PROPOSAL FOR CLASSIFICATION OF SUPPORTED EXCAVATIONS

LA PROPOSITION POUR LE CLASSEMENT DES FOUILLES AVEC SOUTENEMENT

Igor Sorić[1] *Davorin Kovačić*[2]

[1]Geotehnički Studio, Design and Geotechnical Engineering Company, Zagreb, Croatia
[2]Faculty of Mining, Geology and Petroleum Engineering, Zagreb, Croatia

SYNOPSIS: The paper deals with design approach to supported excavations in urban areas. The distinction is made between the excavation stability problem and adjacent buildings deformation problem. Stability - deformation criteria are proposed based on the magnitude of allowable angular distortion of the building and related earth pressure coefficient. In the excavation classification, the terms "deep excavation" and "shallow excavation" are introduced and the concept of design procedure is presented.

INTRODUCTION

The construction of a new building in an urban area is usually preceeded by the construction of deep excavation supported by a retaining structure. The primary task of the retaining structure is to keep the sides of the excavation vertical. But at the same time the retaining structure should prevent or at least reduce to acceptable values the subsidence of the ground behind it in order to protect the adjacent buildings.

The design of a retaining structure should be based on the evaluation which takes into account the resistance of the structure to lateral earth pressure (excavation stability) and the prediction of settlements in the zone of interest (adjacent buildings deformation). If only excavation stability criterion is satisfied independently of the magnitude of soil deformations, cracks are likely to occur in the structural elements of the adjacent buildings or it could be seriously damaged.

Therefore the design of a retaining structure for a deep excavation should distinguish the problem of the excavation stability and the problem of the adjacent buildings deformation. Obviously these problems are interrelated.

DEFORMATION ASPECTS

In the case of a simplified approach in which only the stability of the excavation is taken into account, the completion of the new building might be succesfull, not causing any problem to the adjacent buildings. But rather frequently various types of damages to adjacent buildings occur. The type of damage could range from tiny cracks without any influence to the stability of the building to serious damages threatening the stability of some structural elements or even the overall stability of the building.

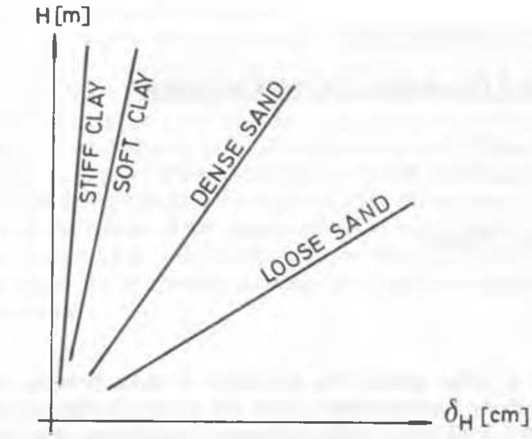
The main reason for the occurence of such damages is the fact that the relationship between the criterion of the excavation stability and the criterion of the allowable settlements of the adjacent buildings is not uniquely defined. An attempt to establish such relationship is described thereafter.

In order to simplify the approach it is assumed, in the first part in the cosideration, that the support of the excavation sides is provided by a cantilever wall. It is also assumed that there is no influence of groundwater to the stability of the excavation. This assumption does not impose any restrictin to the present concept. It can be equally applied in the general case where a retaining structure is subjected to both earth pressure and water pressure.

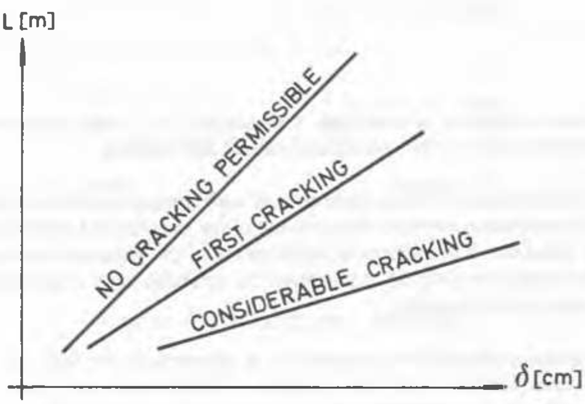
The consideration is based on two points. The first is the magnitude of horizontal displacement δ_H at the top of the wall required to achieve active Rankine state of stress in the backfill. Typical values of δ_H for different types of soil are given by Bowles (1988). The appropriate graph is the set of straight lines shown on Fig.1a.

The second point is the magnitude of allowable settlement δ_V of the adjacent building. The value of δ_V is related to the practical use of the building and its structural system. Bjerrum (1963) proposed damage criteria in terms of angular distortion δ/L "being defined as the settlement difference between two points divided with their horizontal distance apart". For the particular case of panel walls the apropriate criteria are shown on Fig.1b.

The following chapter describes the proposed concept by means of the practical example.



a) Excavation depth vs. horizontal displacement

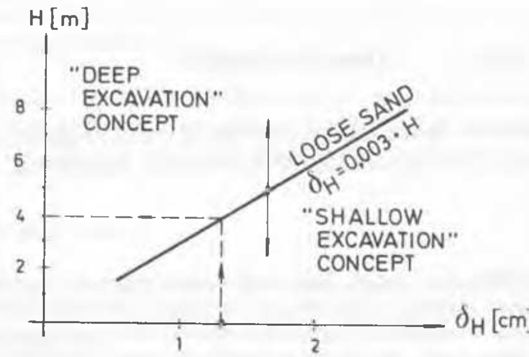


b) Column spacing vs. differential settlement

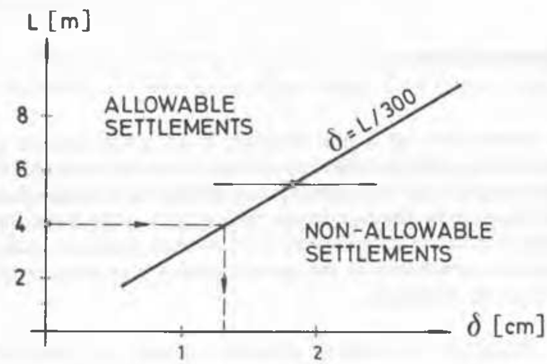
Fig. 1. Relationships between stability and deformation criteria

STABILITY - DEFORMATION CRITERIA

Panel walls building with column spacing L = 4 m, laid on a layer of loose sand should be protected due to deep excavation. The magnitude of the allowable settlement, which is in this case defined by the criterion "limit where cracking in panel walls is to be expected", is cca 1 cm (Fig.2b.). If we make the assumption $\delta_H \approx \delta$, which is quite in accordance with the diagram presenting maximum settlement difference vs. maximum settlements for buildings on sand, given by Bjerrum (1963), then according to the graph on Fig.2a., the excavation depth H should not exceed 4 m. Deeper excavation would produce larger lateral deformation and the magnitude of differential settlement would exceed allowable value.



a) Excavation depth vs. horizontal displacement



b) Column spacing vs. differential settlement

Fig. 2. Stability - deformation criteria for a panel walls building on a loose sand

But if deeper excavation should be constructed with the same limitation on the value of differential settlement, the restriction on the horizontal displacement at the top of the wall would result in a higher lateral earth pressure. In that case the retainig structure must provide greater rigidity.

DESIGN EARTH PRESSURE COEFFICIENTS

The approach described above clearly shows that the excavation depth H > 4 m would produce active (minimum) earth pressure on the retaining structure, but cracks would occur in the walls of the adjacent building. The elimination of cracks, i.e. the reduction of horizontal displacement implies higher lateral earth pressure on the retaining structure. The appropriate coefficient of lateral earth pressure K_n falls in the range:

$$K_a < K_n < K_o$$

where K_a is the coefficient of active pressure and K_o is the coefficient of earth pressure at-rest. The at-rest stress state is preserved in the case the retaining structure is rigid, i.e. no horizontal displacement is occuring. Therefore the coefficients K_a and K_o define lower and upper bound of the actual earth pressure.

This relation could be approximated by linear function on the well known graph $K = f(\delta_H)$, Fig.3.

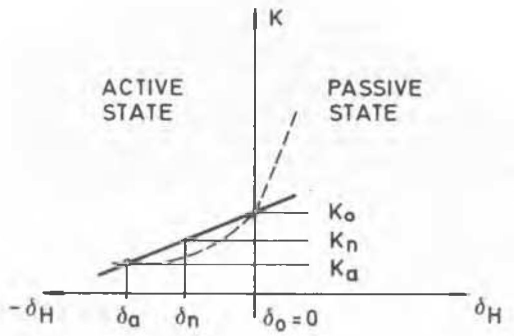


Fig. 3. Coefficients of earth pressure vs. horizontal displacements

CONSTRUCTION ASPECTS

The magnitude and the distribution of lateral earth pressure does not depend solely on the stiffness of the retaining structure. The construction method used and the sequence of operations related to the amount of time needed to complete the construction play a major role in the magnitude and distribution of earth pressure. As stated by Hunt (1986) the lateral distribution can vary substantially from that calculated for the design.

In case of braced excavations in sand one could rely on empirical rule given by Terzaghi and Peck (1967). Similar approach for braced excavations in clays was proposed by Peck et al. (1974).

As reported by Bjerrum et al. (1972), in the case of flexible retaining structure, arching causes the reduction of earth pressure on a yielding portion of the structure and its increase on the adjoining portions (support points).

In the context of retaining walls in stiff clay Padfield and Mair (1984) described the reduction in soil strength with time.

Among other influences the effect of soil relaxation in the backfill upon the excavation stage should be mentioned. It is usually followed by the redistribution of pressure. The time dependence of the soil relaxation is closely related to the type of the structure as suggested by the graph on Fig.4.

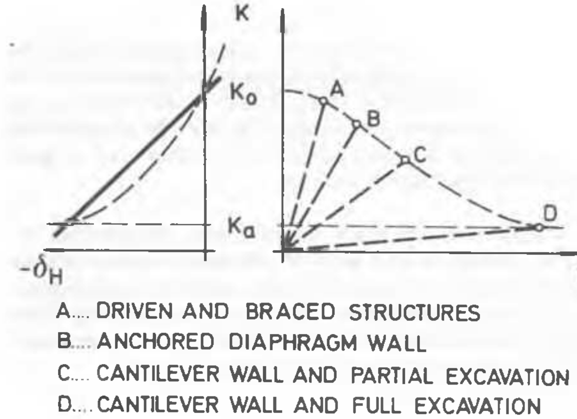


Fig. 4. Approximate relation between coefficient of earth pressure and time

EXCAVATION CLASSIFICATION AND DESIGN CONCEPT

The proposal for the classification of deep excavation is based on the criteria shown on Fig.1.

If the relationship between L, H, δ and δ_H is such that there are no cracks in the building along with the existence of active stress state, the excavation is defined as "shallow excavation". In the opposite case the relationship between L, H, δ and δ_H would result in crack occurence along with the existence of active stress state, and the excavation is defined as "deep excavation".

The direct consequence of the proposed definitions is somewhat modified and extended design concept instead of a conventional approach.

The first step is the classification of the excavation according to proposed criteria and based on the actual values of L, H, δ and δ_H. If the excavation is classified as "shallow excavation" further stages in the design procedure follow standard lines.

In the case the excavation is classified as "deep excavation", the selection of the type of retaining structure should be made in order to comply with the deformation requirements according to criteria shown on Fig.1. The required stiffness of the retaining structure could be achieved either by the appropriate cross section of the embedded cantilever wall or by flexible, braced or anchored wall. The internal forces in the structure are then calculated as induced by earth pressure with coefficient K_n.

This recommendation should apply to the magnitude of total pressure on the retaining structure. As for the actual distribution of the earth pressure along the depth of the excavation, one could rely on empirical rules, given by Terzaghi and Peck (1967) and Peck et al. (1974), as already mentioned in the preceeding chapter. Both references suggest the increase of total lateral pressure in relation to Rankine state. Similar recommendation could be found in the texbook by Lambe and Whitman (1969). The concept presented in this paper gives rise to the same conclusion, although some quantitative evaluation of coefficient K_n is still needed.

CONCLUSION

The design of retaining structures in open excavations must provide for the compatibility of backfill displacements and earth pressure on the structure. In urban areas excessive settlements can cause damages to the adjacent buildings. Therefore an adequate design procedure should take into account the relation between stability criterion and deformation criterion.

Yet, it is necessary to point out that total deformations of the adjacent buildings are the result of subsidence which occurs during excavation construction and settlements due to the imposed loading of new building. Consequently, the design of the retaining structure should not exclude the prediction of the settlements of new building and its influence to the adjacent buildings.

REFERENCES

Bjerrum, L. (1963). Discussion. *Proc. of European Conf. on Soil Mech. and Found. Eng.*, Wiesbaden, Vol. 2, pp. 135-137.

Bjerrum, L., Clausen, C.J.F. and Duncan, J.M. (1972). Earth pressures on flexible retaining structures - A state of the art report. *Proc. of 5th European Conf. on Soil Mech. Found. Eng.*, Madrid, Vol. 2, pp. 169-196.

Bowles, J.E. (1988). *Foundation Analysis and Design*. Fourth Edition. McGraw-Hill Book Company, New York.

Hunt, R.E. (1986). *Geotechnical Engineering Analysis and Evaluation*. McGraw-Hill Book Company, New York.

Lambe, R.B. and Whitman,R.V. (1969). *Soil Mechanics*, John Wiley & Sons, New York.

Padfield, C.J. and Mair, R.J. (1984). *Design of Retaining Walls Embedded in Stiff Clay*, CIRIA, London.

Peck, R.B., Hanson, W.E. and Thornburn, T.H. (1974). *Foundation Engineering*, 2nd ed., John Wiley & Sons, New York.

Terzaghi, K. and Peck, R.B. (1967). *Soil Mechanics in Engineering Practice*, 2nd ed., John Wiley & Sons, New York.