gravel soils. The design load transferred to one pile was F = 689 kN. Calculations of bearing capacity Q of piles, made using the static formula and basing on the Polish Standard PN-83/B-02482 (1983) showed that piles of total length 9 m (bearing length 7 m) should bear the required load.

During driving of steel casing pipes for the Vibro-Fundex piles (with closed toe), very large penetrations, of 30 to 50 mm per blow, were attained. Calculations checking pile capacity by several dynamic formulas showed that the bearing capacity is much lower than the design value and the value obtained from static formulas, and was of the order of 300 - 400 kN, see Table I. The reason for this fact had to be explained and a decision as to the further system of piling had to be reached.

With these objectives in mind, dynamic calculations were made for piles driven into the soil to depths of 13.05 and 14.05 m (bearing length 11.6 and 12.6 m respectively). Also static loading tests for these two lengths were carried out.

Analysis of geotechnical conditions, results of static and dynamic calculations for different depths of driving, correlation of the results of calculations with loading tests allowed a final evaluation of real bearing capacities of the piles, and assumption of such length of the piles that safe transfer of loads from the structure could be effected.

TABLE I. Comparison of pile capacities

Pile No.	Pile driving depth (m)	Pile penetration per blow (mm)	Capacity from dynamic formulas (kN)				Bearing capacity from static formula	Bearing capacity from loading tests
			Delmag formula	Own investigations	Polish Standard PN-69/B-02482	Hiley formula		
34	13	33.3	310	318	250	336	1345	-
15	13	27.3	369	380	301	400	1345	-
3	14	7.3	960	1038	869	1071	1434	-
4	13	20.0	462	478	385	504	1345	942
65	14	4.0	1462	1611	1295	1517	1434	1178

DESIGNED STRUCTURE AND SUBSOIL

The designed object is a land-side foot foundations under a crane on the harbour wharf. The load from the device and reinforced conrete foot is transferred by means of pile foundations to the subsoil. There are six piles in one foot foundation, and axial spacing of these foundations is 9.0 m. Type Vibro-Fundex piles made in the soil were designed: 457 mm diameter steel pipe closed at the toe (which stays in the soil) of 630 mm diameter, is driven with a DELMAG hammer into the soil, to required depth. After putting in the reinforcement and filling its interior with concrete, the pipe is lifted with a winch, simultaneously using a vibrator fixed to

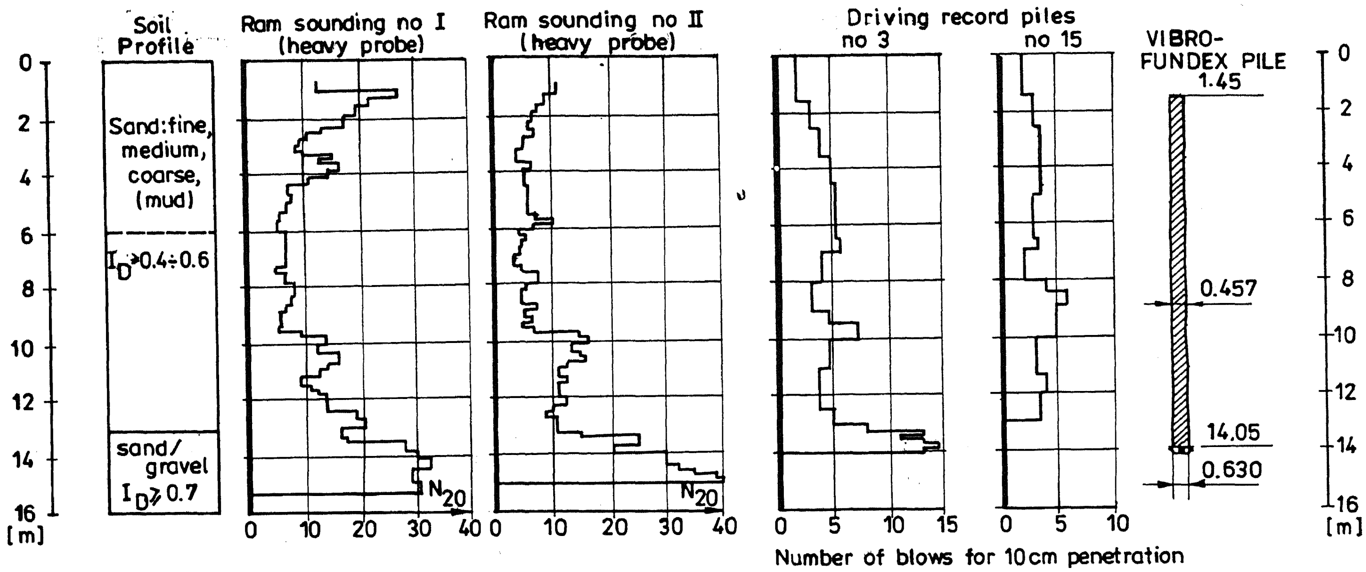

Fig. 1. Geotechnical characteristic of soil and pile conditions

the pipe.

The subsoil, Fig. 1, is multilayered, consisting of natural and dredged soil. Below terrain surface, to about 1.5 m, are noncontrolled fills. Below, to about 13 m depth are sandy soils of various grain size, mainly medium and coarse sands, locally with several centimeter thick laminations of organic soils (muds). This layer is in average compacted state (I_D = 0.4 - 0.6), with rather large differentiation at standard deviation σ_{I_D} = 0.20. The conditions are complicated by the fact that down to about 6 m depth these are sandy, uni-fractional, of uniform grain size soils pumped during construction of the port (age about 60 years). Below are sandy gravel soils of $I_D >$ 0.7 compaction.

EVALUATION OF BEARING CAPACITY OF THE PILES

Typically, in Poland designing of piles consists in evaluating their bearing capacity from the static formula given in the Standard PN-83/B-02482 (1983) and Gwizdała at al. (1992). This Standard gives the values of unit resistances q under pile base and values of friction resistance t at the shaft, depending on kind and state of soil and pile type. Many years of experience in using it allow safe evaluation of bearing capacity of different type of piles.

The calculated according to the Polish Standard capacity Q was Q = 740 kN for a 7 m long pile (depth of driving 9 m). Driving of first piles down to 10 - 11 m showed excessively large penetrations per blow, of the order of 30 mm. Penetration was calculated as displacement of the pile in effect of one blow of the hammer, evaluated from measurements from the last 30 cm of pile driving. Driving of the piles even to 13 m did not improve the situation, penetrations per blow were from 30 to 50 mm. This meant that though from sounding measurements the soil was considered as medium compacted, resistances of soil under the pile base were small during driving. Using measurements made during pile driving bearing capacity was calculated first on the basis of four dynamic formulas:

a - Delmag formula,
b - medified, from own investigations, Delmag formula (1984),

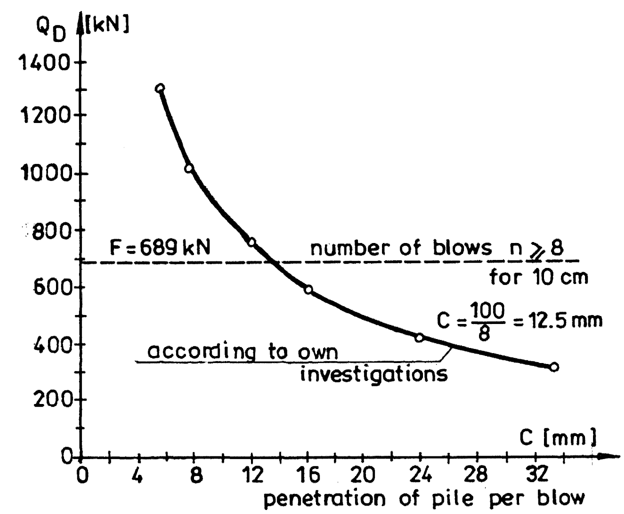

Fig. 2. Relationship between dynamic capacity and penetration per blow

c - Polish Standard PN-69/B-02482 (1969, 1983),
d - Hiley formula.

Results of calculations for several piles are shown in Table I. Capacity determined from dynamic formulas, at safety coefficient γ_D = 2.2 (Zadroga (1991)), for example for pile No. 34 is 310 kN, 318 kN, 250 kN and 336 kN respectively. These values were much smaller than the required capacity. Therefore calculations were performed in order to determine the relationship between dynamic capacity and pile penetration per blow, using results of own investigations (Tejchman, Kłos (1984)). It was found that at penetration per blow less than 12 mm the piles shall bear the required loads (see Fig. 2). Finally, in order to attain the required objective (F < Q) piles were driven to 14 m. For example, for pile No. 3 dynamic capacity Q = 1038 kN was obtained for measured penetration per blow c = 7.3 mm, Table I. During piling works penetrations per blow were measured for every pile, all the time checking resistances during driving. Pile capacities calculated from dynamic formulas were checked by static loading tests.

STATIC LOADING TESTS OF PILES

Two loading tests were carried out:
- for pile No. 4 of 13 m length, penetration per blow c = 20 mm,
- for pile No. 65 of 14 m length, penetration per blow c = 4 mm

Using dynamic measurements and the results of static loading tests, the correlation coefficient was determined in accordance with the Polish Standard PN-83/B-02482 (1983) as the ratio of the capacity from loading tests to calculated dynamic capacity. Calculation of real capacity for each pile allowed to design correctly the foundation and to balance capacity for each pile support. For the tested piles following capacities were obtained: 943 kN for pile No. 4 and 1178 kN for pile No. 65.

Results of soundings with heavy penetrometer (ram sounding), measurements of penetration per blow during pile driving (see Fig. 1), and results of loading tests clearly shoved that in the subsoil, to the depth of 13 m, a loose sandy subsoil is present. Large scatter in measurements of resistance at driving both the heavy probe and the piles still did not guarantee sufficient capacity if piles of this length were to be used. Lengthening the piles to 14 m, and checking pile penetration during the final blows allowed safe founding and elimination of the difference in bearing capacities resulting from the irregularities of the bottom of the loosened layer.

SUMMARY

Bearing capacity of Vibro-Fundex driven piles calculated on the basis of typical static formulae appeared insufficient, because the soil parameters obtained from sounding by means of heavy penetrometer were incorrect. It was necessary to provide additional calculations using dynamic formulas and to correlate it with the results from pile loading tests.

In spite of many years experiences, the pile bearing calculations requires for some cases the complex analysis consists of: static calculations, dynamic calculations, loading tests and of course in situ investigations of correct soil parameters.

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