INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

EFFECT OF SWELLING CLAY ON PILES

L'EFFET DU GONFLEMENT DE L'ARGILE SUR LES PIEUX
ВЛИЯНИЕ НАБУХАНИЯ ГЛИНЫ НА СВАИ

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SYNOPSIS. The problem is discussed of evaluating the forces exerted on piles by the swelling of expansive clay soils, in order to design for adequate resistance and stability. A method is proposed which requires tests on clay specimens which have been wetted under various vertical pressures and conditions of initial moisture and density, resulting in development of corresponding lateral swelling forces. Analysis is made from the viewpoint of the stress-strain behavior of the clay. Results are given for tests made on sections of 25 cm diameter concrete piles which were buried in clay and anchored at their bottom, instrumented to show the loads developed when the clay is wetted. Recommendations for design criteria are given, and a typical analysis furnished.

INTRODUCTION

Bored cast in place concrete piling has been extensively used in many regions where a potentially expansive clay soil is encountered as a foundation material. This method of construction allows for the penetration of the most active upper layers of swelling soil and the transfer of the loads to the more stable deeper strata. However, no generally acceptable design criteria have been established as to the forces acting on such piles owing to the swelling clay environment. The problems involved are presented and some approaches given to allow prediction of the forces involved and how the pile design may take the various factors into account.

GENERAL DESIGN REQUIREMENTS

1) Piling must develop adequate bearing capacity under the worst moisture conditions expected. Since both upward and downward friction forces may develop on the side of the pile in the active zone, only the underlying layers can be taken into account for frictional and base resistance.

2) If the permanent load on the pile is greater than the upward swelling forces, it may be possible to design the pile without reinforcement against tensile forces. However, reinforcement in both the pile and structure is required against horizontal forces from differential clay movements associated with moisture regime variations within and outside of the structure.

3) When swelling forces exceed the pile load the pile should be designed to act as an anchor. It is hence necessary to determine the zone of potential swelling, and the forces which may act against the pile in this zone, as well as the "pull-out" resistance of the anchor portion. Anchoring may be achieved by deepening the pile and/or utilizing underreaming to form an enlarged base. A study of the use of multi-under-reamed piles was made by Mohan et al (1969).

VARIATIONS IN FIELD MOISTURE AND SUCTION

Moisture conditions at a site, and their variations with seasons may be determined by actual measurement of the moisture and/or suction values. An example, after Komornik and Zeitlen (1961), is shown for one Israeli location in Fig. 1a. Such data is a guide as to the anticipated depth of the most active zone. For comparison, there is presented in Fig. 1b a plot of assumed possible suction variations in the soil profile, following the approach of Aitchison and Woodburn (1969). Determination of suction values could have some advantages, particularly if used to predict future design conditions for only partial wetting.

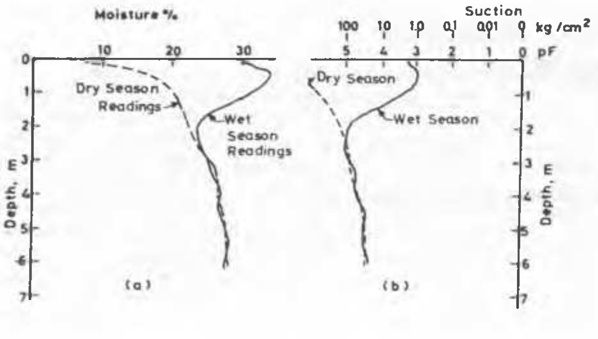

Fig. 1 Site Conditions Prior to Construction

LABORATORY INVESTIGATIONS

Testing in the laboratory should include triaxial shear strength determinations, with pore pressure measurements for saturated specimens, so that failure envelopes may be obtained for effective stress conditions. Fig. 2 shows stress-strain curves for two series of tests where $\sigma_3{}^1$ is effective lateral pressure.

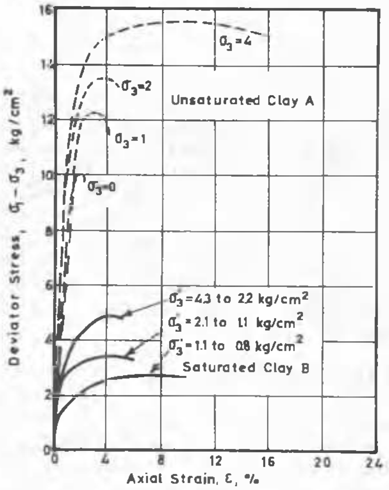

Fig. 2 Typical Stress-Strain Relations from Triaxial Tests

Swelling pressure tests are to be made in special oedometers, instrumented to furnish the lateral pressure, σ_h, associated with particular values of vertical pressure, σ_v, as described by Komornik and Zeitlen (1965). Determinations of the amount of vertical swell and lateral pressure are made for separate specimens which are first loaded and then allowed free access of water. Typical data for one initial condition of density and moisture are presented in Fig. 3.

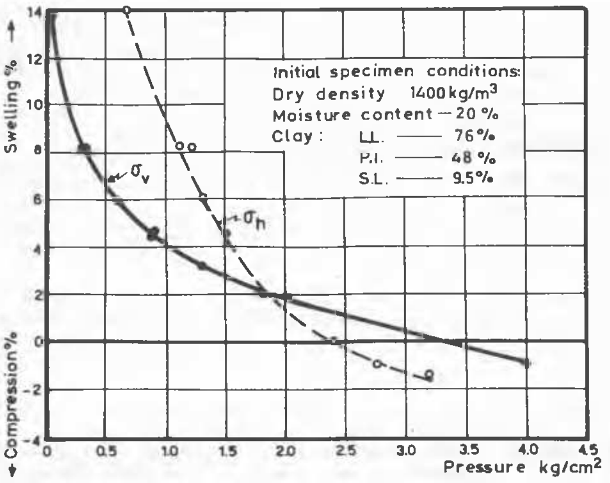

Fig. 3 Typical Functions of Per Cent Swell for Specimens Tested Under Various Vertical Pressures in Oedometer

If this type of data is obtained for the initial moisture and density conditions expected in the field, it will be possible to predict the amount of swell which would occur after wetting at any vertical pressure or conversely, to determine the vertical and horizontal pressures which would be exerted by the soil for various amounts of vertical strain under conditions of no lateral yield. As discussed later, pressures developed under partial wetting are comparable to those found in these tests.

MODEL PILE TESTS IN ISRAEL

Dr. A. Komornik conducted a special research at the Israel Institute of Technology on two instrumented model piles, to determine the forces acting on anchored piles in a clay environment (Komornik, 1962). The measuring of the forces was accomplished through the use of electrical resistance and vibrating wire gauges mounted to the reinforcement of the piles. The reinforcement was made of four 1-1/2 inch steel pipes. The gauges were cemented to the inner face of the pipes and the wires connecting the gauges to measuring devices passed through holes in the pipe. The length of the piles was 1.65 meters and they were divided into five vertical sections, the height of each being 33 cm. The diameter of the piles was 25 cm. The piles were anchored to rock through a large pressure cell resting on iron profiles. The profiles were inserted through an excavated channel underneath the floor and covered with reinforced concrete to the level of the floor of the room. A drum of internal diameter of 1.25 m, filled with clay at a predetermined moisture and density, surrounded the lower four sections of each pile.

The drum walls were in sections which could rise as the clay swelled. Pressure cells were installed for measuring swelling pressures on the drum walls as well as on the periphery of the piles. Two types of pressure cells were used: small cells instrumented with electrical resistance strain gauges and installed within the piles, as well as large cells instrumented with vibrating wire gauges installed in the walls of the drums. The clay was placed at a density of 1400 kg/cu., and a moisture content of 20%. The first portion of the program was aimed at finding the vertical frictional swelling forces. The clay surrounding Pile I was simultaneously wetted throughout the entire height of the pile. Uniform wetting of the clay was sought by providing access to water through horizontal sand layers. The swelling of the clay produced tensile forces in the pile reinforcement. Contact shear stress between concrete and clay reached as much as 2.4 kg/cm^2, with an average value of 1.6 kg/cm^2 where maximum anchoring load was obtained. Despite all efforts to produce homogeneous compacted clay and uniform wetting conditions, the tensile forces varied across the pile section. The forces developed attained their maximum values within several days in spite of the relatively thick clay layers. It was noted, however, that no appreciable swelling of clay layers occurred during that period. It was thus indicated that there was no need for a significant change in moisture content to produce swelling forces. In fact, a moisture change of the order of 1 to 2 percent was sufficient to develop the maximum tension in the pile. This phenomenon is important from two points of view: the first is, that maximum swelling forces should be expected even with small changes in moisture content, such as under covered areas. Similar findings were reported by Kassiff and Ben Shalom (1971) in their measurements of swell pressure with controlled and gradual moisture content increase. The second is, that for such changes the shear strength of the clay proper and the shear resistance between clay and concrete can be developed, thus making possible the full transmission of swelling forces from the clay to the pile. The shear strength of the clay and the friction between clay and concrete were found to vary with the normal pressure as measured by the pressure cells on the pile face. In the second phase of the program, a second pile, Pile II, was subjected to uneven wetting through pipes placed in vertical holes drilled beside the pile and backfilled with sand. A solid drum was used, so that some confinement of the clay occurred. The upward shear forces on the pile reached about the same average value of 1.6 kg/cm^2 that was found for Pile I, or about one-half of the lateral pressures measured. It may be remarked that moments of as much as 600 kgm were measured on the pile during the test, due to uneven wetting conditions. On Fig. 4 are plotted the results of the lateral pressure readings on both piles, together with, for comparison, the vertical and horizontal pressures found in oedometer testing. Other data on this figure shows the vertical swell of the clay layers next to the piles, plotted against the overburden pressure. It is of particular interest to note that except for the uppermost layer of clay next to the piles, swells were only several percent, and horizontal pressures exceeded that shown on the oedometers.

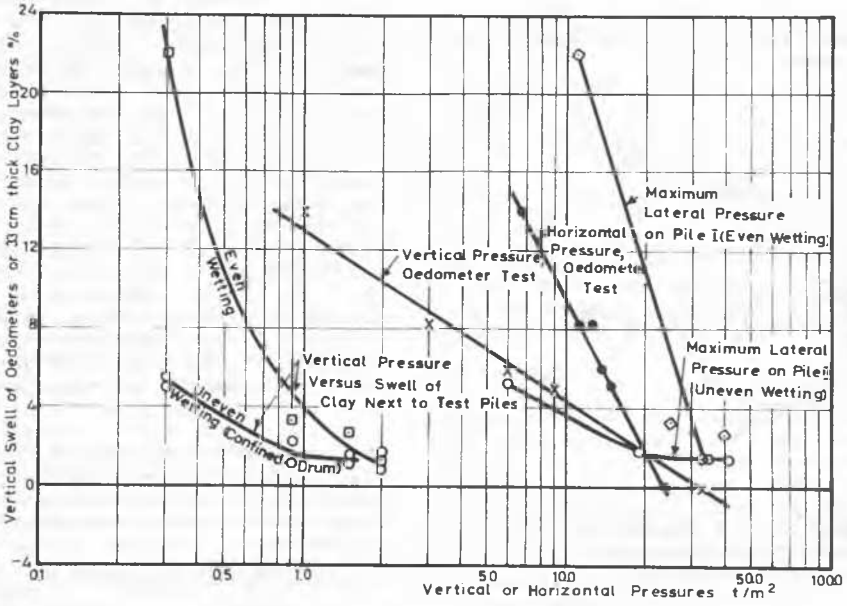

Fig. 4 Lateral Pressures on Piles versus Amount of Swell

PREDICTION OF FRICTIONAL FORCES AGAINST A PILE

The upper portion of an anchored pile may be considered, as in Fig. 5. If the stresses are considered in the middle of a zone free to swell when wetted (Element A of Fig. 5), the values of vertical swell and lateral pressure would correspond to those developed in a test as shown in Fig. 3, with vertical pressure equal to the overburden load.

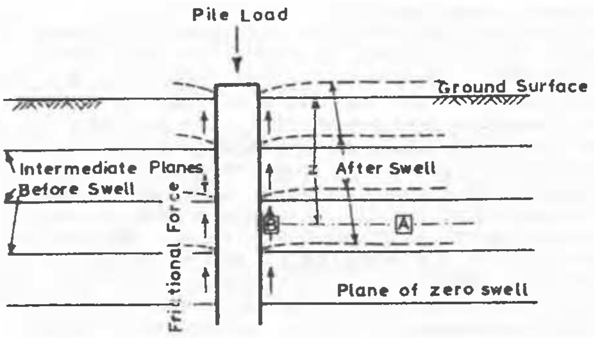

Fig. 5 Anchored Pile in Swelling Clay Media

Lateral movements are not permitted in either the field or the laboratory test. Stresses may be represented by circle A in a Mohr diagram plot (Fig. 6). If the clay is completely prevented from swelling (zero percent vertical swell in Fig. 3), the stresses would increase to values as shown in circle A^1 of Fig. 6. It may be observed that the principal stresses remain vertical and horizontal in both cases.

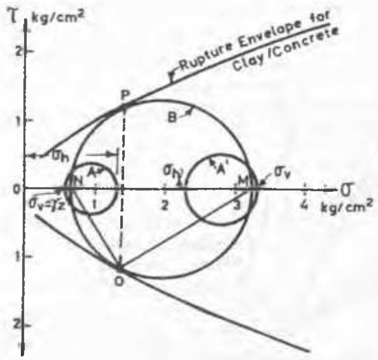

Fig. 6 Mohr Circle Representation of the Stresses Developed in Swelling Soils

If the element B, next to the pile in Fig. 6 is examined, it may be recognized that the development of frictional forces cause rotation of the principal planes as the swelling occurs. Upward movement is greatly restrained by these frictional forces, in addition to the overburden pressure. Lateral movement cannot occur. Hence, the major principal stress will remain high, being reduced from the σ_v values of circle A only because of the shear strains occurring concurrently with development of the frictional forces along the pile circumference.

For clay at a particular moisture content, the value of maximum shear stress which can be developed, and the strain required for its development are dependent on σ_3' (Fig. 2), which itself depends on the amount of movement which occurs (Fig. 3).

For analysis, an average value of axial strain necessary to develop full shearing resistance may be taken for an assumed lateral pressure, and then converted to shear strain ε, and hence to axial strain in the oedometer. Thus, plots of the type of Fig. 3 may be used to find the lateral and vertical pressure corresponding to the vertical strain value. It is proposed that the principal stress values thus found correspond approximately to the major principal stresses acting in the clay directly adjacent to the pile.

It would then be possible to represent stress conditions next to the pile by plotting a circle B on Fig. 6, since both the maximum principal stress (M) and the rupture envelope are known. From circle B it may be observed that M and N represent the major and minor principal stress values and that the applicable rupture envelope is that corresponding to shear failure between concrete and clay at the pile interface. In the absence of special tests of concrete/clay surfaces, such shear values may be approximated by multiplying the shear strength of the clay by a factor (between 0.5 to 0.8) allowing for reduced friction. OM and ON represent the directions of major and minor principal stress planes. The σ and τ values of point P represent the normal and shear stresses in the soil next to the face of the pile, (Element B) as represented by the plane OP.

The value of shear stress developed on the pile surface may be integrated for the area involved, in order to find the total tension forces developed in the pile by the swelling of the clay.

APPLICATION TO PILE DESIGN

To illustrate an application of the proposed method, a 40 cm diameter cast in place concrete pile, 10 meters long, is considered as carrying a 20 ton load in a swelling clay.

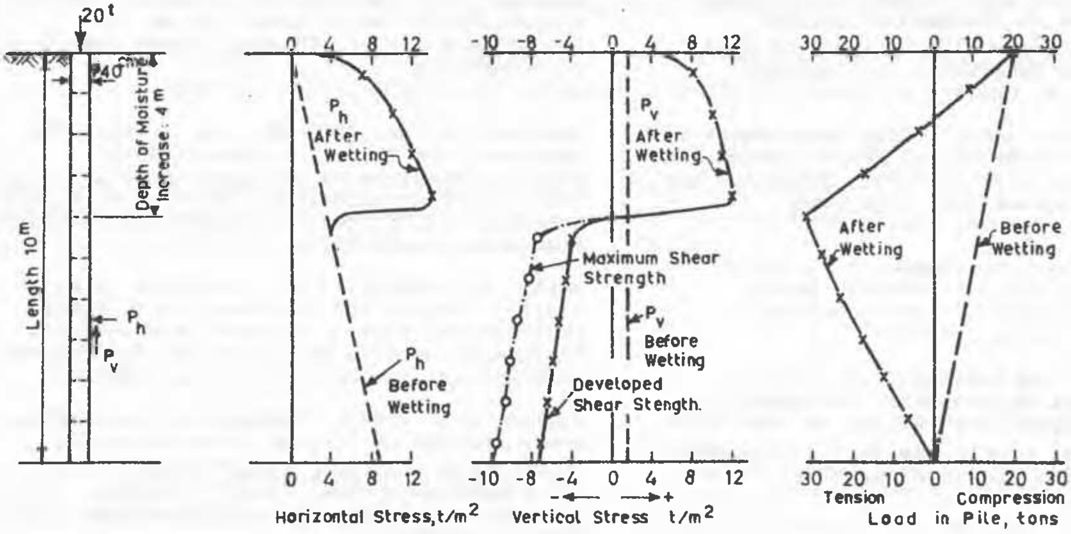

Fig. 7 Example of Application to Pile Design

The pile is rigid in relation to the clay. The soil swelling behavior corresponds to that shown in Fig. 3, with possible wetting to a depth of 4 meters. Before wetting, the horizontal pressure, p_h, may be computed by assuming at rest conditions, and vertical shear stress, p_v, may be estimated by assuming uniform shear resistance throughout the depth and negligible end resistance. Obviously, other assumptions may apply for a particular case. After wetting, the horizontal pressure will increase to values which are proposed to be similar to the lateral pressure developed under the same surcharge in laboratory tests as shown in Fig. 3 and Fig. 4. The vertical strain in the field, it is true, may in reality be somewhat lower than in the laboratory studies, and, as the test pile behavior showed, the lateral pressure on the pile may be higher. However, the resulting shear stress is expected to be comparable because the lesser strains would result in development of less than the maximum shear stress for the higher pressure. To derive the design vertical shear stress against the pile, Fig. 6 may be employed to find the value of τ corresponding to the computed p_h, and defining it as p_v. Results of this analysis are shown in the diagrams on Fig. 7. For the case considered, where anchoring was achieved by use of the buried portion of the pile in stable material, the anchoring shear stresses were computed on the assumption that extension of the pile was negligible and that a constant proportion of maximum shear strength would be developed for the full anchor length. Should a pile with an enlarged base have been considered, an important point is that the upward swelling would involve net uplift forces, in this example, of about 30 tons, and appreciable uplift of the pile may be required to mobilize adequate resistance. The use of straight anchor piles takes advantage of the stiff lower strata to provide the anchoring reaction with minimum heave. The proposed method also allows for the use of isolating envelopes, such as asphalt, to reduce the frictional forces on the upper portion of the pile. In such a case, the pertinent Mohr envelope should be modified to allow for the reduced friction value, but otherwise the same approach is applicable.

OTHER PILE TESTS

Particular note should be made of a pile test in expansive soil in South Africa, reported by Donaldson (1967), in which a 9"concrete pile was found to develop more than 17,000 lb. tension from wetting of the upper 15 feet of strata. Field experiments are also mentioned in a report from Russia by Sazhin (1968), which notes that more than 9 tons of uplift load was developed in a 20 cm diameter cast in situ pile when placed only 2 meters deep. Soil data was not available to allow checking of the method described above.

CONCLUSIONS

Analysis of the stresses involved in the uplift forces of swelling clay against piling show that it is possible to approximately evaluate them by use of laboratory tests for shear, and by swelling pressure studies. Small scale tests have shown shear stresses and swelling pressures which were of the same magnitude as would have been predicted by the proposed method.

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