Analysis of the Stress of Reinforced Concrete Pillars as Affected by the Stiffness of the Subsoil

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Abstract

The paper presents a numerical analysis of the internal forces in the wall pillars of an apartment building. The analysis was done with different types of elastic support of the structure. Elastic support of the structure was implemented using a foundation plate on flexible subsoil. In the conclusion, different values of internal forces are analyzed.

Keywords: analysis, stress, reinforced concrete pillars, stiffness, subsoil

Introduction

In this paper, we present different approaches to the solution of the stress state of the wall piers of the reinforced concrete structure of an apartment building. The apartment building is rectangular in plan 52.5 x 16.5m. The structure has two underground floors and 6 floors above ground. The vertical load-bearing structures consist mainly of reinforced concrete walls, in the underground parking area also of columns - wall pillars which are the subject of the present analysis. The magnitude of the internal forces in the pillar is analyzed as a function of the stiffness of the subsoil and its physical model.

When dealing with foundation structures on elastic subgrade, one of the following elastic subgrade models can be chosen:

1. Elastic half-space (Boussinesq solution) is modeled as:

-body of large volume with constant deformation depth,

-a large volume body with a varying deformation depth, the magnitude of which depends on the contact stress

-infinite half-space,

The solution of this subsurface model can be encountered in [1],

2. The two-parametric model (Pasternak) can be solved

-with constant specified parameters C1 ($N.m^{-3}$), C2 ($N.m^{-1}$)

-with parameters C1, C2, solved from geological layers and from active deformation depth using software (Soilin).

This model can be encountered in the work [2, 3]

3 One-parameter Winkler model

-with constant subgrade stiffness parameter k ($N.m^{-3}$)

-modified Winkler subgrade model

In solving for the redesign and stress of the foundation slab analyzed in this paper, we used the Winkler bedrock model described by equation (1):

$$p(x, y) = k.w(x, y) \tag{1}$$

where k is the coefficient of subgrade stiffness ($N.m^{-3}$),

p - contact stress (N/m^2),

w - deflection (m).

For a plate on a Winkler model of the subgrade, the differential equation of the deflection surface is valid w (x,y):

$$\nabla^2 w(x,y) + kw(x,y) = q(x,y) \tag{2}$$

Where D – plate constant $D = \frac{Eh^3}{12(1-\nu^2)}$

E – modulus of elasticity of the plate material,

h – thickness of the plate,

ν – Poisson's coefficient of the plate material,

Laplace operator $\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y}$

k - je stiffness of the subgrade

q – the area load

Currently, this problem is solved using the finite element method, where we assume the minimum potential energy of the plate and elastic substrate system:

$$\pi = \pi_p + \pi_e + \pi_s = min \tag{3}$$

where the plate energy is defined by: $\pi_d = \frac{1}{2}\iint_\Omega \varepsilon^T \sigma \, d\Omega = \frac{1}{2}\iint_\Omega \varepsilon^T D\varepsilon \, d\Omega$

energy of external forces (plate load): $\pi_e = \frac{1}{2}\iint_\Omega \varepsilon^T \sigma \, d\Omega = \frac{1}{2}\iint_\Omega \varepsilon^T D\varepsilon \, d\Omega$

energy of the subsoil: $\pi_e = \frac{1}{2}\iint_\Omega kw(x,y)^2 \, d\Omega$

A modified Winkler subsoil model was solved by the authors of [4]. They determined the increased stiffness of the foundation below the edge of the foundation slab from the strain energy of the two-parameter foundation outside the foundation slab. In our case, we start from the two-parameter subsoil model of [3] to determine the spring size, where in terms of the established soil model, the response of the soil Q(x) along the perimeter of the slab in the x and y directions is as follows:

$$Q(x) = w(x)\sqrt{2tk} \tag{4}$$

In relation (4) denotes:

$$k = \frac{E_s}{(1-\nu_s^2)}\int_0^H \chi'^2(z)dz \quad t = \frac{E_s}{4(1-\nu_s)}\int_0^H \chi^2(z)dz \tag{5}$$

The function χ(z) is a function of the attenuation of vertical deformation to depth H (deformation zone). According to [3], it depends on the properties of the subsoil. It can be, e.g., in the form of a linear function (6).

$$\chi(z) = \frac{H - z}{H} \tag{6}$$

Then for the response of the subsoil to the edge of plate, the following applies:

$$Q(x) = w(x)k_w \tag{7}$$

where k_w can be calculated using the coefficients of the two-parametric subsoil.

$$k_w = \sqrt{C_1 C_2} \tag{8}$$

The k_w value represents the elastic support at the edge of the plate. The obtained value is entered into the computational model of the plate as a boundary condition.

FEM model of the construction

The structural system of the building is a transverse load-bearing system - slab-wall. Vertical load-bearing elements are walls, except for the underground floors where the inner walls are replaced by wall pillars of dimensions 350 x 900mm. Ceiling slabs are 200mm and 240mm thick, respectively, and 260mm thick with 360mm headers. The slabs are reinforced in both directions. The walls in the underground floors are 250 and 200mm thick and 220 and 200mm thick in the above ground floors.

The base slab is of variable thickness 600 - 1000mm. The slab is reinforced to a thickness of 1000mm at the points below the most heavily loaded columns. The walls and wall pillars of the underground floors are implemented on the foundation slab.

The columns continue on the first floor. In the ceiling above the first floor, the column bearing system transitions into a typical transverse wall bearing system. The transition of the structural system is by means of beams under the slab. The transverse walls and partly the perimeter walls are load-bearing. The longitudinal walls of the corridor are hung into the transverse walls. All walls are 220 or 200 mm thick and made of C25/30 concrete. (Figure 1, 2)

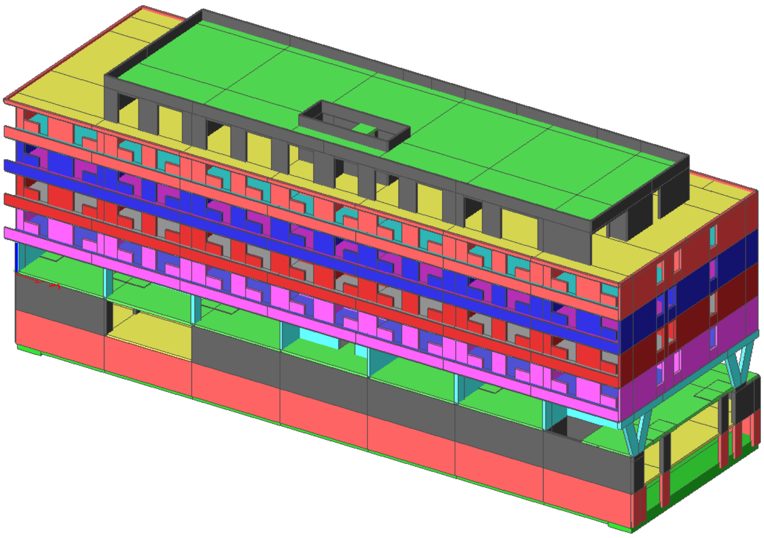

Fig. 1. Construction, view of the FEM model


Fig. 2. Realization of walls and columns on the foundation plate.

The individual ceiling slabs in the above-ground floors are 200mm thick. These are cross braced slabs supported mainly by transverse load bearing walls and the perimeter wall. The ceiling slabs project outwards to the exterior where they form loggias or balconies.

Individual geological boreholes are taken from the relevant geological survey for this apartment building. These have been generalized to a single geological profile for the static calculation.

0.00-0.30 brown clay slightly humusy O
0.30-3.00 clay with low plasticity solid (Ic =0,95) (CL) F6
3.00-5.30 clay with medium plasticity (CI) F6
5.30-13.00 clay with low to medium plasticity (CL) F6
13.00-15.00 light brown clayey gravel (GC) with sandy layers (SC) G5

The groundwater level is located at depths of approximately 15 m below ground level and will not have an immediate impact on the foundation of the building.

For the analysis of the stresses in the wall pillars, we chose the fixed support in the first calculation step. The other options for supporting the structure were to model the subgrade together with the foundation slab. The subgrade model was the Winkler model and the modified Winkler subgrade model [4]. Based on the geology described above and the known relationships, we calculated the stiffness of the subsoil. We introduced two extreme values for the stiffness coefficient of the subsoil into the calculation k = 3600 a 5300 kN/m^3.

For the modified Winkler subgrade model, we used the relations given in [2] and [3] to calculate the stiffness coefficient of the subgrade beneath the foundation plate k = 5300 kN.m^3. The authors of [4] try to get the stiffness of the subgrade outside the foundation into the classical Winkler model. They express the stiffness of the surrounding subgrade by the stiffness of the spring that supports the edge of the slab. In this case, the spring stiffness was k_w = 3500 kN.m^{-1} (resp. 4800 kN.m^{-1}). In our example, we considered linear support only on both long sides of the base slab. On the shorter sides of the building, the expansion from the adjacent objects is (Figure 3).

We have calculated 5 different types of support structures:

1., rigid support of wall pillars, model - m1
2., foundation slab with subsoil stiffness k = 3,600 kN.m^{-3}, model - m2
3., foundation slab with subsoil stiffness k = 5,300 kN.m^{-3} model - m3
4., foundation slab with subsoil stiffness k = 5,300 kN.m^{-3}, linear support k_w = 3,500 kN.m^{-1}, model - m4
5., foundation slab with subsoil stiffness k = 5,300 kN.m^{-3}, linear support k_w = 4,800 kN.m^{-1}, model - m5

The details of the structural model of the foundation slab and the individual pillars are shown in Figure 3.

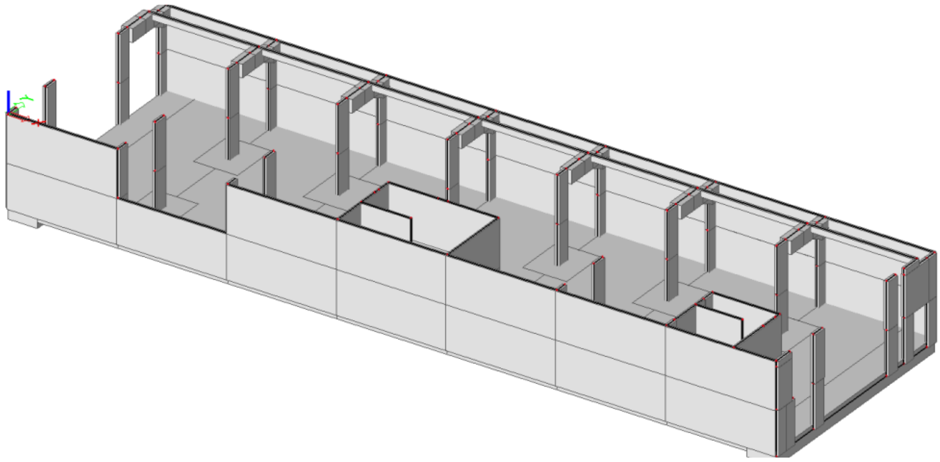

Fig. 3. Position of pillars and walls in underground floors – FEM model.

We analyzed the normal force acting in the wall pillars of the underground floor. The structural model of the apartment building was created in SCIA Engineer (Figure 1.), which uses the finite element method (FEM). Figure 4 shows the numbering of the modular axes and the number of the wall pillar lying at the intersection of the axes.

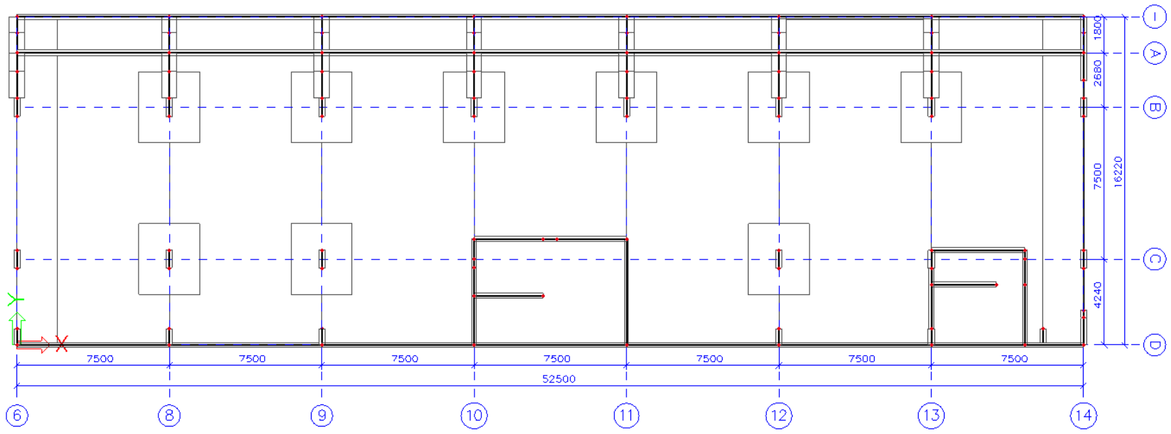

Fig. 4. Numbering of pillars in module axes B and C.

Conclusion

We monitored 11 wall pillars. Two pillars (axis 6) were at the beginning of the structure and located in the expansion joint. The others are inside the building. If we take the fixed support of the pillars as the base value (column m1 of Table 1), we can see that in the pillars at the edge of the foundation slab (B/6 and C/6), there is a reduction in the value of the normal force for elastic settlement. For the other wall pillars, there is an increase in the value of the normal forces when elastic support is introduced. The highest values are for the Winkler model with a smaller stiffness coefficient column 2 of the table. When a larger stiffness coefficient is used for the Winkler model, the values of the observed forces in the wall piers decrease (m3). A significant reduction occurs when the modified Winkler model is used. This is for the linear support of the edge of the foundation slab column m4. If the stiffness of the spring support along the edge of the foundation slab is increased column 5 the values of the normal forces will decrease in the wall piers compared to column 4. The comparison is Table 1.

Tab 1. Values of normal forces in individual pillars with different subsoil stiffness.

model No. pilier	**m1** **N (kN)**	**m2** **N (kN)**	**m3** **N (kN)**	**m4** **N (kN)**	**m5** **N (kN)**
B/6	4581.5	3271.3	3288.3	3087.8	3022.0
C/6	3057.1	3364.0	3355.0	3020.3	2914.3
B/8	5016.2	7228.6	7143.2	6732.6	6597.4
C/8	4251.4	7725.2	7595.6	7158,8	6759.4
B/9	5216.0	7133.8	7032.9	6633.6	6501.9
C/9	4056.0	7596.4	7451.3	6738.0	6633.7
B/10	4886.3	6302.1	6275.6	5959.9	5854.9
B/11	5433.3	6877.2	6855.3	6470.7	6342.2
B/12	5611.6	7736.3	7624.5	7150.4	6992.6
C/12	3829.8	8069.9	7914.5	7204.0	6977.2
B/13	4730.1	6864.3	6790.5	6790.5	6294.4

The following conclusions can be drawn from the resulting values of the normal forces in the individual wall piers and at different support stiffnesses. For the wall pillars in the middle of the building, there is an increase in the values of the compressive forces with elastic support. The softer the subgrade, the more unfavorable the redistribution of forces to the columns and the greater the increase compared to rigid support. In this case, the task of the structural engineer is to specify the correct stiffness of the subgrade and, in particular, to take into account the stiffness of the subgrade in the vicinity of the foundation slab. Due to the relatively soft subgrade, footings could not be used as in literature [6], but the foundation slab had to be as in the case of lit. [5].

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