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The Application of Negative Friction Piles to the Reduction of Settlement

Pieux à frottement négatif pour réduire les tassements

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Summary

Owing to general subsidence in Mexico City, point bearing piles are not recommended there, because nearby structures and public utilities are liable to be damaged, unless suitable steps are taken by the designers to prevent this.

Raft foundations alone or raft foundations combined with friction piles are generally employed. One type of friction pile receives its load through the soil by negative friction, consolidation occurring under the loads imposed by the raft or from other causes. At their upper ends, the piles are free from the raft, the pile shoes resting on an underlying firm stratum.

The author quotes a case of a twelve storey building with this type of foundation, explaining its behaviour in the light of present knowledge. This type of pile can easily be used to arrest settlement, because it can be jacked against a structure. Complex underpinning is not required because no load is transmitted to the pile head.

Introduction

A leading piling contractor in Mexico City has for many years made use of negative friction developed on the shafts of point-bearing piles, to sustain part of the load of many structures.

Negative friction in piled foundations has always been considered as undesirable; because it decreases the load carrying capacity. In Mexico City this problem is particularly serious because of widespread subsidence.

The following is a description of a building supported by negative friction piles.

Description of building

This building has twelve storeys, its weight of 5 300 metric tons distributed over an area of 422 square metres, giving a loading pressure of 1.25 kg per sq. cm. When the building was originally constructed in 1952, this load was taken by 113 timber piles, each 25 cm in diameter, resting on a firm stratum at a depth of 20 metres below the pavement level.

Since many buildings on point-bearing piles were being affected by general subsidence, it was decided to modify the design of the new building and to employ a special type of foundation. It consists of a raft combined with point-bearing piles not fixed to the raft, but with a patented load-transmitting device fixed to their heads (Fig. 1), which allow the foundation to follow the surface subsidence (1952). Fig. 2 shows a plan and cross section of the foundation, with the layout of the piles. In 1953, the piles were unloaded with the exception of those shown in solid black in Fig. 2. Total load transmitted to the pile heads was about 990 metric tons.

Sommaire

Les pieux portant sur la pointe ne peuvent être recommandés dans la ville de Mexico à cause du tassement général de la cité : les immeubles ainsi fondés émergent peu à peu du sol adjacent, provoquant des dommages aux structures voisines et aux installations publiques à moins que des précautions spéciales n'aient été prises dans les projets.

À l'extrémité supérieure le pieu peut traverser librement le radier cependant que la pointe reste sur une couche résistante.

Le cas réel d'un immeuble de douze étages utilisant ce mode de fondation est analysé dans le présent article et une tentative est faite pour expliquer son comportement à la lumière de nos connaissances actuelles.

Les pieux de ce type peuvent être employés pour arrêter aisément un processus de tassement, car ils peuvent être foncés au vérin en prenant appui sur la structure et ils ne nécessitent pas l'emploi de reprises en sous-œuvre compliquées puisqu'aucune charge n'est transmise en tête des pieux.

Subsoil conditions

The nature of the subsoil and the variation of its water content, as well as the unconfined compressive strength with depth; are shown in Fig. 3. Compressibility curves corresponding to samples obtained from test borings on site are shown in Fig. 4, and the liquid limit in relation to the plasticity index is shown in Fig. 5; some points fall on the

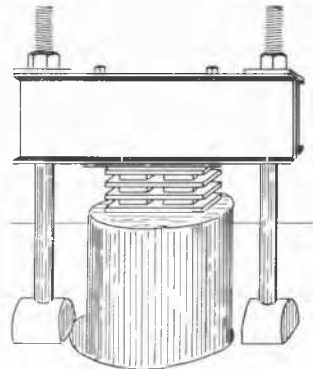


Fig. 1 Device for controlling the load.
Dispositif de contrôle de la charge.

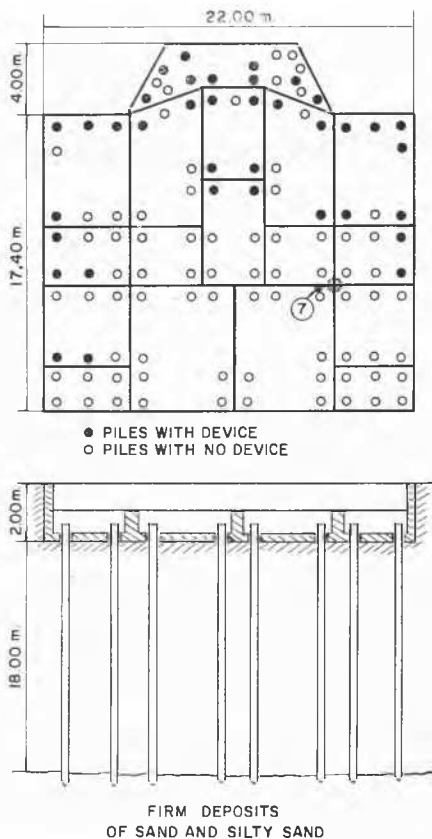


Fig. 2 Plan and vertical section of foundation.
Plan et coupe verticale de la fondation.

A line as anticipated, but two of them relate to organic clays and these are below the A line.

The site is located in an area occupied by lake deposits. Water content and compressibility of the clays are lower than the average and the unconfined compressive strength is higher than the average in this area. The thickness of compressible deposits is 20 metres, which is also less than the average in the area.

Pore pressures were measured by piezometers installed at different depths; the results in Fig. 6 show that very considerable reduction of piezometric head was obtained.

Settlement

Settlement of this building was observed over a period of five years, related to bench marks.

The record for point number 7 (Fig. 1) is shown in Fig. 7. This represents what happened to the building after releasing the loads acting on the pile heads with the exception of these indicated in Fig. 2.

Since the bench marks are located at ground level in a near by park which is not influenced by any adjacent struc-

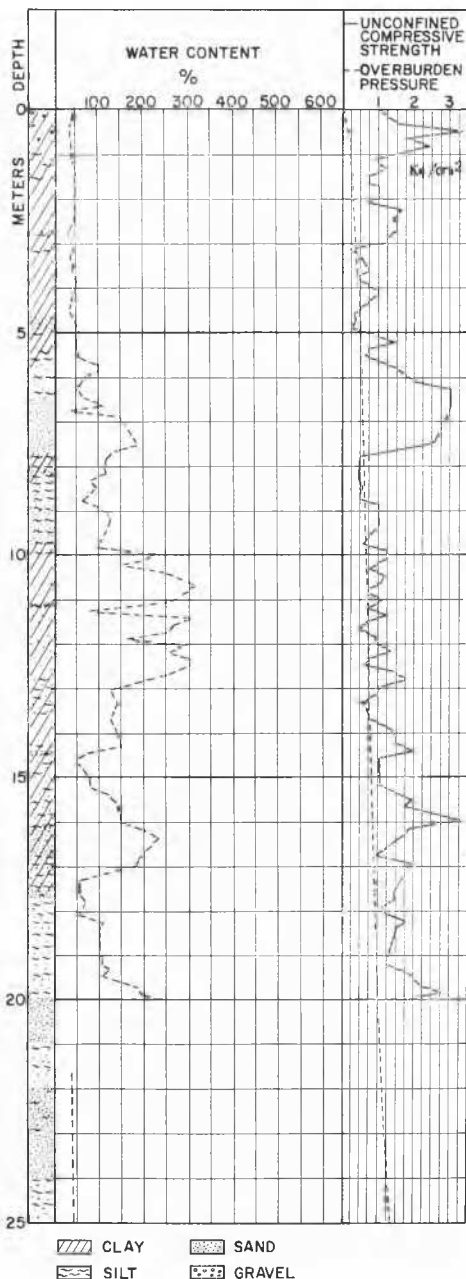


Fig. 3 Subsoil profile and test results.
Profil du sol et résultat des essais.

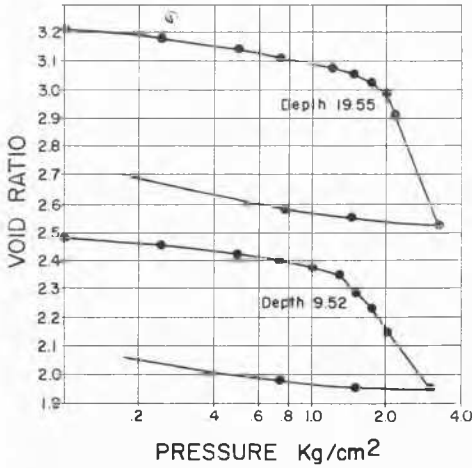


Fig. 4 Compressibility curves.
Courbes de compressibilité.

ture, but which is affected by general subsidence in the area, observation of the settlement time curve proves that when the bench marks settle faster than the building, the rate of settlement appears to be negative.

By assuming that there are no piles, a computation of the final settlement of point number 7 shows that the figure should be about 40 cm. By comparing the calculated with the recorded values, it can be concluded that negative friction has been responsible, for bearing a considerable proportion of the load imposed by the building.

Theoretical considerations

According to ZEEVAERT (1957) a shell is moulded around the pile shaft when a pile is being driven, the thickness of which is equal to the diameter of the pile, and the shearing

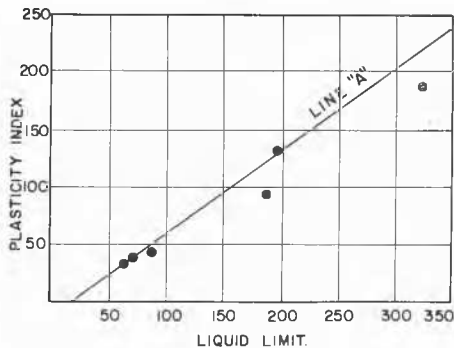


Fig. 5 Plasticity chart.
Classification du sol : plasticité.

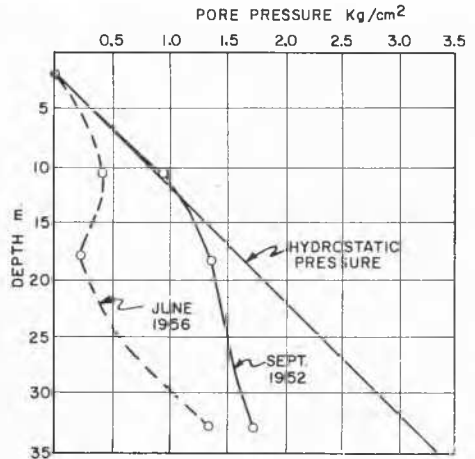


Fig. 6 Variation of pore pressure with depth.
Variation de la pression interstitielle avec la profondeur.

strength in this zone for the local clay of Mexico City is given by : $\tau_f = 0.3q_u$ where q_u is the unconfined compressive strength.

Since relative movement between the piles and the soil corresponding them takes place very slowly, reduction in the shearing strength of the soil is considered for clay (CASA-GRANDE and WILSON, 1951) but this effect is counterbalanced by the increasing strength with time due to consolidation and thixotropy. At present we do not know what the final effect will be.

Reference to Fig. 8 (a) will show how negative friction contributes towards reduction of settlement and how it is developed. The reduction of pore pressure resulting from the lowering of piezometric levels will increase the effective normal stresses represented by the abscissa to the curve *FECI*. Without piles, these effective stresses would be increased by these due to the weight of the building like *CD*,

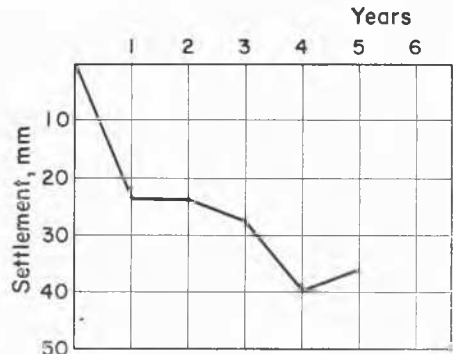


Fig. 7 Recorded settlements.
Tassements mesurés.

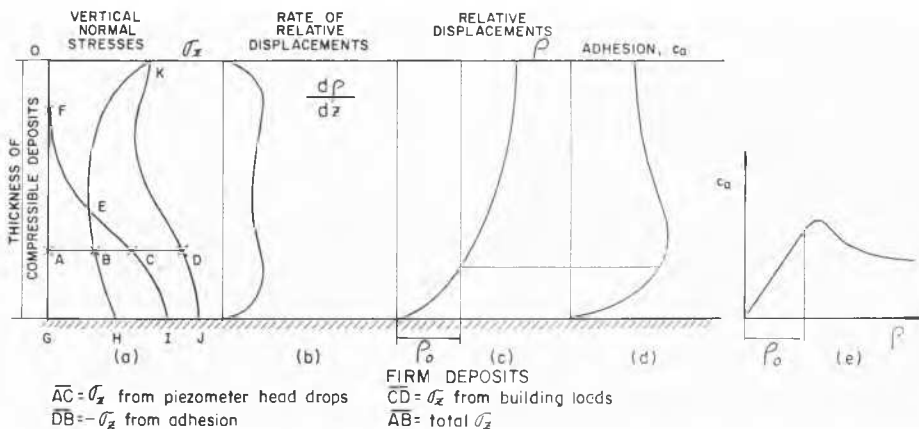


Fig. 8 Distribution of vertical normal stresses, relative displacements and adhesion with depth.
 Distribution des contraintes normales verticales, des déplacements relatifs de l'adhésion en fonction de la profondeur.

obtaining the curve KDJ . These increased stresses cause consolidation of compressible strata, and if the piles are of point-bearing type, negative friction forces are developed at the contact surfaces between the piles and the soil. Negative friction increases normal effective stresses upwards which decreases the σ_z values to those limited by the curve $KEBH$.

Thus the settlements on site due to general subsidence have been reduced because the effective stresses developed from the lowering of piezometric levels have also been reduced by the difference in abscissa from the curves ECI and EBH . This phenomenon has resulted in the formation of dome shaped areas all over Mexico City. Normal vertical stresses imposed by the building have also been reduced by the normal stresses, due to negative friction and the reduced values are those bounded by the curves KE and OFE in Fig. 8 (a). Settlements of the building relative to the ground surface are those computed on the basis of these latter stresses; they are a mere fraction of these obtained without piles, the area $OKEF$ being very much smaller than the area $OKJIEFO$.

The rate of relative displacement between soil and pile (Fig. 8 (b)) can be computed if the curve $KEBH$ which limits the remaining σ_z stresses, and the coefficient of compressibility of the soil are known.

From these values, the relative displacement ρ (Fig. 8 (c)) can be obtained either graphically or by numeral integration.

From pile load rests on site, the relationship between adhesion and relative displacement can be obtained, and the approximate range of values for negative friction force can be determined. A new trial is worked out based upon the computed value of the negative friction, assuming a simple distribution of normal stress due to this force, because the more cumbersome formulae obtained from the Theory of Elasticity are based upon hypotheses which do not apply to this case.

Conclusions

1. Point-bearing piles, the heads of which are free within a raft foundation when settlement of a building occurs, are very effective in substantially reducing such settlement.
2. Such piles have a greater load bearing capacity than positive friction piles, because the adhesion between pile and soil is at its peak value in the first case, and has only a fraction of this value in the latter case.
3. From field data, laboratory experiments and pile-loading tests on site, it is possible to forecast the anticipated settlement of a structure.
4. Negative friction piles are most efficient when the lowering of piezometric levels has influenced the compressible strata penetrated by the piles. The reason for this is that larger relative displacements between the pile and the soil develop maximum values of adhesion along almost the whole length of the pile shaft.

Acknowledgement

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