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Small Diameter Piles in Karstic Rock

Fondation sur Pieu de Petit Diamètere en Terrain Karstique

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SYNOPSIS Spread footings, manually excavated in the Karstic limestone of Karmiel, were always time consuming due to the rock hardness. Large clay pockets in the cavernous rock resulted in deep foundation excavation to reach a non-swelling condition. The differential behaviour of clay and limestone further complicated the problem.

A newly developed drilling machine introduced an alternative foundation method with small diameter piles. High skin friction values from loading tests allowed an economical solution and the fast drilling rates saved a considerable amount of time.

FOUNDATION PROPERTIES OF KARMIEL ROCK

Most of the northern Israeli town of Karmiel is situated on dolomitic limestone belonging to the Turonian age. The unconfined compressive strength of the limestone is about 800 Kg/cm^2. Solution channels (Karst) are prevalent in the rock mass to great depths (up to 50 m.). The solution channels and pockets, about 0.5 to 3 m. in diameter, are filled with fat clay of high swelling potential.

Since the clay filled cavities occupy about 40-50% of the rock mass, swelling is the determining factor of the foundation depth. Three to four meters are considered to be the safe depth regarding moisture and volume changes.

However, the difference in behaviour of limestone and clay still remains a problem when deciding on depth of spread footings.

IMPROVEMENT BY MECHANIZATION

Spread footings to a depth of 3 - 6 m. were usually excavated manually with jack hammers. This is considered to be an expensive and time consuming proceedure.

A newly developed drilling machine, capable of producing up to 30 cm. diameter holes in the hard rock, introduced an alternative foundation concept.

The drilling is rotary-percusive with a penetration rate of about 5 m. per hour. This is a fast rate and also relatively cheap.

Small diameter piles were proposed to replace the spread footings. The pile solves both the problem of adequate bearing capacity and restraint of the swelling. Fig. 1 illustrates an exposed pile.

Fig. 1 Exposed typical Micropile.

FRICTION VALUES OF CONCRETE PILES IN ROCK

Moore (1964) quotes pile loading tests for the Golden Gate bridge in fractured and weathered shale and sandstone, resulting in allowable shaft friction of 5 Kg/cm^2.

On a sewage project on the Hudson river Feld (1974) allowed 14 Kg/ cm^2 friction in New York bedrock.

Tomlinson (1976) quotes ultimate shaft friction values for bored cast-in-place concrete piles in chalk, marl, mudstone and shales of 0.8 to 5 Kg/cm^2.

David (1973) reports on a loading test in the hard karstic limestone of Jerusalem. The core recovery in the rock was 40% and the compressive strength was 800 Kg/cm^2. Under load of 175 tons and still in the range of "elastic" settlement (2 mm.), friction of 4.8 Kg/cm^2 was mobilised.

LOADING TESTS IN KARMIEL

Four 30 cm. diameter piles 0.55 m.; 1m.; 1.5 m. and 3.1 m. in length were tested in Karmiel. The piles were isolated at their base and loaded to 204 tons. Settlements measured were 1.8 mm. - 2.75 mm.. These settlements are close to the elastic range and the conjunctive friction measured was between 8 Kg/cm^2 and 39 Kg/cm^2. Results are presented in Figs. 2 and 3.

Failure could not be reached because the 204 ton load was the maximum available counterweight.

It is possible that shearing resistance along the pile shaft is increased due to the "poisson phenomenon". Lateral displacement of the pile towards the rock accompanied with increased lateral pressure may contribute to the bearing capacity of the pile which is very high.

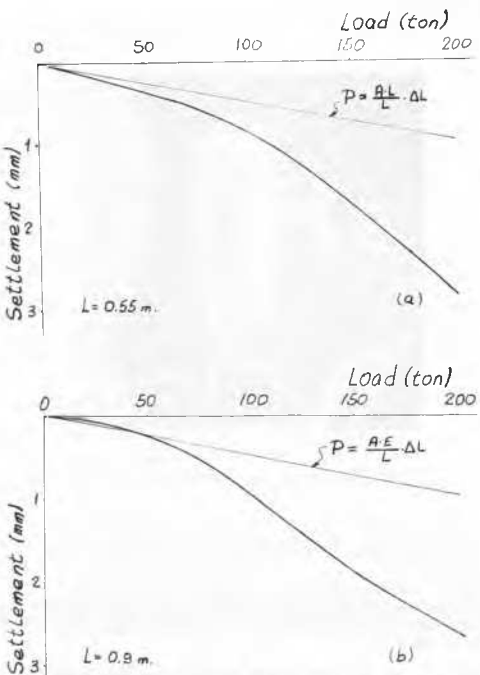

Fig. 2 Small diameter pile loading test results

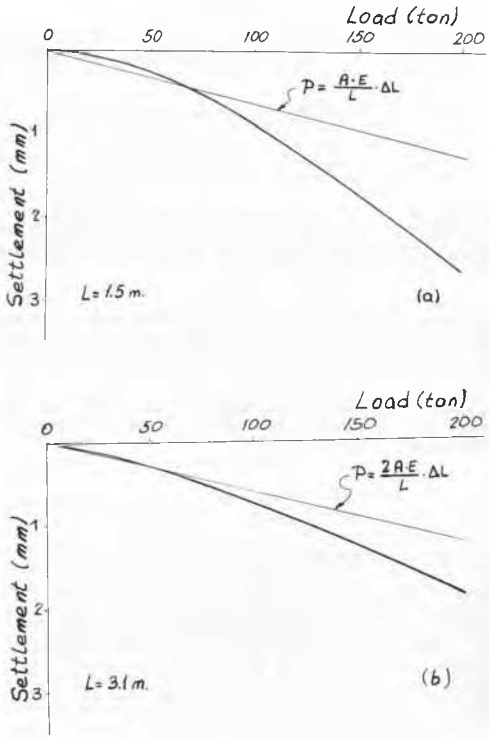

Fig. 3 Small diameter pile loading test results

ALLOWABLE VALUES FOR FOUNDATION DESIGN IN KARMIEL

Shaft friction of 2 - 3 Kg/cm^2 was allowed in the design of pile foundations for 30 residential 4 - 8 storey buildings. These are conservative figures and take into consideration presence of clay pockets. Two years after completion of the buildings no settlements have been noticed.

PILE ECCENTRICITY

The eccentricity of the pile during execution is limitted to 3 cm.. The resulting bending moment for a 75 tons columnar load is 2 ton-m.. Such moments are restrained by the foundation beams.

PILE BUCKLING

The critical buckling load on a centrally loaded rod in elastic media is according to Timoshenko (1961):

$$P_k = P_e \left(m^2 + \frac{B}{m^2}\right) = \frac{\pi^2 EI}{L^2}\left(m^2 + \frac{KL^4}{m^2 \pi^4 EI}\right)$$

$$B = \frac{KL^4}{\pi^4 EI}$$

where:

P_e - buckling load in air according to Euler= $\frac{\pi^2 EI}{L^2}$

EI - stiffness.
L - pile length.
m - no. of sinusoidal buckling half waves.
K - horizontal soil subgrade reaction, $K=K_o\phi$.
K_o - horizontal soil subgrade reaction for 30x30 cm. plate.
ϕ - pile diameter.

Use of Timoshenko's formula is within reasonable approximation in particular for a pile reaching bearing stratum, where the friction above the base is small.

In the case of a friction pile, the result is on the safe side since the axial force is reduced with depth. The "m" derivative for $m = B^{1/4}$ results in $\bar{P}_k = 2(KEI)^{1/2}$ indicating that the buckling load is not dependant on pile length. Assuming a factor of safety of 2.5 for P_k the factor of safety for K_o is $2.5^2 = 6.25$. In soils with horizontal modulus of subgrade reaction exceeding 1 Kg/cm^3 no buckling is to be expected. Only in extremely soft soils can one expect pile buckling.

Experience with small diameter piles (micropiles) (10 - 30 cm.) confirmed the above calculations.

SPECIFICATIONS FOR PILE DESIGN AND EXECUTION

a. Concrete should have a cube crushing strength of at least 300 Kg/cm^2, a slump of 12.5 cm. with maximum aggregate size of 2 cm.

b. Casted concrete will be vibrated.

c. Allowable stress in the concrete cross section will not exeed 100 Kg/cm^2.

d. Reinforcement will be of deformed bars calculated according to the following:

$$P = 68.15 + 2.08\, A_s$$

where:

P - axial load in tons.
A_s - cross sectional area of reinforcement bars.

e. Reinforcement overlap will be 30 times bar diameter.

f. Helical reinforcement is to be used with steps equal to 15 times bar diameter - but not more than 25 cm..

g. Minimal reinforcement will be 4 No. 10 mm. bars, 3 m. long.

h. Reinforcement cage diameter will be 8 cm. less than hole diameter, hung centrally in the hole.

j. Allowable exentricity will be 3 cm.

k. In the case that clay pockets are encountered during drilling,the piles are lengthened to compensate for loss of friction.

EXECUTION TIME AND COST

Execution time of a typical small diameter pile foundation carrying loads of 50-75 tons is 1 - 2 hours including boring and concrete casting.

In two days 15 foundations can easily be completed. An equal number of footing foundations take about 1 month to complete.

Compared to the conventional spread footings up to 50% saving was realized by the mechanised system producing the small diameter piles.

CONCLUSIONS

1. Small diameter piles proved to be time saving and economic as foundations in karstic rock containing large clay pockets.
2. Loading tests in continuous rock resulted in large skin friction values.
3. Values of skin friction for design are reduced due to the presence of clay pockets.
4. Pile buckling (with horizontal subgrade reaction exeeding 1 Kg/cm^3) is not expected and therefore high compressive stress is allowed in the concrete.
5. The piles which are anchored in the rock are satisfactorily stable in spite of the swelling clay.
6. Specifications for pile design and execution are to be followed very strictly.

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