Earth Pressure on Retaining Walls in Cuttings in Clay

Poussée des Terres sur les Murs de Soutènement dans les Tranchées Argileuses

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SYNOPSIS Retaining walls, nowadays made as large diameter pile walls or other rigid structures, can be installed before the excavation is made of the corresponding earth bench. Small deformations of the ground occur during the excavation of the preceding benches. Therefore the earth pressure acting on the wall has a magnitude between that of the pressure at rest and that of the active earth pressure. Another problem is the stability of slopes of the preparatory cutting in the period of pile boring.

INTRODUCTION

Horizontal forces present in the clayey earth masses are often large, the coefficient K_o being of the order of 1 to 1.5, although even greater magnitudes have been measured (Marchetti, 1979). After the first benches of a cutting have been excavated a displacement of the soil mass takes place towards the excavated area. This is accompanied by a stress release in the soil mass within the slope. Let us assume that a large diameter pile wall or other rigid structure is to be carried out before the excavation of the successive bank begins. Two important questions appear. First, whether the slopes of the provisory stage of the cutting will remain stable during the period of the pile boring, and second, how large the earth pressure will be acting on the pile wall.

STATIC ANALYSIS

The finite element method was used to answer the questions. The incremental analysis was adopted to simulate the unloading of the soil during excavation. Three depths of a cutting (10 m, 13.5 m, and 16 m) and four coefficients of lateral pressure K_o (0,5, 0.75, 1, and 1.5) were considered. The slope angle was 18°. A nonlinear, stress-dependent stress-strain behaviour was assumed. The basic magnitudes of the deformation moduli of the modelled stiff Neogene clay were 7000 kPa for loading and 21000 kPa for unloading, under the conditions of the all-round pressure of 100 kPa. The normality condition was respected to compute the shear strain volume changes but the results were corrected during the iterative processes in order to obtain the realistic values of dilatancy, corresponding to the measured values. These are the thickness of the slip surface 1 mm, its maximum increase owing to dilatancy 0.3 mm, shear strain at which the dilatancy begins to develop in the slip surface 0.5 to 3, the latter value being valid for the sum of principal stresses equal to 1000 kPa, above which the dilatancy is assumed to change into contractancy. The contractant behaviour was simulated by a more intensive decrease in the tangent deformation moduli associated with the decrease of the factor of safety in shear. The shear strength parameters were defined in terms of stress invariants, nevertheless, they can be compared to the values of 25 kPa and

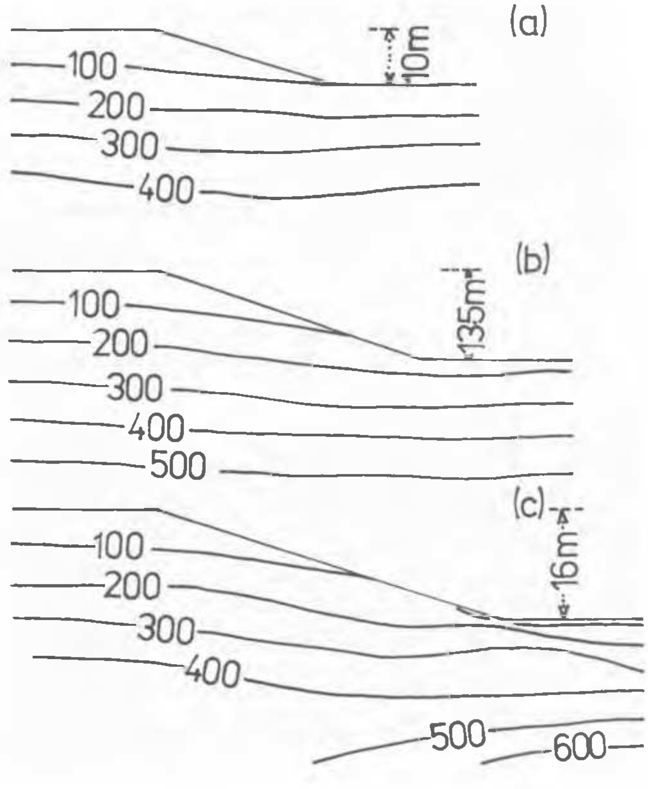

Fig.1 K_o=1, no ground water. Isolines of horizontal normal stress (kPa) for the excavation depths 10 m, 13.5 m, and 16 m

18° in Mohr's representation. A decrease in the shear strength was assumed to exist near the co-ordinate origin, in order to simulate the effect of frost and rain-water on the surface layers of the clay. Both the lack and the presence of ground water were considered.

RESULTS

(1) <u>Stability of slopes of preparatory excavations</u>

A method which may be called a "horizontal forces equilibrium method" was used to examine the stability of slopes. In Fig.1 the isolines of equal horizontal stresses are shown which remain in the soil mass after excavating the provisory cutting necessary for the boring of the pile wall. From the diagrams the horizontal forces acting on the soil body located above a potential slip surface may be computed. The forces are plotted in the form of a loading diagram in Fig.2, for the case of K_o=1, no

not consider the forces as they would be activated if the limit equilibrium was achieved. But the applied method takes into account the existence of horizontal forces that can produce a progressive failure which the classical stability analysis cannot detect. Moreover, a good coincidence has been obtained with the results of the finite element method in other cases. For example, in the case of K_o=0.75, D=16 m, it yields F=1.94, while the finite element method yields F=1.8, and the "classical" stability method F=2.1. In the case of K_o=1.5 the cutting cannot be excavated to the depth of 16 m, because the slopes would fail. For D=13.5 m, the finite element method yields F=1.4, the classical analysis F=2,6, and the "method of horizontal forces" F=1.6, if the yielding of the soil as described by Mencl (1977) is considered.

The influence of forces X is relatively small because they diminish the factor of safety by only 3 to 4 per cent. Therefore their magnitude may be estimated by guess. In order to obtain a notion on the development of these

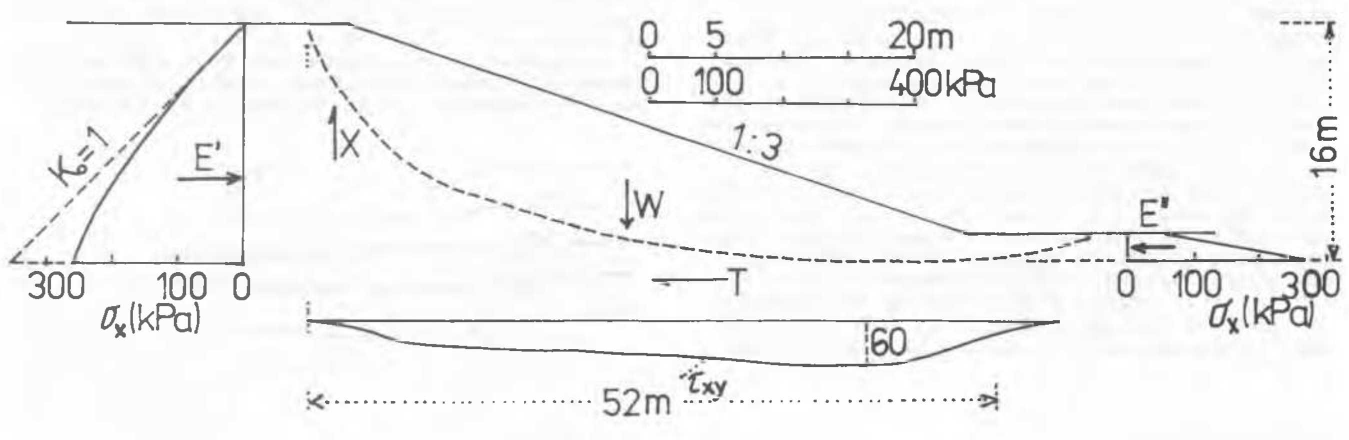

Fig.2 K_o=1, no ground water. Loading diagram of horizontal forces E′, E″, T and forces X, acting on a body of soil located above the potential slip surface

ground water present, depth of the cutting 16 m. The sum of forces E′ and E″ is resisted by horizontal shear force T acting along the potential slip surface. Loading diagram of horizontal tangential stress is also plotted in Fig. 2. Force T equals 2384 kN. The sum of forces ΣE=T=2384 kN can be compared with the limit resistance in the horizontal direction given by $S=(W-X)\tan\varphi + cL = (6700-374)\tan 18° + 25 \times 52 =$ =3355 kN. This gives the factor of safety F= =3355/2384=1.41. This value is not far from that of 1.54, obtained by using the finite element analysis, but is far from F=2.1, obtained from the "classical" methods of stability analysis.

It may be objected that the method of equilibrium as applied does not satisfy the principles of stability analysis, because it does

forces isolines of tangential stresses are shown in Fig.3 for the cases of K_o=1, D=16m, at both the ground-water conditions (the original water table at the depth of 8 m). The crucial question is that of the reduction in the magnitudes of forces E. These can be investigated in two ways. Either from the isolines of the horizontal stress, as they have been shown in Fig. 1 for the case of K_o=1. Or from the loading diagrams as plotted on the sides of Fig. 2, also for the case of K_o=1. The advantage of the latter of the two representations is that the reduction in the horizontal stresses caused by the excavation is perspicuous. In order to be useful to both the approaches, the isolines of horizontal normal stress are plotted in Fig. 4 for K_o=1, in the presence of ground water. Fig. 5 illustrates the case of K_o=1.5

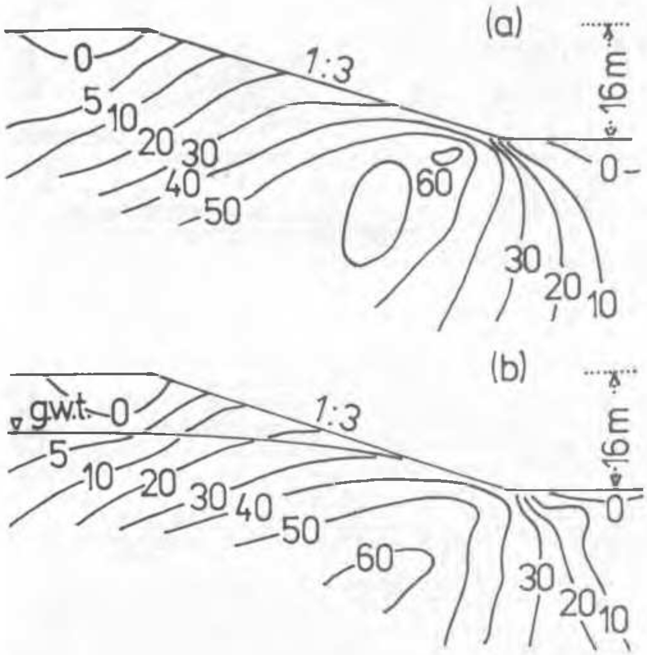

Fig.3 Isolines of tangential stress τ_{xy} for K_o=1, D=16 m, (a) no ground water present, (b) ground water table at the depth of 8 m

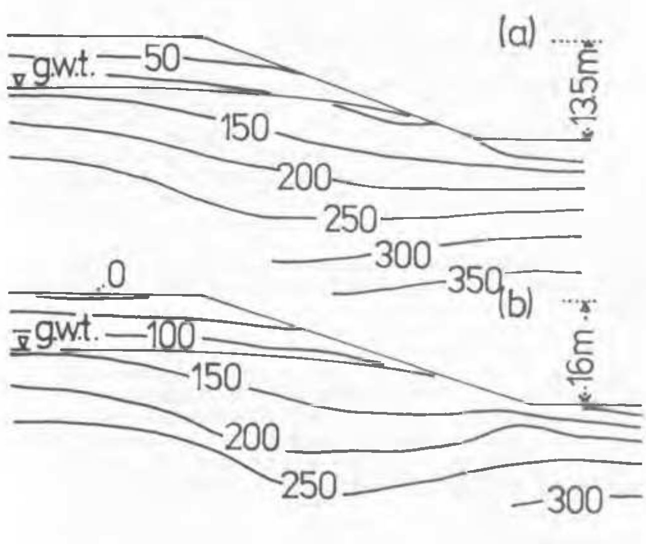

Fig.4 Isolines of horizontal normal stress (kPa) for K_o=1, and depths (a) 13.5 m, (b) 16 m, with the presence of ground water table at the depth of 8 m

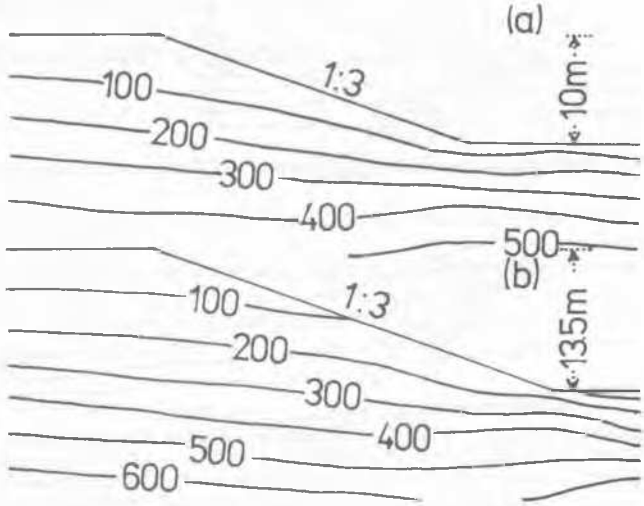

Fig.5 Isolines of horizontal normal stress for K_o=1.5 and depths (a) 10 m, (b) 13.5 m, no ground water present

and Fig.6 that of K_o=0.75. The latter case is probably infrequent but can occur in cuttings crossing elevated hummocks. For the purpose of the second approach two more loading diagrams are shown in Fig.7. The three loading diagrams (Fig.2 and Fig.7) probably can serve as patterns for other cases, but the authors should like to elaborate a "pattern book" for several cases corresponding to the common geological situations. This could not, of course, substitute more elaborate analyses when serious cases (e.g. deeper excavations, large horizontal stresses in the ground) occur.

(2) Earth pressure on rigid walls in cuttings.

The reduction in forces E caused by the excavation is accompanied by a horizontal rebound of the slope mass (Fig.8). These displacements are too large to be shared with by a rigid wall. The forces a simple wall is capable to resist, are of the order of only 250 kN and therefore stiff anchored pile walls are necessary. Therefore, when a conservative solution is aimed, the horizontal earth pressure, acting on the wall, should be calculated from the horizontal stresses present in the ground when the depth of the cutting reaches to top of the future pile wall. The diagrams shown in Fig. 1, 4, 5, and 6 can, therefore, be helpful when estimating the horizontal earth pressure acting on a wall at this mode of solution.

The following results may be recorded:

(i) K_o=0.5, no ground water

The top of the wall at the depth of (m)	10	13.5	16
the bottom of the cutting at the depth of (m)	16	19.5	22
the horizontal earth pressure: at the top of the wall (kPa)	30	40	50
at the level of the cutting bottom	120	120	120

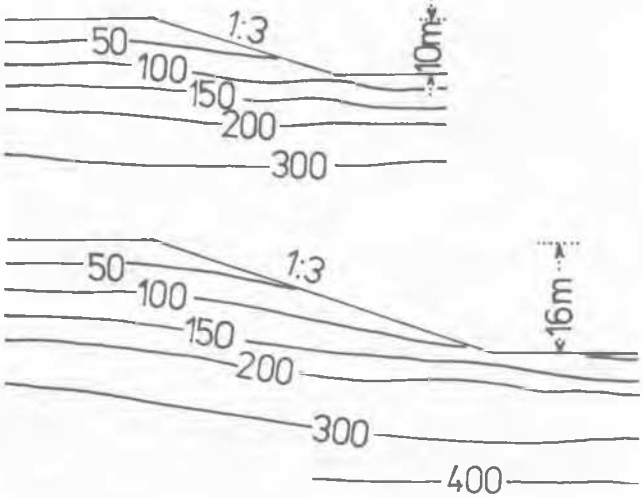

Fig.6 Isolines of horizontal normal stress for K_0=0.75 and depths (a) 10 m and (b) 16 m, no ground water

(ii) K_0=0.75, no ground water
the top of the wall at the depth of (m)
10 13.5 16
the bottom of the cuttings at the depth of (m)
16 19.5 22
the horizontal earth pressure: at the top of the wall (kPa)
90 110 120
at the level of the cutting bottom
200 215 240

(iii) K_0=1, no ground water
The top of the wall at the depth of (m)
10 13.5 16
the bottom of the cutting at the depth of (m)
16 19.5 22
the horizontal earth pressure: at the top of the wall (kPa)
100 110 120
at the level of the cutting bottom (kPa)
260 290 360

(iv) K_0=1.5, no ground water
The top of the wall at the depth of (m)
10 13.5
the bottom of the cutting at the depth of (m)
16 19.5
the horizontal earth pressure: at the top of the wall (kPa)
100 250
at the level of the cutting bottom
400 450

(3) Decrease in the earth pressure caused by the displacement of the wall. Fig. 8 shows that a pile founded at the depth of 12 m below its top, will experience displacements at the toe after the cutting will be excavated to a full depth. This will decrease the loading of the wall and the magnitudes of the earth pressure, as outlined in the foregoing will decrease. The reduction will be of the order of 10 kPa at the top and 20 kPa at the level of the bottom of the cutting, respectively.

CONCLUSIONS

Horizontal compression present in a clay mass under the natural conditions decreases after a cutting has been excavated. Several data showing the intensity of the decrease have been outlined. The knowledge of the magnitudes of the horizontal forces that have remained in the soil mass makes it possible to compute the factor of safety of the slope and the earth pressure acting on a retaining wall.

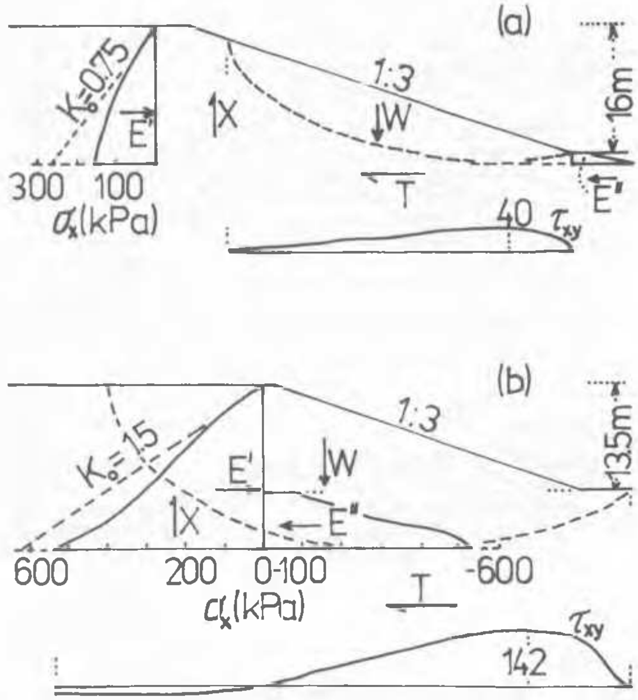

Fig.7 Horizontal normal and tangential forces acting on the reverse of the potential slip surfaces; (a) K_0=0.75, D=16 m, and (b) K_0=1.5, D=13.5 m, no ground water

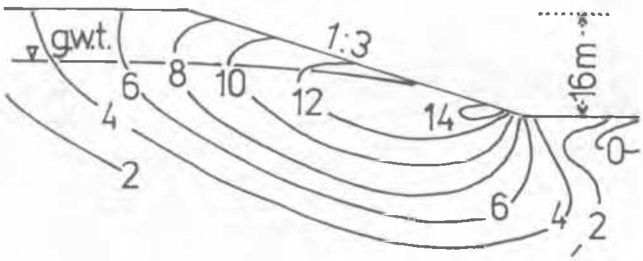

Fig.8 Horizontal displacements (m) of the soil mass in a slope of the 16 m deep cutting, K_0=1

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