ROCZNIKI INŻYNIERII BUDOWLANEJ – ZESZYT 11/2011
Komisja Inżynierii Budowlanej Oddział Polskiej Akademii Nauk w Katowicach

UTILIZATION OF EXPERIMENTALLY VERIFIED DEFORMATION PARAMETERS OF SOILS IN THE PROGNOSIS OF SETTLEMENT OF A HIGH-RISE BUILDING FOUNDED IN A DEEP EXCAVATION PIT

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1. Introduction

The high-rise buildings usually constitute the dominants of a whole complex of objects. The footing bottoms of those objects are usually situated at a common depth level. The load acting upon the subsoil by the high-rise building is a multiple of the load of the foundation construction of other low-rise parts. For this reason, the construction of foundation is usually resolved by raft foundations separated by dilatation. During excavation of the excavation pit, noticeable unloading occurs across the whole area of the footing bottom of the complex of objects; however, noticeable loading occurs in the footing bottom only in the area delimited by the foundational construction of the high-rise building.

2. Parametric study – definition of the parameters

The expression of the effects of unloading (by excavation of the excavation pit) or loading of the subsoil (by realization of the building construction) can be expressed by a change of the state of stress in the subsoil of a high-rise building. For expression of the changes of the state of stress in the subsoil, the theory of linearly flexible semispace can be used. The behaviour of the vertical stresses is influenced by: intensity, shape and area extent of the stress which is found on the surface of the linearly elastic semispace. The manifestation of the effects of the vertical stresses is emphasized with the increase of the intensity of load/unload and the size of the area on which the load acts upon. Besides that, the effects of the vertical stresses are also influenced by the shape of the load area. The dilatation units, into which the raft foundations of the complex of buildings are divided, have mostly squared or rectangular shape. If we consider the same intensity and the same load area, the manifestation of the effects of the vertical stresses is more distinct in the case of rectangular shapes of the foundational constructions. The excavation depth of the excavation pit and therefrom resulting unloading of the subsoil, as well as the intensity of the acting load of the high-rise building onto the subsoil, can be different. Also, the shape of the excavation pit (unloading) and the shape of the raft foundation under the high-rise building (loading), can vary. Varying can also be the ratio of the area on which unloading occurs, and the area on which loading of the subsoil takes place.

The final value of deformation of the subsoil of the high-rise building, quantified by calculation, is in a decisive extent influenced by the considered behaviour of the vertical stresses in the subsoil, which were induced by building of the construction, as well as by the applied deformation characteristics of the subsoil. In the presented parametric study, the final value of the subsoil deformation of a high-rise building is compared in diverse ways of considering intensity, area and shape of load of the footing bottom. For specific cases of load, the respective behaviours of vertical loads under the centres or loaded/unloaded footing bottoms are expressed, with the respective deformation parameters of soils. Using the parametric study, the following cases of load of the footing bottom were analyzed:

Case No. 1 (Fig. 1a) :

- constant dimensional parameters of the excavation pit (width b = 62,8m; length l = 174,6m; depth h = 10,0m; unloading by excavation σ = 200kPa);
- constant dimensional parameters of the footing bottom of a high-rise building (width b = 15,0m; length l = 45,0m; depth of foundation d = 10,0m);
- varying parameter of loading of the footing bottom (σ = 200; 300; 500; 850kPa).

Case No. 2 (Fig. 1b) :

- constant dimensional parameters of the excavation pit (width b = 62,8m; length l = 174,6m; depth h = 10,0m; unloading by excavation σ = 200kPa);
- constant parameter of loading of the footing bottom of a high-rise building (σ = 300kPa).
- varying area of the footing bottom of a high-rise building (the area of of the footing bottom expressed as percentage of the area of the excavation pit – 3%; 6%; 15%; 30%).

Case No. 3 (Fig. 1c) :

- constant dimensional parameters of the excavation pit (width b = 62,8m; length l = 174,6m; depth h = 10,0m; unloading by excavation σ = 200kPa);
- constant parameter of loading of the footing bottom of a high-rise building (σ = 300kPa)
- varying parameter the shape and area of load of the footing bottom of a high-rise building (the shape of the area of the footing bottom expressed by the proportion of the sides b/l = 1/1; 1/3; 1/10, whereby b = 15,0m).

The behaviours of the vertical stresses in the subsoil are, for the individual cases of load of the footing bottom, graphically presented in Fig. 2a, b, c. Besides the behaviour of the vertical stresses induced by loading of the footing bottom σ_z (by a different intensity, area and the shape of load), in Figs. 2a and 2c there are also expressed the behaviours of the original subsoil stress σ_{or} (geostatic stresses) and the behaviours of structural strength of soil $m.\sigma_{or}$ ($0,2.\sigma_{or}$). The intersections of the behaviours of vertical stresses and behaviours of the structural strength provide, at the same time, a conception of the extent of the deformation zone. From Figs. 2a and 2c, there is also evident the manifestation of effects of unloading of the footing bottom by excavation of the excavation pit $\sigma_z^{excavation}$.By experimental measurements it is proven that at repeated loading of the soil, after its previous unloading, to the level of originally acting load ($\sigma_z<\sigma_{or}$), the values of the deformation parameters of soils are noticeably more favourable than after repeated loading above the level of originally acting load ($\sigma_z>\sigma_{or}$). This phenomenon is also called „soil memory“ – the soil remembers the load which acted upon it in the past. In Fig. 3, the area of the deformation zone is divided in two parts. In the first part, the vertical stresses from vertical load exceed the original stress (the vertical load is higher than the effect of unloading by excavation of the excavation pit). It is necessary to assign to this part in computing analysis the *„less favourable“* deformation characteristics $E_{oed}{}^{\sigma z>\sigma or}$ (expressed from the oedometric test for primary loading).

In the second part, the vertical stresses from vertical load are smaller than the effects of

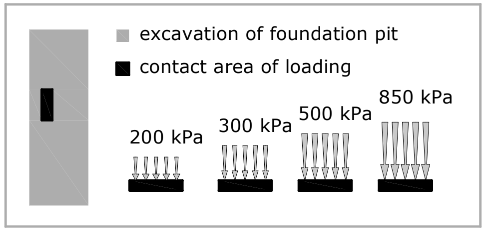

Fig. 1a Loading of the footing bottom

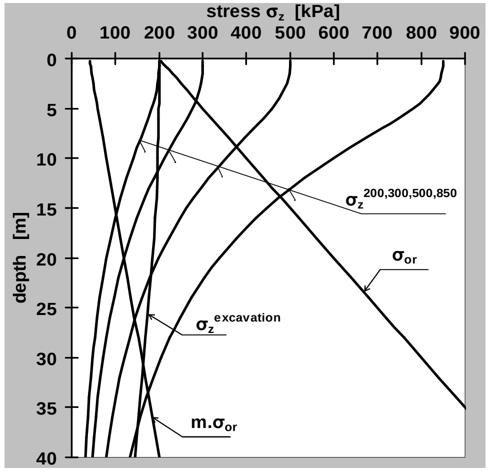

Fig. 2a Behaviours of the vertical stresses

Tab. 1a Subsoil deformation – Case No.1

loading [kPa]	Deformation characteristics		difference	
	experiment [cm]	standard [cm]	Δ [cm]	%
200	4,03	7,95	3,92	49
300	12,01	15,78	3,77	24
500	26,56	33,95	7,39	22
850	52,45	69,78	17,33	25

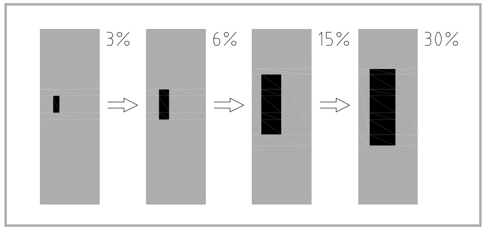

Fig. 1b Loading area of the footing bottom

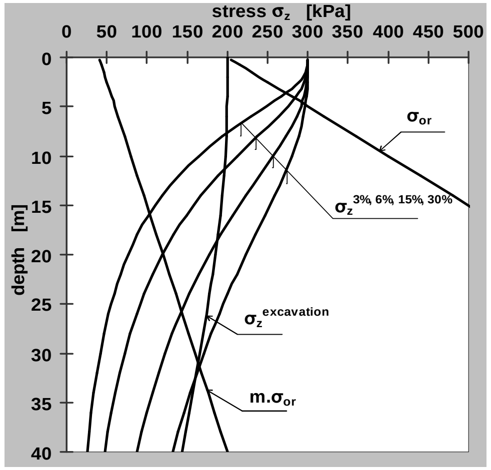

Fig. 2b Behaviours of the vertical stresses

Tab. 1b Subsoil deformation – Case No.2

loading area [%]	Deformation characteristics		difference	
	experiment [cm]	standard [cm]	Δ [cm]	%
3	9,31	11,82	2,51	21
6	12,01	15,78	3,77	24
15	15,82	21,05	5,23	25
30	19,04	26,09	7,05	27

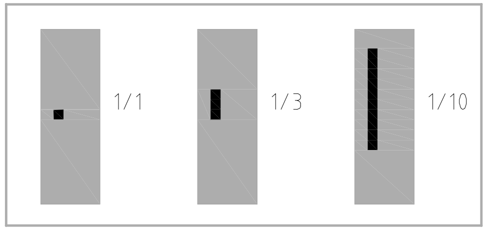

Fig. 1c Loading shape of the footing bottom

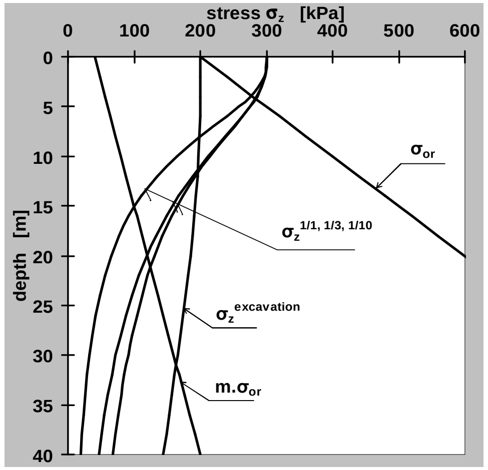

Fig. 2c Behaviours of the vertical stresses

Tab. 1c Subsoil deformation – Case No.3

loading shape b/l	Deformation characteristics		difference	
	experiment [cm]	standard [cm]	Δ [cm]	%
1/1	10,07	11,76	1,69	14
1/3	12,01	15,78	3,77	24
1/10	12,16	16,32	4,16	25

unloading by excavation of the excavation pit. This area of the deformation zone can be characterized by *„more favourable"* deformation parameters of soils $E_{oed}^{\sigma z<\sigma or}$ (expressed from the oedometric test for repeated loading after unloading). For calculation of the final value of subsoil deformation, the results of experimental verification of deformation properties of Neogene soils were taken in the locality Bratislava-Račianska street. In Fig. 4, there are expressed the functions of dependence of change of more favourable $E_{oed}^{\sigma z<\sigma or}$ and less favourable $E_{oed}^{\sigma z>\sigma or}$ deformation characteristics on the depth under the terrain surface [1]. For comparison of the final value of subsoil deformation, there was also performed a calculation using the standard value of deformation module chosen from [2] for the low-plastic to medium-plastic clays CL-CI on the boundary having firm to stiff consistence (I_C = 1,0). Those types of soils participate prevailingly in building of the Neogene subsoil in the central part of Bratislava. The standard value of the deformation module [2] was considered to be constant along the entire depth of the deformation zone E_{oed} = 17,0MPa.

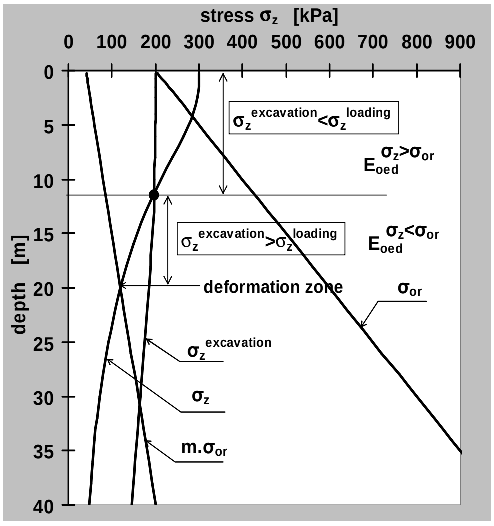

Fig. 3 The method of use of the deformation moduli in the extent of the deformation zone

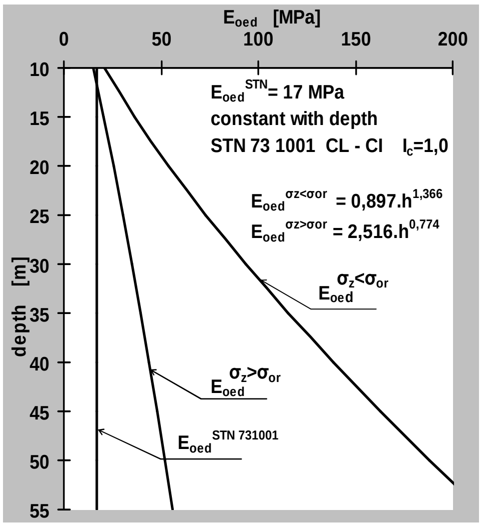

Fig. 4 Depth dependencies of the deformation moduli

3. The method of calculation of the final value of settlement

The calculation of the final value of subsoil deformation depending on the action of the contact stress in the footing bottom under the high-rise building was performed according to the formula [2] :

$$s = \sum_{i=1}^{n} \frac{\sigma_{z,i} - m_i.\sigma_{or,i}}{E_{oed,i}} \cdot h_i \qquad (1)$$

where: $\sigma_{z,i}$ is the vertical stress under the considered point in the footing bottom; m is the corrective coefficient of vertical load (in the calculation, it was considered to be constantly 0.2); σ_{or} is the geostatic (original) stress; h is the thickness of the stratum; E_{oed} is the oedometric module of deformation.

The vertical load σ_z of each stratum is reduced to its effective component (σ_z–$m.\sigma_{or}$), which causes the deformation. The structural strength of soil (m – multiple of the geostatic stress) represents the resistance of the soil being loaded against overstrain. By reducing the vertical load to its effective component, the calculation, along the depth, is limited to the thickness of the deformation zone, within which the subsoil deformation is manifested.

4. Parametric study – results

The results of the parametric study are, for the individual cases, summarized in Tabs. 1a to 1c (Case No.1 – Tab. 1a; Case No.2 – Tab. 1b; Case No.3 – Tab. 1c). The final values of subsoil deformation under the centre of the footing bottom of a high-rise building were determined by using experimentally set deformation characteristics of the subsoil (Fig. 4) and, at the same time, by using a constant standard value of the deformation characteristics (E_{oed} = 17,0MPa). The resulting deformations are given in Tabs. 1a, b, c, mutually compared, whereby the difference is expressed in absolute values [cm], and also as percentage [%].

Case No.1 (Tab. 1a) describes the change of the final value of deformation, if the contact stress gradually rises from the value 200kPa, which is equal to unloading by excavation, up to the extreme stress of 850kPa. Fig. 2a depicts the behaviour of stresses under the level of the footing bottom. The application of the deformation characteristics along the depth of the deformation zone will be dependent on the comparison of the behaviours of stresses of unloading of the footing bottom (by excavation) and its loading (by the construction). There, where the course of stresses from loading of the footing bottom lies above the course representing its unloading ($\sigma_z^{excavation} < \sigma_z^{loading}$), it is necessary to apply for the calculation of the final value of subsoil deformation the more unfavourable values of the deformation characteristics $E_{oed}^{\sigma z>\sigma or}$; and there, where the course of stresses from loading of the footing bottom lies under the course representing its unloading ($\sigma_z^{excavation} > \sigma_z^{loading}$), the more favourable subsoil deformation characteristics $E_{oed}^{\sigma z<\sigma or}$ can be used. At the contact load of the footing bottom of 200kPa, it is possible to describe the entire deformation zone by a function expressing the dependence of the more favourable subsoil deformation characteristics on depth (Fig. 4). On the other side, at the extreme contact load of 850kPa it is inevitable to use, in the extent of the whole deformation zone, the less favourable deformation characteristics (Fig. 4). The final values of subsoil deformation for the stresses between 200–850kPa are presented in Tab. 1a. For the experimentally determined subsoil deformation characteristics, the deformation values range between 4,03–52,45cm and, for the constant standard value of the deformation characteristics, they range between 7,95–69,78cm. The difference between the calculated values is from 22 to 49%. The biggest difference (49%) can be observed in the case when the entire deformation zone was characterized by more favourable, experimentally verified deformation characteristics of soils (at contact load of the footing bottom being 200kPa).

Case No.2 (Tab. 1b) follows the development of the final value of the subsoil deformation at the increase of the area of contact load with respect to the area of unloading (excavation of the excavation pit). The shape of the load area is constant, b/l = 1/3. In Fig. 2b, the behaviours of vertical stress are depicted, for 3, 6, 15 and 30% fraction of the area of contact load on the area of unloading. The contact load was considered with an intensity of 300kPa. From the behaviour of the stresses in Fig. 2b it is evident that the part of the subsoil which will be characterized by the more favourable deformation characteristics $E_{oed}^{\sigma z<\sigma or}$, decreases with the increase of the area of loading. The final values of subsoil deformation for the gradually increasing fractions of the load area are given in Tab. 1b. For the experimentally determined deformation characteristics, the deformation values range between 9,31–19,04cm and, for the constant standard value of the deformation characteristics, they range between 11,82–26,09cm. The difference between the calculated values is 21–27% and its increase can be observed with the increasing load area.

Case No.3 (Tab. 1c) describes the change of the final value of deformation in case of modification of the shape and area of the load of the footing bottom. The shape of the load area is expressed by the ratio of sides b/l = 1/1; 1/3 and 1/10 for the constant width b = 15m. Fig. 2c depicts the behaviours of the vertical stress for individual shapes of load of the footing bottom. The intensity of the contact load of the footing bottom was considered similarly as in Case No.2 (300kPa). The extent of the deformation zone, which is characterized by more favourable deformation characteristics $E_{oed}^{\sigma z<\sigma or}$, decreases with the change of the load shape. For the square load shape (ratio b/l = 1/1), by the more favourable deformation characteristics $E_{oed}^{\sigma z<\sigma or}$ the largest part will be described; in case of a prolonged strip (ratio of sides b/l = 1/10) it will be the smallest part of the deformation zone. The final values of deformation for the changing shape and area of the load of the footing bottom are given in Tab. 1c. For experimentally determined deformation characteristics of the subsoil, the deformation values range between 10,07–12,16cm; for the constant standard value of the deformation characteristics they span between 11,76–16,32cm. The difference between the calculated values ranges between 14–25%.

5. Conclusion

The method by which it is possible to utilize the experimental measurements for the calculations is presented in the submitted parametric study. The results of the parametric study represent a document of what is the influence on the final value of subsoil deformation resulting from the intensity, area and shape of the load of the footing bottom induced by a high-rise building, taking into account the unloading of the footing bottom by excavation of a deep excavation pit. The comparison of the final values of subsoil deformation, determined on the basis of experimentally verified deformation parameters of soils and the standard parameters, points out noticeable differences (14–49%).

References

[1] Šujan, M., Blažo E., Menzelová, O., Masarovičová, M., Slávik, I., Kovács, T.: Polyfunkčný dom Slovan, Podrobný IG prieskum, EQUIS spol. s.r.o., Bratislava, 2008.
[2] STN 73 1001 Základová pôda pod plošnými základmi

POUŽITIE EXPERIMENTÁLNE OVERENÝCH DEFORMAČNÝCH PARAMETROV ZEMÍN V PROGNÓZE SADANIA VYSOKEJ BUDOVY ZALOŽENEJ V HLBOKEJ STAVEBNEJ JAME

Anotácia

V prezentovanej parametrickej štúdii je porovnaná konečná hodnota deformácie podložia vysokej budovy pri rôznych spôsoboch uvažovania intenzity, plochy a tvaru zaťaženia základovej škáry. Pre konkrétne prípady zaťaženia sú vyjadrené odpovedajúce priebehy zvislých napätí pod stredmi zaťažených resp. odľahčených základových škár. Do prognózy sadania sú premietnuté deformačné parametre zemín zohľadňujúce zmeny stavu napätosti v priebehu budovania konštrukcie opísané v predchádzajúcom príspevku.