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Uncertainty in the classical analytical design approach of excavations on soft soils

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ABSTRACT: The classical design approach of excavations on soft soils usually leads to unrealistic depth of embedment and excessive deflection of the bottom of the wall. The National Working Group "Excavation" EAB of the German Geotechnical Society is at present preparing a draft recommendation for the design of excavations on soft soils. Within the framework of the draft recommendation, a number of comparative analysis, both analytical and numerical, had been conducted and a new design as well as construction approaches had been recommended.

1 INTRODUCTION

The National Working Group "Excavation" EAB of the German Geotechnical Society is at present preparing a draft recommendation for the design of excavations on soft soils. With in the framework of the draft recommendation, a number of comparative analysis, both analytical and numerical, had been conducted. These comparative studies reveal that the classical design approach for excavation on soft soils usually leads to unrealistic depth of embedment and excessive deflection of the bottom of the wall, specially, for deep excavations with ground water located at a shallow depth and surcharge load from the nearby structures. In such situations, experiences show that the depth of penetration based on the classical approach may exceed more than twice the depth of excavation.

The draft recommendation has assessed many design and construction cases, however the paper shall focus only on one case of excavation as shown in Figure 1. The paper shall present the uncertainty in the classical design approach, and the new recommended design and construction approaches with the help of comparative analytical and numerical studies and by means of an example.

2 CLASSICAL APPROACH

The first step in the design of a retaining structure is to determine the depth of penetration of the wall. The free or/and fixed earth support methods of determining depth of embedment usually give excessively large depth of penetration for excavations on soft ground independent of the number of struts. Figure 1 shows a typical excavation with depth of excavation 6 m, two rows of struts at a spacing of 2 m and a bottom support either in the form of soilcrete or reinforced concrete beams. The excavation is supported by a sheet pile type Hoesch 134. It was assumed that a building with approximate surcharge load of 50 kN/m² exists at a distance of 2 m behind the wall. The traffic load during the construction was assumed to be 10 kN/m². The following soil parameters were assumed for the idealized excavation profile in Figure 1.: $\gamma = 19$ kN/m², $\varphi_s' = 25°$, $\delta = (1/3)\cdot\varphi_s'$, $R_f = 0.90$, $m = 0.80$, $K_0 = 1 - \sin\varphi_s'$, $\nu = 0{,}37$; $E = 5{,}2$ MN/m², $p_{ref} = 100$ kN/m², $E_{50\%} = 2{,}6$ MN/m², $E_{ur} = 15{,}6$ MN/m², $E_s = 4$ MN/m². The definition of the symbols are given in Appendix.

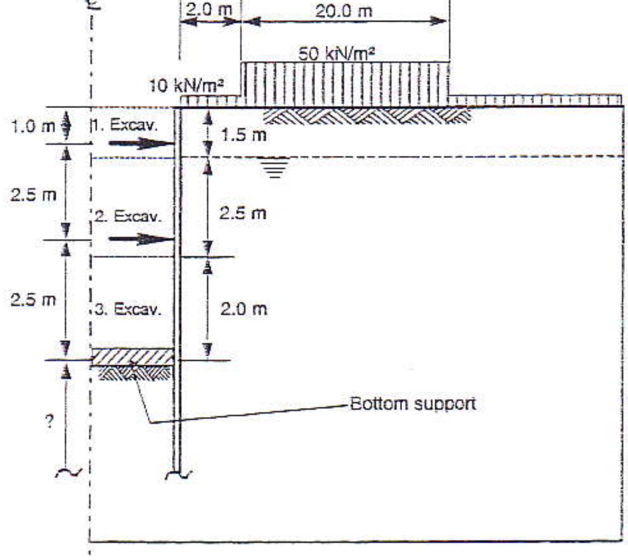

Figure 1. Idealized excavation profile

Using a GGU program, Verbau 2.12 (an analytical program for the design and analysis of retaining structures) and assuming a global safety factor of 2.0 for the passive resistance, the penetration depth was found to be 11.7 m and 17.3 m based on the free and fixed earth support methods respectively. This values are almost twice and three times the depth of excavation respectively, and result in a very large bending moment in the wall, which makes the structure uneconomical.

3 THE NEW DESIGN AND CONSTRUCTION APPROACH

The following sections present the new recommended design and construction approaches in the draft recommendation.

3.1 Construction measure

Excavation with more than 5 m depth of excavation may need additional support at the bottom of the excavation at least before the final excavation, for example after the 2nd excavation stage in Figure 1. The way in which the bottom supports are installed, are shown schematically in Figure 2. Figure 2a shows stepwise insertion of the reinforced concrete beams at the bottom of the excavation after the second construction stage. The construction begins somewhere at the middle of the excavation and proceeds along the length of the excavation. The hole for the installation of the bottom beam should be narrow enough in order to keep the deflection of the wall as much as possible minimum. This type of construction seems to be more appropriate for long excavations. The second method of providing bottom support before full excavation is the soilcrete method as shown in Figure 2b.

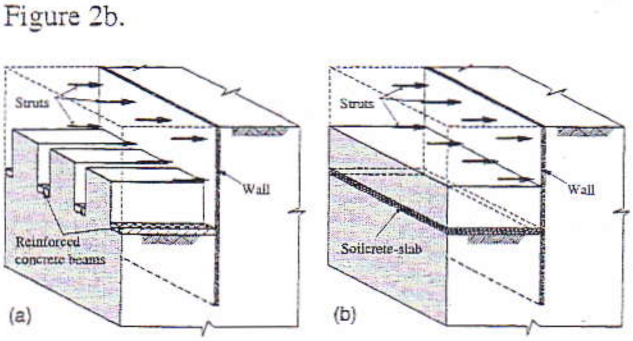

Figure 2. Stepwise installation of the bottom support.

3.2 Determination of the depth of embedment

According to the new draft recommendation of EAB [1], the depth of penetration in the case of excavations with stepwise introduced bottom support shall be determined before the introduction of the bottom support, for example after the 2nd excavation stage (Fig. 1) but before the installation of the 2nd rows of struts and bottom support. This is based on the assumption that the bottom support will provide sufficient support to the wall at the bottom even after the final excavation. For the given example in Figure 1, the depth of penetration is found to be 8.1 m. This penetration depth will be used for further construction stages.

3.3 The distribution of the active earth pressure

The active earth pressure in excavations on soft soil deposits may be calculated based on the classical earth pressure theory provided that the deformation of the wall at top is more than the deformation at the bottom of the excavation due to the first excavation phase. Otherwise, if on one hand the first strut is prestressed and on the other hand sufficient passive resistance is available at the bottom of the wall, a superimposed earth pressure, for instance, trapezoidal or rectangular type distribution, may be assumed.

3.4 Passive resistance

In the case of excavation with stepwise installed bottom support in the form of a soilcrete or reinforced concrete beam as shown in Figure 2, the bottom support is assumed to secure the equilibrium of the forces acting on the wall. Provided that the bottom support is already in position before a considerable deformation of the wall at this location occurs, it may be assumed that the original earth pressure at rest governs the earth pressure distribution, even after full excavation. However, because of the rotation of the principal stresses directly below the bottom slab, full mobilization of the passive pressure may be assumed in this zone. In other words, up to the intersection point of the passive earth pressure distribution at limit state and the earth pressure at rest, the passive pressure at limit state governs the reaction and thereafter the earth pressure at rest (see Fig. 3).

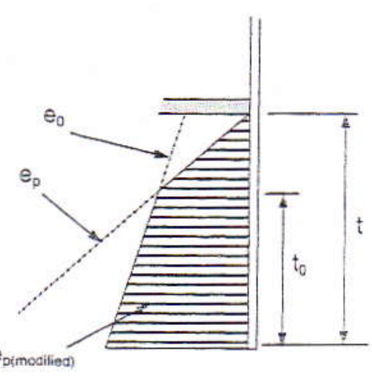

Figure 3. Modified passive resistance

However, in the case of deep excavations in soft deposits with ground water located at shallow depth and subjected to an additional surcharge load from nearby structures as shown in Figure 1, the sum of the forces acting on the active side of the wall below the bottom of excavation is much lager than the passive resistance given in Figure 3 (see also Fig. 5). This results in an excessive and unrealistic deformation of the bottom of the wall in analytical analysis as shown in Figure 4. Figure 4 shows the sum of the horizontal deflections of the wall including all the previous stages. On the other hand, a comparative numerical analysis using FEM program PLAXIS version 7.2 shows that the deflection of the wall at the bottom is not as such exaggerated as it was shown in the analytical result (Fig. 4). The earth pressure distribution on the passive side from the numerical analysis in Figure 5 also shows that there still exist a higher passive resistance than it was assumed in the modified approach. Based on the above facts, the passive pressure diagram in Figure 3 was once more modified to include a subgrade reaction in order to provide an additional reaction at the bottom of the wall as shown in Figure 6. The subgrade reaction k_s may be approximated from

$$k_s = \frac{E_s}{t_0} \tag{1}$$

A comparison of the horizontal deflection at the bottom of the wall from analytical analysis (with and without the subgrade reaction) and numerical method is shown in Figure 7. Figure 7 does not include the horizontal deflection of the wall in the previous excavation stages. It appears from Figure 7 that there is a good agreement between the analytical method with the subgrade reaction and numerical results. Similarly, Figures 8 and 9 also show a relative fair agreement between analytical and numerical results of the passive earth pressure and the bending moment distributions of the wall respectively.

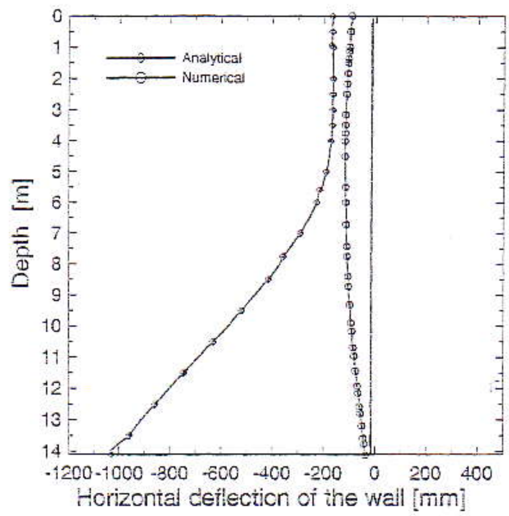

Figure 4. Comparison of the horizontal deflection of the wall

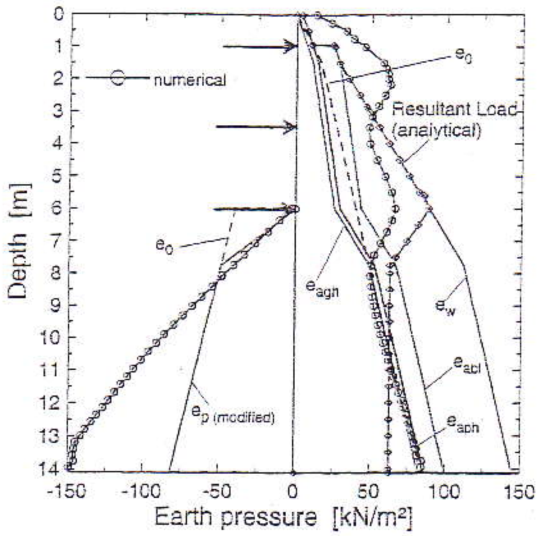

Figure 5. Comparison of the earth pressure distribution

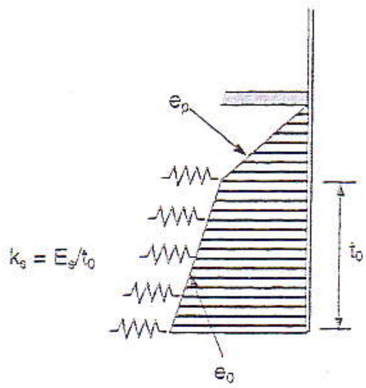

Figure 6. Modified passive resistance with subgrade reaction.

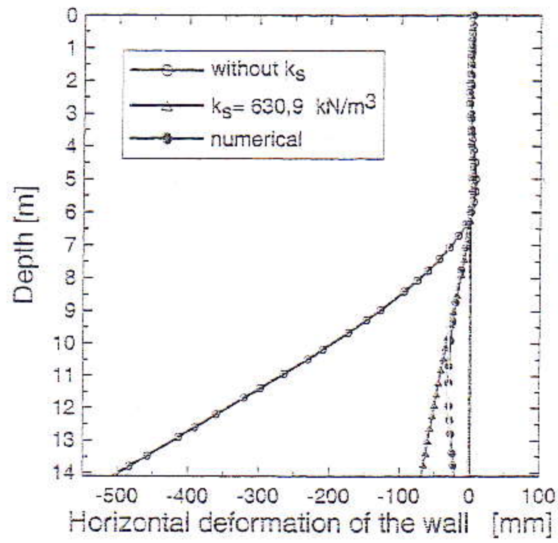

Figure 7. Comparison of the deflection of the wall

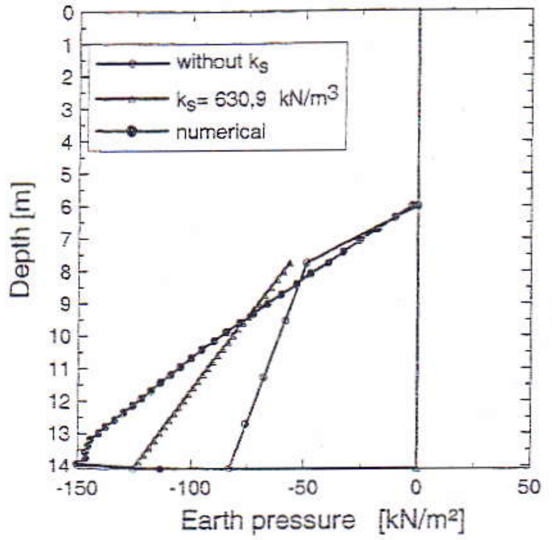

Figure 8. The passive resistance with and without a subgrade reaction

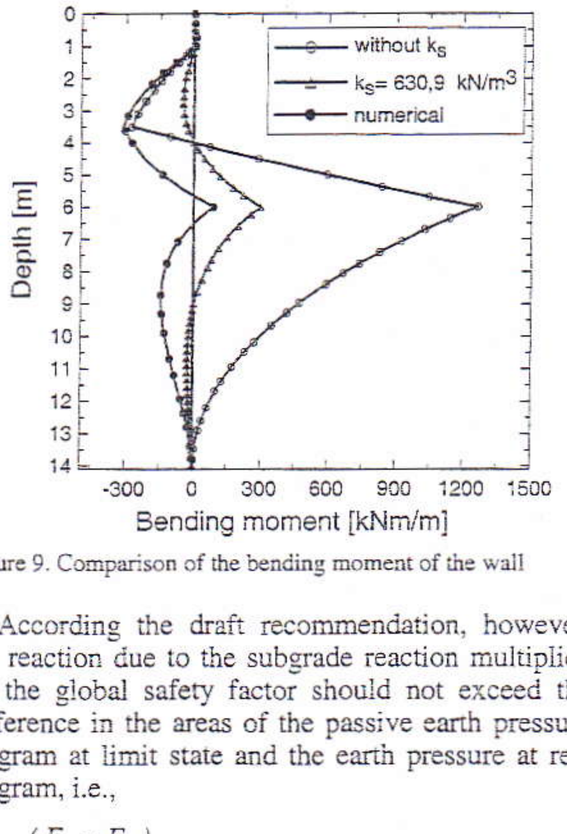

Figure 9. Comparison of the bending moment of the wall

According the draft recommendation, however, the reaction due to the subgrade reaction multiplied by the global safety factor should not exceed the difference in the areas of the passive earth pressure diagram at limit state and the earth pressure at rest diagram, i.e.,

$$R_p \leq \frac{(E_p - E_0)}{\eta_p}, \quad \eta_p \geq 1.5 \tag{2}$$

4 CONCLUSION

The recommended approach for the design of retaining structures is a result of a number of comparative analytical and numerical studies and the huge experiences in this area of the members of the Working Group „Excavation" EAB of the German Society of Geotechnical Engineering. The type of variants included in the study were: 4 excavations with different depth of excavations and arrangement of the struts, with and without ground water, with and without building load, and flexible and rigid walls.

The recommended design approach shall only applied in connection to the construction measures, namely the installation of the bottom support before considerable movement of the wall occurs at the bottom of the excavation.

REFERENCES

[1] EAB 2002 *Draft recommendation for the design and construction of retaining structure on soft soils: in* preparation.

APPENDIX I. NOTATION

The following symbols and abbreviations were used in the text and diagrams.

φ_s'	= effective friction that include the effect of cohesion
δ	= wall friction
γ	= saturated unit weight of the soil
m	= stress exponent
R_f	= the ratio of the shear stress at failure and the ultimate shear stress in Hardening Soil Model PLAXIS
e_0	= earth pressure at rest extending from the surface
e_{agh}	= active earth pressure due to soil weight
e_{abi}	= active earth pressure due to surcharge load
e_{aph}	= active earth pressure due to traffic load
e_p	= fully mobilized passive earth pressure
e_p'	= e_p/η_p
η_p	= global safety factor for passive resistance
$e_{p(modified)}$	= modified passive earth pressure
E_p	= the area of the passive pressure diagram at limit state
E_0	= the area of the earth pressure at rest diagram
R_p	= Soil reaction due to subgrade reaction
k_s	= the subgrade reaction
E_s	= constrained modulus of elasticity
$E_{50\%}$	= reference secant modulus of elasticity at 50% the maximum deviatoric stress and at a reference pressure of 100 kN/m²
E	= initial modulus of elasticity at a reference pressure of 100 kN/m²
E_{ur}	= the modulus of elasticity for loading and unloading at a reference pressure of 100 kN/m²

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