ROCZNIKI INŻYNIERII BUDOWLANEJ – ZESZYT 13/2013
Komisja Inżynierii Budowlanej Oddział Polskiej Akademii Nauk w Katowicach

INFLUENCE OF SUBSOIL QUALITY ON DESIGN OF SLAB FOUNDATION

Peter POLLÁK, Lenka ZLATINSKÁ
Slovak University of Technology, Bratislava

1. Introduction

Reliable and economically effective design of foundation structures can be achieved only by responsible approach to the solved problem with consideration of all important factors. Between the most significant of them belongs the relative stiffness of the “foundation – subsoil” system. In engineering practice, every problem associated with proposal of geotechnical structures is exceptional because of environment, which the construction is placed in. Subsoil represents very important boundary condition, upon which depends the design of structure foundations itself.

The subject of this article is implementation of comparative calculation, which analyses the influence of different relative stiffness of “foundation – subsoil” system on the vertical normal contact stresses s_z [kPa]. Calculations are made on two models of slab foundations in software Midas GTS [1], which works on the base of Finite Element Analysis (further FEA). Models vary in the quality of subsoil. The subsoil was modeled by homogeneous isotropic elastic half-space without considering the improvement of deformation properties (E_{def}, n) with depth.

In the valid Slovak technical standards (STN 73 1001) [2] is the parameter k of relative stiffness of the “foundation – subsoil” system expressed as follows:

$$k = \frac{E}{E_{def,a}} \cdot \left(\frac{t}{L} \right)^3 \qquad (1)$$

For relative stiffness k<1 is the foundation classified as flexible, for k>1, it is considered as a rigid structure.

2. Geometry of the structure

The solved slab forms a foundation structure under 5-storey object with monolithic concrete frame supporting system. Overall construction stability is provided by transverse and longitudinal supporting frames. Cross section dimensions of columns are 0,4 x 0,4 m and beams 0,6 x 0,4 m. The modular solution corresponds to raster 6,0 x 6,0 m, construction height is 3,0 m. Foundation slab has thickness t = 0,5 m and is cantilevered

1 m from the outer columns. Its total dimensions are 26,0 m x 20,0 m. The ground plan and cross section of described object are in Fig. 1.

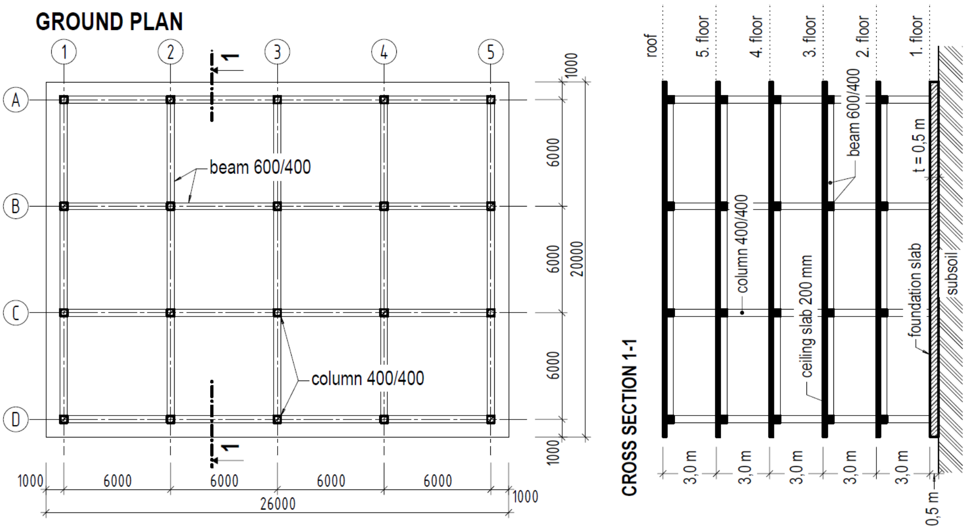

Fig. 1 Scheme of the solved construction – ground plan and cross section

3. Load from the upper structure

In order to achieve real size of reactions from vertical support members to the foundation slab, spatial model in software ESA Scia Engineer was made (Fig. 2). Contact stresses were analyzed with the combination, which contain long-acting loads. These loads are divided into three following load cases:

- self-weight of the structure – reinforced concrete (C30/37, reinforcement B500 B)
- other long-acting loads (flooring, long-acting utility load), intensity 2,0 kN/m^2
- lightweight cladding on the circumference of the ceiling slabs, intensity 2,25 kN/m

The resulting normal forces in the columns in contact with the foundation slab, which enters the comparative calculations are in Fig. 3.

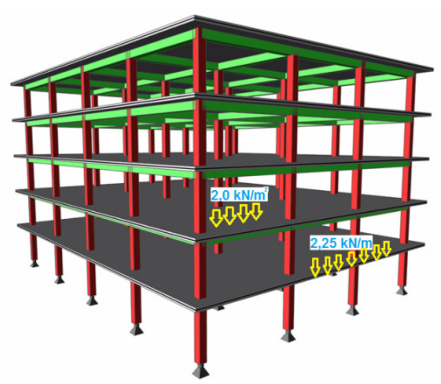

Fig. 2 Model for calculation of internal forces in supporting members

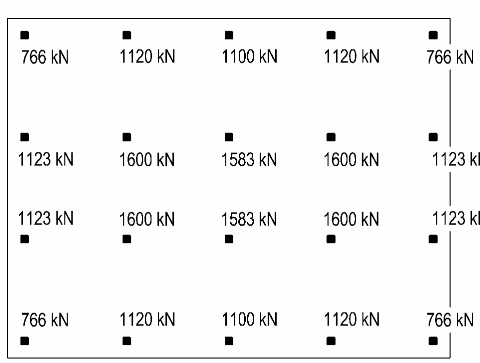

Fig. 3 Resulting normal forces in columns in connection to the foundation slab

4. Boundary conditions for numeric models

Material characteristics of homogeneous isotropic half-space are in Tab. 1. Into the comparative calculations were chosen soils, which represent relatively flexible and rigid subsoil. In the first variant, the subsoil is modeled by clay with extremely high plasticity (F8-CE) with deformation modulus E_{def} = 2,0 MPa. In the second variant, it is formed by compacted, well-graded gravel (G1-GW) with deformation modulus E_{def} = 400 MPa. Geotechnical characteristics were determined in accordance with STN 73 1001 from year 1987 (appendix 5 – Indicative normative characteristics of subsoil) [3].

Tab. 1 Geotechnical characteristics of soils under the foundation slab

variant	soil name	soil class	density γ [kN/m^3]	Poisson constant ν [-]	deformation modulus E_{def} [Mpa]	consistency index I_C [-]	density index I_D [-]
1.	plastic clay	F8-CE	20.5	0.42	2.0	0.30 (soft)	–
2.	well-graded gravel	G1-GW	21.0	0.20	400.0	–	0.90 (compacted)

The foundation slab is considered as reinforced concrete, monolithic with elastic modulus E = 32 GPa and Poisson ν = 0,2. Its thickness is t = 0,5 m. Within the solution of stress-strain problems in geotechnics using FEA, it is very important to determine the borders of numeric model. In places, where stress evoked by the structure is negligible, it is necessary to prevent deformation of subsoil in numerical model. In the comparative calculations, the area was determined in dependence of foundation slab dimensions (Fig. 4). The subsoil is modeled to the distance of length or width of slab to each side of the slab edges. The depth of deformation zone is 20,0 m under the foundation slab.

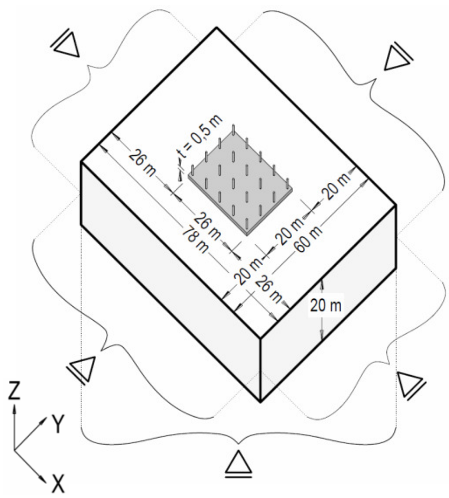

Fig. 4 Range of numeric model with applied ground supports

Because of more accurate results from calculations by Finite Element Method (FEM), the subsoil is modeled through three regions, which differs at length of element edge. With consecutive debugging of the finite element mesh, the optimum ratio between the number of elements (computation time) and required accuracy of results was achieved.

The complete computation model with element mesh in software Midas GTS is in Fig. 5a. Element mesh in the regions around the connections of columns and foundation slab was thickened because of higher concentration of stress forced by acting load. The diagrams of contact stresses on two different models will be compared in cross-section A-A (Fig. 5b).

Contact stresses from calculations are expressed in relative values as a ratio to the value of average contact stress: $\sigma = \sigma_z / \sigma_{avg}$ [-]. The average contact stress σ_{avg} under the foundation structure is determined by uniform redistribution of load from columns to whole contact area between the slab and subsoil, also with contribution of self-weight of the foundation slab as follows:

$$\sigma_{avg} = \frac{\sum F_i}{B.L} + \gamma_c.t = \frac{23802\ kN}{20m.26m} + 25\ kN.m^{-3}.0,5\ m = 58,27\ kPa \qquad (2)$$

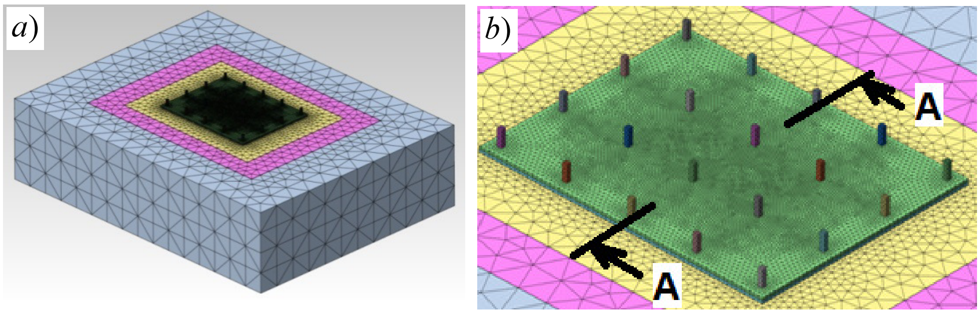

Fig. 5 Computation model with element mesh division (Midas GTS)
a) whole model, b) detail of foundation slab with cross-section A-A

5. Results evaluation of the comparative calculations

Subsoil was modeled with geotechnical characteristics mentioned in Tab. 1. The foundation slab compared to the flexible subsoil is formed by a much stiffer material (deformation modulus is by 3 orders higher). After application of the inputs into the formula (1) is the foundation slab for the both variants classified as flexible (k < 1):

$$k_1 = \left(\frac{32000MPa}{2MPa}\right).\left(\frac{0,5m}{20m}\right)^3 = 0,250 \qquad k_2 = \left(\frac{32000MPa}{400MPa}\right).\left(\frac{0,5m}{20m}\right)^3 = 0,00125$$

Variant 1:

The diagram of calculated contact stresses (Fig. 7) corresponds to the theoretical redistribution of stress under perfectly rigid foundation (Fig. 6). The greatest stress is concentrated in the regions of foundation slab edges, where the shear strength of soil material is reached actually. Because of very low stiffness of subsoil, contact stress is redistributed approximately constantly on the whole contact area between the foundation slab and subsoil. Therefore also the settlement calculation of foundations, which depends on contact stress, would not be very far from the physical substance, when we use analytical methods with constant stress on the contact surface.

Variant 2:

Contact stresses (Fig. 7) reach their maximum values (almost 3-times average contact stress value) under columns, in areas between the columns they markedly fall under the value of average contact stress. Stiffness of subsoil is relatively very high, which causes the concentration of contact stresses under the greatest load from vertical supporting members (columns). For the settlement calculation in this case, it is much more appropriate to use numeric methods, for example FEM.

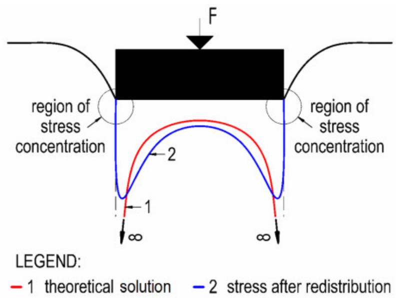

Fig. 6 Distribution of contact stress under rigid foundation – in lit. [4]

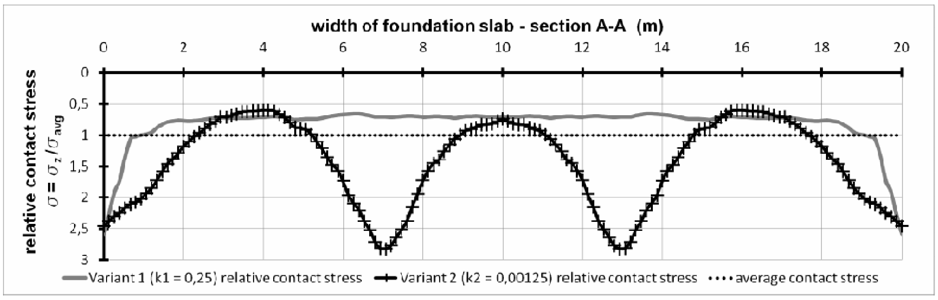

Fig. 7 Diagram of relative contact stresses for variant 1 and 2

The best conception about behavior of foundation slab on elastic isotropic half-space can be acquired from the surface diagram of contact stresses. Fig. 8 shows absolute values of vertical stress on contact surface between subsoil (clay) and foundation slab for variant 1 in software Midas GTS. Contact stresses for variant 2 can be seen in Fig. 9.

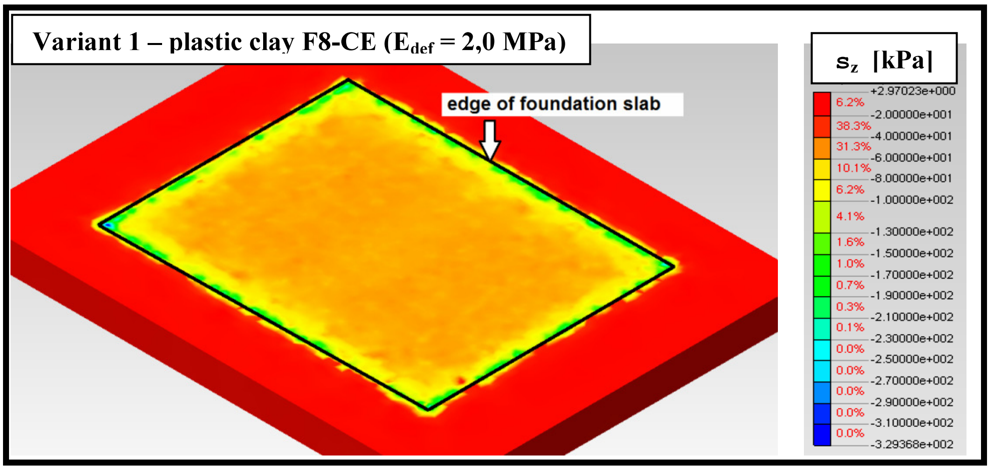

Fig. 8 Absolute values of vertical stress on the contact surface – variant 1

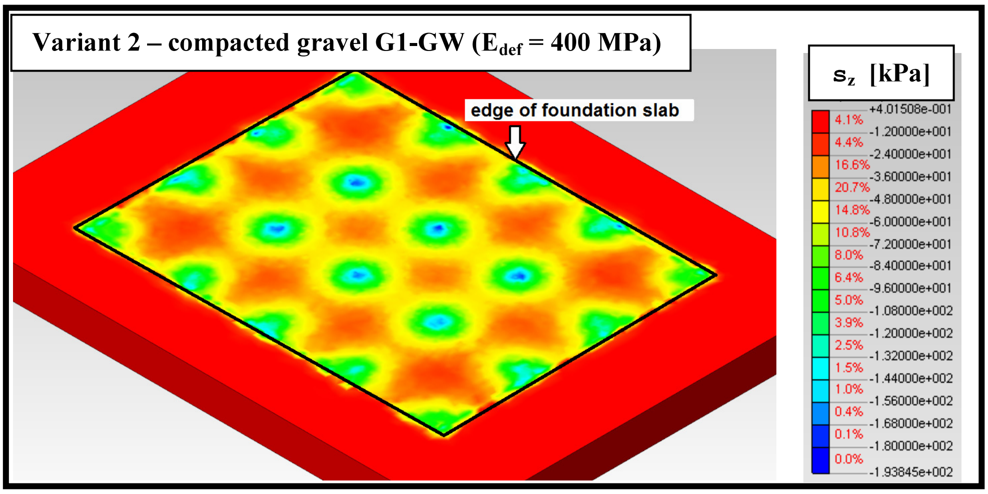

Fig. 9 Absolute values of vertical stress on the contact surface – variant 2

6. Conclusion

This comparative calculation shows that it is necessary to place adequate importance to representativeness of the subsoil properties during the design of foundation structures. Their values within the deformation zone under future structure can be obtained from sufficiently detailed survey and laboratory tests. With correct determination of these parameters, the design of foundation structures becomes reliable and economically efficient. Early enough can be avoided the problems, which can occur during construction or lifetime of the structure.

The current Slovak technical standards do not consider the soil-structure interaction (SSI) sufficiently. Concept of design and assessment of structure foundations depends on the parameter of relative stiffness of "foundation-subsoil" system. With development of numerical methods, question of inclusion the upper structure stiffness in SSI becomes much more actual. From impact of settlement of foundation structure, redistribution of internal forces in supporting members of upper structure occurs. The consideration of this fact provides the engineer much more realistic vision about behavior of the whole construction on the given type of subsoil. The current problematic of SSI problems is actually moving this direction. Therefore it is very important to gain representative inputs from geotechnical survey.

Denotations of symbols

E – elastic modulus of the foundation structure [MPa], $E_{def,a}$ – average deformation modulus of subsoil within the active zone [MPa], t – thickness of the foundation structure [m], L – characteristic dimension of foundation structure (width or length) [m]

References

[1] Analytic manual for software Midas GTS®, website: http://en.midasuser.com/downloads/programs_view.asp?idx=69070&bid=76&strPro=&nCat=

[2] STN 73 1001:2010, Geotechnical constructions, structure foundations. Slovak technical standard (In Slovak)

[3] STN 73 1001:1987, Subsoil under shallow foundations. Slovak technical standard (In Slovak)

[4] Myslivec A., Eichler J., Jesenák J.: (1970): Soil mechanics. 1st ed. Prague, SNTL 1970, 388 p. (in Slovak)

VPLYV VLASTNOSTÍ PODLOŽIA NA NÁVRH ZÁKLADOVEJ DOSKY

Zhrnutie

Článok sa zaoberá sledovaním vplyvu relatívnej tuhosti systému „základ – podložie" na návrhové veličiny základovej dosky. Porovnávací výpočet bol realizovaný pre základovú dosku v dvoch variantoch s relatívne poddajným, resp. tuhým podložím. Podložie bolo modelované ako homogénny izotropný pružný polpriestor. Získané výsledky numerických výpočtov s využitím metódy konečných prvkov (MKP) poukazujú na fakt, že charakteristiky základových pôd majú významný vplyv na návrh založenia budúceho objektu. Preto je veľmi dôležité dbať na stanovenie reprezentatívnych charakteristík podložia, ktoré sa dajú získať len dostatočne podrobným geotechnickým prieskumom a laboratórnymi skúškami zemín.