$F_\ell + F_p$ increases.

5) For two piles of different length and same total imposed load, the lateral friction curves do not superpose.

For the shortest pile, the F_ℓ / F_p ratio is smaller and the point resistance F_p higher than

a) the point resistance of the longest pile
b) the resistance remaining on the longest pile at the depth of the point of the shortest pile.

Horizontal component of earth pressure.-

Let ω = material density
χ = pile perimeter
h = depth
H = pile length
φ = internal friction angle

we have
$$F_\ell = \int_0^H \omega \chi h A \, . \, dh$$

where A is a pure dimensionless number.

M. LEHUEROU-KERISEL has shown in the case of a pinched driven pile that A is constant, when ultimate bearing capacity is reached, along the whole pile, and is only a function of φ

Its value being
$$tg\left(\frac{\pi}{4} + \frac{\varphi}{2}\right) e^{(1,77 + \varphi)\, tg\varphi} \sin\varphi$$

The above relation, which defines A, derived, we obtain
$$A = \frac{d F_\ell}{d h} \cdot \frac{1}{\omega \chi . h}$$

The experimental results show that before ultimate bearing value for a certain length pile:

1st) A reaches a maximum near the mid length whatever be this one.

2nd) The A curve, as a function of h, is deformed when the total load increases.

3d) At a certain depth A increases with the total load

4th) The greatest values found for A are close to those given by M. LEHUEROU-KERISEL.

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VII a 23

ABOUT AN OBSERVED CASE OF NEGATIEVE FRICTION ON PILES

J. FLORENTIN
G. L'HERITEAU

SUMMARY OF THE FRENCH REPORT

The piles of 0,80 m diameter, upon which a shed is founded, were driven through a fine sand fill, 4 m. thick, and a layer of very soft clay, about 14 m. thick, in process of consolidation. The clay lies above a compact marl (probably cenomanian) slightly decompressed on about 1 m. (fig. A)

Field observations.

1) The shortest piles, probably driven only to decompressed marl, settled considerably, up to 30 cm. in 3 years. (fig. B)

2) The previously levelled soil, settled under the fill and its own weight. After 3 years, the settlement in the centre was about 10 cm. less than around piles, resulting in an overload. (fig. C).

Laboratory tests.

Moisture contents are plotted on fig. A and consolidation curves on Fig. D.

Atterberg's limits averaged to :

Soft clay	L.L. = 50 %	I.P. = 30 %
Marl	L.L. = 52 %	I.P. = 28 %

Therefore, soft clays behave as viscous liquids.

Compressibility measured by the oedometer varies progressively with the depth.

It seams that we deal with the consolidation of the clay under its own weight.

The internal friction, measured by HVORSLEV's apparatus was 23°.

For marl, at 18 m. $\varphi = 19^o$ C = 1,5 Kg/cm^2 (on decompressed samples, cohesion drops to 0,500 Kg/cm2) at 19 m. $\varphi = 20^o$ C = 3 Kg/cm^2

For sand $\varphi = 34^o$.

Computing overloading.

Buoyancy accounted, the weight of the piles 18 m. long and 0,80 m. diameter, is about 11 T.; they were loaded to 30 T. During static tests, to 50 T., nothing happened.

Sinking can only be explained by "negative friction" on piles.

Owing to clay's settlement, we had supposed in sand, an "active pressure equilibrium". For soft clay, we had supposed either an active or an hydrostatic pressure equilibrium.

On fig. E, we have plotted the hydrostatic pressures of soil, the densities being calculated with buoyancy. Each area (S) expressed in metric tones, corresponding for each layer, to 1 m. of perimeter.

For each layer, the overloading by negative friction is

$$\pi \,.\, d \,.\, S\, A\, tg\, \varphi ,$$

with d = diameter
φ = angle of friction soil-pile, quite equal to friction soil-soil
A = coefficient of active earth pressure in the Boussinesq-Resal equilibrium, with A = 1 for hydrostatic equilibrium.

The negative friction thus calculated would be of 117 T. in case of hydrostatic equilibrium, and 43 T. in case of an active equilibrium of pressure, in the soft clay, with $\varphi = 23^o$. The truth lies between the two, because it is difficult to think that in the soft clay, stresses can be both hydrostatic and have a tangential component against the pile.

The observed settlement cannot be explained only by the consolidation of the marl, under the influence of the total load. But if some of the shortest piles have not reached the compact marl, the ultimate strength of the decompressed marl may be depassed.

After some successive lifting of the beams lining the piles, the compact marl has been reached by the pile tip and the settlement stopped.

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SUB-SECTION VII b

HORIZONTAL PRESSURES ON PILE FOUNDATIONS

VII b 3

THE EARTH PRESSURE AND DEFLECTION ALONG THE EMBEDDED LENGTHS OF PILES SUBJECTED TO LATERAL THRUST.

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SYNOPSIS

The problem of computing the lateral earth pressures, the deflections, the shears and the moments at all points throughout the embedded lengths of either individual piles or a row of sheet piling is solved by difference equations.

The analysis involves the solution of thirteen simultaneous difference equations, four of which apply to the boundary conditions for the problem and nine for the lateral earth pressures at nine equally spaced points along the embedded lengths of the piles.

Illustrative numerical examples are presented. The method of differences permits the use of various expressions for the variation in the modulus of earth reaction, k, with depth of soil, without complicating the solution of the simultaneous equations. Graphs and diagrams show the deflection curve, the load, moment and shear curves for the bent pile.

INTRODUCTION

This paper deals with the earth pressures acting on a single pile or on a row of sheet piling, with the upper end free to rotate and subjected to a lateral thrust, P, per pile or per unit length of wall. It deals also with the deflections, moments and shearing forces for the pile or piling throughout its embedded length. The solution is applicable (but not equally accurate) to any depth, L, of embedment of the pile or sheet piling and for any type of earth whose resistance to lateral yield increases, linearly or otherwise, with depth.

The basic differential equation for this problem is:

$$EI \frac{d^4y}{dx^4} = - p = - k\left(\frac{x}{L}\right)^n y \qquad (1)$$

where E and I are the modulus of elasticity and the moment of inertia, respectively, for an individual pile of width b or for a length b of a row of sheet piling, x is any variable distance along the length of pile (positive downward), y is the deflection, p is the earth pressure at any depth, x, along the embedded length, k is the modulus of earth reaction (lateral) at the depth, L, and n is any real, positive number, greater or less than unity.

The solution of equation (1) is the deflection curve, $y = f(x)$, of the pile. Equation (1) can be solved by expressing y as an infinite series. The solution for the case, $n = 1$, was published by J. Rifaat 1). A solution of the problem by difference equations was suggested by Dr. H. Marcus, Bureau of Yards and Docks, U.S. Navy Department. The advantage of this method is that various values given to the parameter, n, equation (1), present no especial difficulties that would be encountered otherwise in solving the differential equation by the method of infinite series.

The quantity, k, is taken as a fixed value in any specific problem. This is the lateral modulus of earth reaction at the lower end of the embedded length, L, of the single pile or of the sheet piling. In this paper, its units are pounds per cubic inch. The quantity, $k' = k\left(\frac{x}{L}\right)^n$, is zero at $x = 0$ (see fig. 1)