No. H-5 DYNAMIC FORMULA FOR DETERMINING THE RESISTANCE OF PILES

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The driving of the piles into subsoil (when using a pile-driver) is obtained by the fact that the hammer of a weight Q, falling from a height H produces work

$$W = QH. \quad (1)$$

Not the whole of this work, however, but only part of it is spent in overcoming the resistance which the pile encounters in penetrating the subsoil.

If the resistance of the pile is R, and the penetration from one blow $\underline{e}$, then we get

$$Re = \alpha . QH; \quad R = \alpha \frac{QH}{e} \quad (2)$$

where $\alpha < 1.00$. This coefficient depends on many factors: material and dimensions of the piles, quality of the subsoil, weight of the hammer and height of its fall etc. The dynamic formulae of to-day, contrary to the theoretic-statistic formulae (by Krex, Derr and others) take into account only data referring to the pile itself (material of the pile and its dimensions) absolutely ignoring the quality of the subsoil, and therefore are not apt to yield correct results. To embrace, however, by one formula, all the factors influencing the coefficient α is almost impossible. Therefore we are stating here another indirect method for the determination of coefficient α.

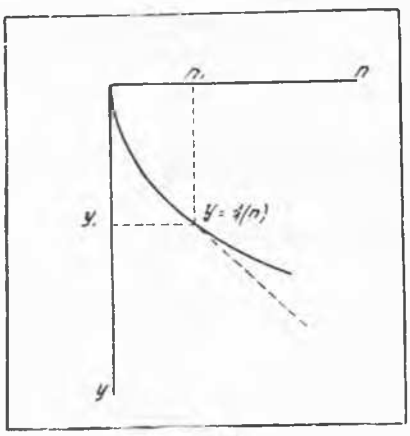


fig N1

When driving piles a curve of the driving can be obtained (Fig.1). The shape of this curve is influenced by all the factors which influence coefficient α in formula 2. The problem consists in establishing the kind of equation $y = f(n)$ of this curve and in determining the dependence between this equation and coefficient α.

Fig. 2 gives the curve of driving for five piles driven when constructing the quay wall in Gorkyi. Of these piles No. 1, 2, 4, and 5 are test-piles, and pile N 77 is one of those pertaining to the structure. Fig. N 3 and 4 give separately the driving curves for pile N 1 and N 4, showing also geological formation. These curves are very like a parabola with equation

$$y^2 = 2\,pn \quad (3)$$

y - being the depth of the piles settlement,

n - number of strokes,

2p- parameter determined from any assumed point on the curve.

Fig. 5 shows the superimposing of the actual curve of driving (dotted line) and the curve obtained by equation 3 (solid line) with 2p = 1850.

The settlement of the pile from the effect of one stroke being

$$e = \frac{dy}{dn},$$

the number of strokes necessary in order to drive the pile for one unit of length (1 cm) is

$$\frac{1}{e} = \frac{dn}{dy} = \frac{d\left(\frac{y^2}{2p}\right)}{dy} = \frac{y}{p} \quad (4)$$

With a thoroughly homogeneous soil and a uniform height of fall for the hammer the difference between the curve of driving and the parabola is scarcely apparent.

When the pile after penetrating one layer of the soil is driven into another layer (Fig. 6) strongly differing from the first, the number of strokes necessary per unit of pile's settlement is

$$\frac{1}{e} = \frac{1}{e_1} + \frac{1}{e_2} \quad (5)$$

where $\frac{1}{e_1}$ is the number of strokes necessary to overcome the resistance of the first layer of the soil;

$\frac{1}{e_2}$ - that for the second layer.

On the basis of formula (4) and Fig. 7a or 7b

$$\frac{1}{e} = \frac{Y_1}{P_1} + \frac{Y_2}{P_2} = \frac{dn}{dy} = \frac{dn_2}{dy_2}.$$

Superposed curves of ramming
Number of strokes

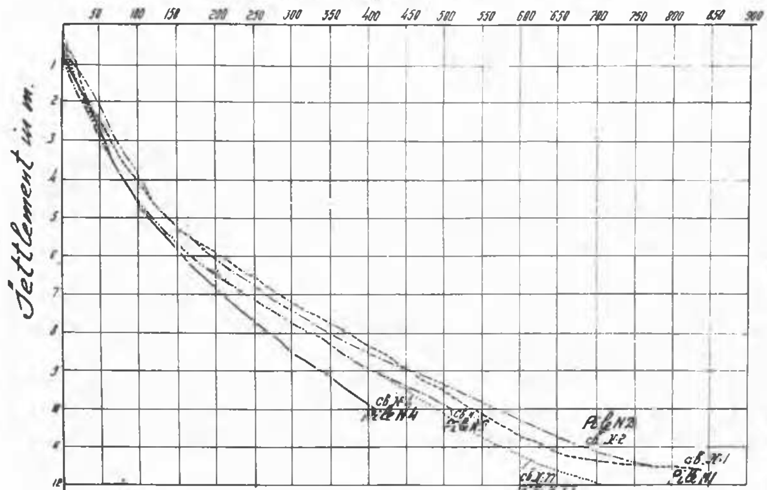
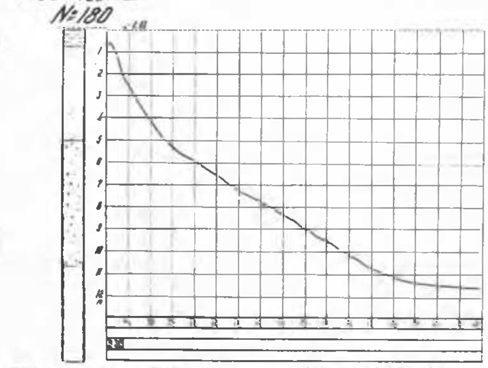


fig N2

Pile N:1

Pit-hole N:180



Diam of pile 28cm.
Length — — 13.0m.
Pile with shoe

Weight of ram 1200kgr.
Settement from last stroke 1m/m. Settlement from first two strokes (after a repose of 11days) 0.0m. each and from the following two Strokes 1m/m each.

fig N3

Pit hole N 183

Pile N4 /Pile driver N2/

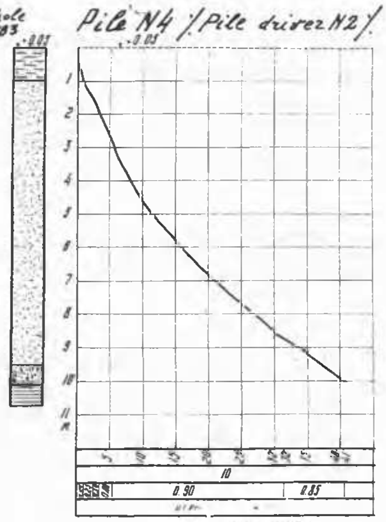


fig N4.

Designations:
/Условные обозначения:/
- Weakly slimy sand
- Slimy sand
- Sand
- Sand with gravel and pebbles.
- Marly clay
- Marl with intermittent layers of gypsum.

Weight of ram 1600kg
Settlement from last stroke 13m/m
— " — (after a repose of 16days) from 1 stroke 1m/m.

fig N6

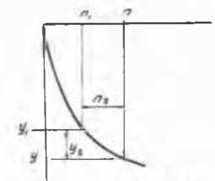


fig N7a

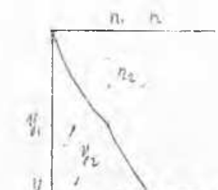


fig N7b

Curve of calculation superposed with the curve of ramming for pile N1.

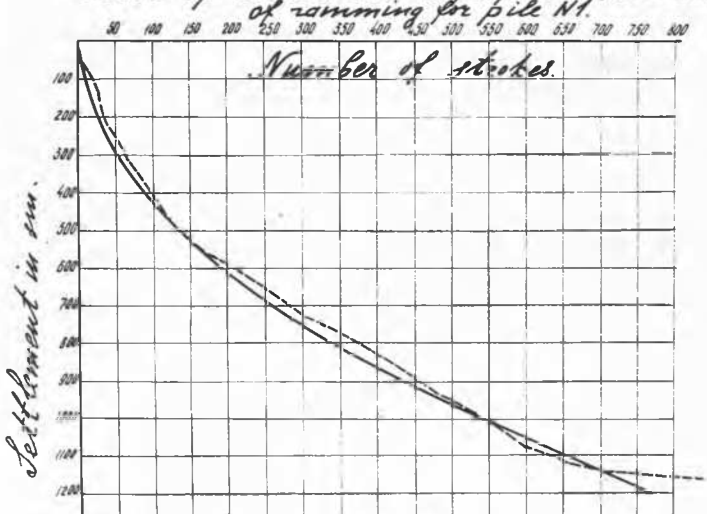


fig 5

Number of strokes.

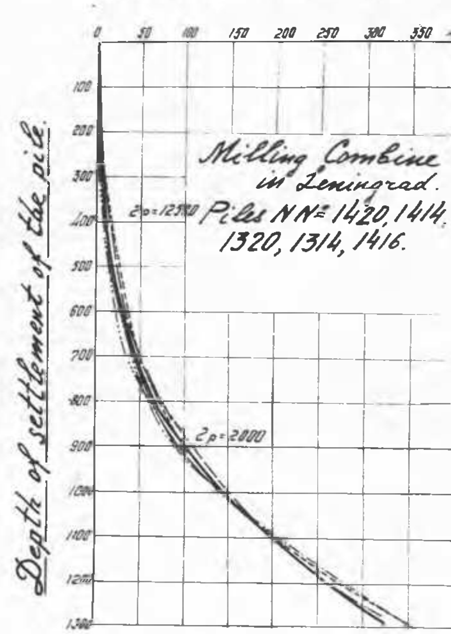


fig N8

Thus we get

$$n_2 = \int \left(\frac{Y_1}{P_1} + \frac{Y_2}{P_2}\right) dy_2 = \frac{Y_1}{P_1} Y_2 + \frac{Y_2^2}{2P_2} \qquad (6)$$

which is the equation of the driving curve for the second layer of the soil. For the first layer of the soil there remains in force the equation (3).

Fig. 8 and 9 give the driving curves of wooden piles driven below the foundation of an elevator under construction in Leningrad. The construction soil is shown by pit-hole N 5 (Fig. 10). The boundary between the brown and grey clay (v.7, 5-M) is formed by the transition of parabola with one parameter into a parabola with another parameter. These parabolas are given on Fig. 8 and 9 with continuous solid lines.

The parameter of the driving curve is indicative of the facility with which the pile sinks into the soil and depends on the same factors as coefficient α in formula 2. There exists the following logical dependence between the coefficient α and parameter of the driving curve:

a) The more difficult the penetration of the pile, the greater is the part of work of the hammer's blow spent in elastic and residuary deformations of the pile (rebound of the hammer, crumpling of the pile's head, etc.), and the less is therefore that part of its work which is spent in pushing the pile into the soil. Consequently, with

$$P = 0 \quad \alpha = 0,$$

i.e. if very strong soils (rocks) are dealt with, or if the blows of the hammer are weak and unable to overcome the resistance of the soil (e = 0), the whole of the hammer's work is spent in producing deformation and nothing remains to produce the penetration.

b) With very weak soil and great values of the hammer's work in producing one stroke, almost the entire work is spent in the hammer's dislocation and there results almost no deformation of the pile; therefore,

$$\text{with } P = \infty \quad \alpha = 1.00$$

These conditions are met with by function

$$\frac{p}{m} = \frac{A \tan^n \alpha \frac{\pi}{2} + B \tan^{n-1} \alpha \frac{\pi}{2} + C \tan^{n-2} \alpha \frac{\pi}{2} + \dots + K \tan \alpha \frac{\pi}{2}}{A + B + C + \dots + K} \qquad (7)$$

Whatever be in reality the mathematical expressions of the relation $\alpha = f\ (p)$ by means of a corresponding selection of the coefficient A, B, C and K and of the index of power n, the Equation 7 may be brought near relation $\alpha = f\ (p)$ with an exactness beyond practical need. We presume that for practical purposes it will be sufficient to adopt the first term, taking n = 2 as index of power.(Here "n" does not represent the number of strokes).

Thus we get

$$\frac{P}{m} = \tan^2 \alpha \cdot \frac{\pi}{2}$$

m - the coefficient characterizing the grade of the curve's concavity and should be established by experience.

The test loading of the test pile N 5 in Gorkyi (Fig. 11) established the value of coefficient $\alpha = 0.2$, whereas according to formula 8 there was determined m = 4250.

Fig. 12 shows the diagram $\alpha = f\ (p)$ drawn up according to formula

$$p = 4250 \tan^2 \cdot \frac{\pi}{10} .$$

The determination of the resistance of the piles is done as follows:

1. According to the driving curve we establish the parameter P of same.
2. According to this parameter we find on the diagram the coefficient α .
3. According to formula 2 we find the resistance of the pile

$$R = \alpha \frac{QH}{C}. \qquad (8)$$

If driving curve consists of segments of two parabolas with different parameters, then two corresponding values are found, and the pile's resistance will be

$$R = R_1 + R_2 = \left(\frac{\alpha_1}{e_1} + \frac{\alpha}{e_2}\right) QH \qquad (9)$$

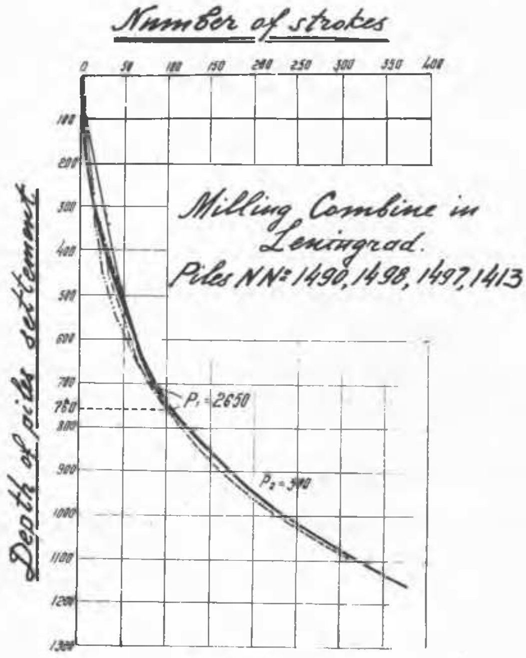


Fig N9

Pit hole N5

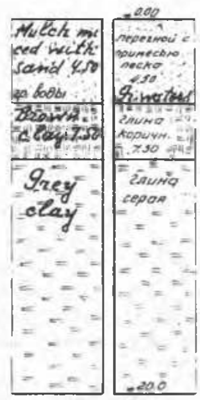


Fig N10

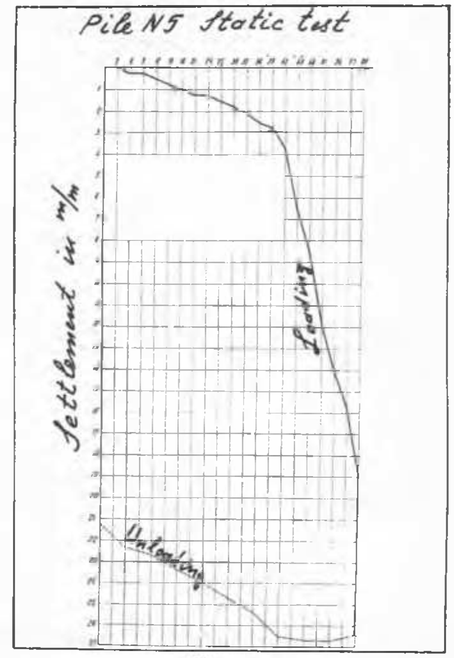


Fig N11

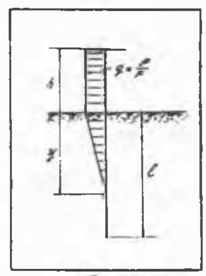


Fig N13

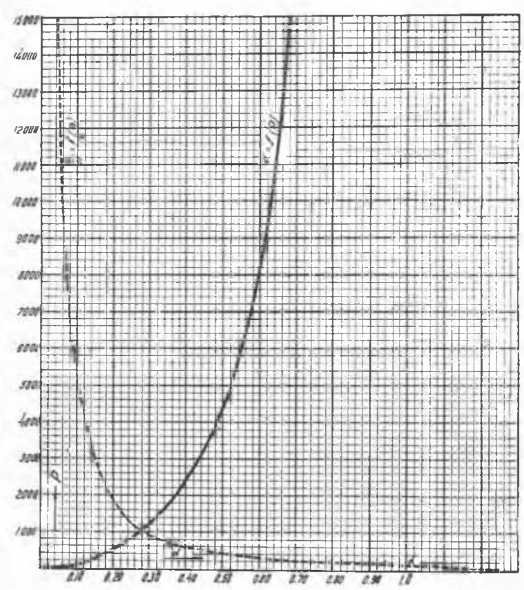


Fig N12

Pile N2 Static test

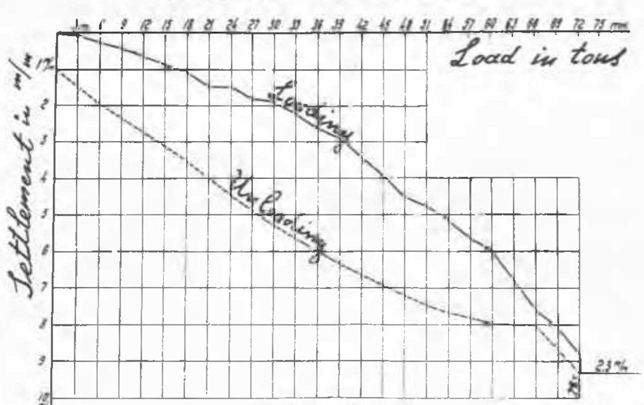


Fig N14

Theoretic curve superposed with the actual curve of deformation in the Port of Gorkiyi

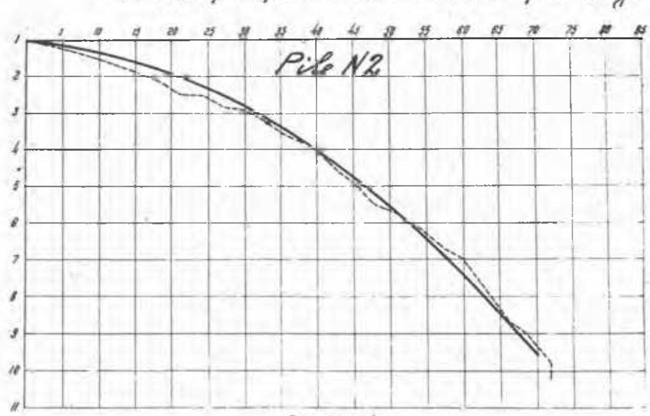


Fig N15

Theoretic curve superposed with the actual curve of deformation in the Port of Gorkiyi.

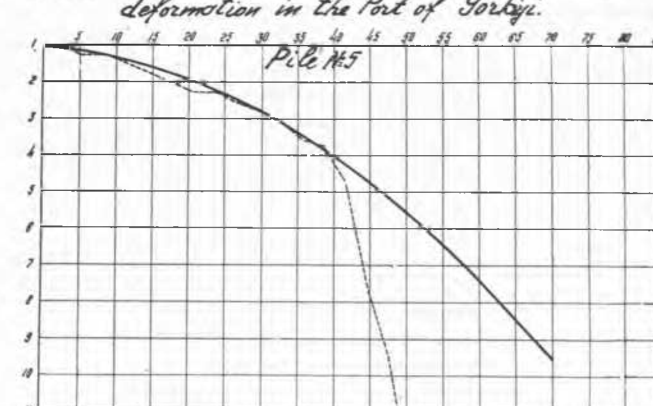


Fig N16

Several soils, when piles are driven in, show only an apparent penetration. Therefore it is necessary to repeat the dynamic test several days after the driving. The parameter then is determined in accordance with the penetration of the piles from one stroke of the hammer, with the so-called supplementary driving of the piles. From formula (4) we have

$$p = ey \quad ....(4')$$

From the parabolic character of the driving curve it can be concluded that the specific resistance of the pile almost does not change with the depth of driving, i.e.

$$A = A' + A'' = \frac{R}{Y} = \sim \text{a constant} \qquad (10)$$

A' - resistance of the lateral surface;

A" - resistance of the end of the pile.

The character of changes in the normal stresses along the axis of the pile is determined by Fig. 13 in which

$$y = \frac{P}{A'} .$$

The linear deformation of the pile will then be:

$$\Delta L = \Delta h + \Delta y = \frac{Ph}{EF} + \frac{P^2}{2A'EF} \qquad (11)$$

Fig. 14 shows the result of the loading of test pile N 2 in Gorkyi. The end of this pile stuck in dense marl and did not show settlement. To a load of $P = 50.0$ tons corresponds a deformation $L = 4.5$ mm and with formula (11) was found $A' = 4.00$ T/M. After this, according to the formula, the theoretical curve was constructed (Fig. 15).

Fig. 16 shows the comparison of this curve with the real curve of determination of pile N 5. Up to the limit of elasticity the coincidence is good.

No. H-6 NOTES ON THE PILE DRIVING FORMULA INCLUDED IN THE PROPOSED BOSTON BUILDING CODE

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In the proposed revised building code for the City of Boston, Massachusetts, U.S.A. (Paper No.Z-17) attempt has been made to provide, so far as is practically possible in regulations, for the three essential requirements for a pile foundation, namely:

1. That the material forming the piles is not over-stressed.
2. That the soil supporting the piles is not over-loaded.
3. That the load on each individual pile is less than its resistance to penetration in the soil.

The method of meeting the first two requirements is evident from a perusal of the Chapter (Paper Z-17). The third requirement is met by providing for the use of a modification of Hiley's formula, application of load tests or both. Previously there had been no provisions for the first two requirements and only the third was regulated by requiring the calculation of driving resistance by the Engineering News formula and by requiring loading tests.

The pile driving formula is based on the following nomenclature, and the modification consists in assuming the coefficient of restitution, (n), = 0, and applying a factor of safety of 3.

R_d = dynamic resistance
R = allowable load
W = weight of striking parts of hammer
P = weight of pile as driven
h = height of fall of hammer
s = penetration of pile per blow
E = modulus of elasticity of pile as driven
A = cross-section area of pile as driven
L = length of pile as driven
n = coefficient of restitution
e = efficiency of hammer
= 0.75 for usual drop hammer
= 0.90 for single acting steam hammer
2C = elastic compression of driving cap
$2C_1$ = elastic compression of pile as driven