Bulletin of the *Transilvania* University of Braşov • Vol. 10 (59) Special Issue No. 1 - 2017
Series I: Engineering Sciences

SIMULATION OF GROUNDWATER LOWERING USING NUMERICAL MODEL FEMWATER

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Abstract: *This paper presents the results of groundwater lowering for eight multi-storey residential and office buildings in Novi Sad. The buildings have 2 underground and up to 8 above-ground floors. The soil parameters are estimated according to soil geotechnical site. laboratory examination results and borehole pumping tests. The groundwater lowering is calculated numerically by finite element method for the unsteady flow regime. Lowering of the groundwater and pit excavation was successfully carried out according to the design documentation.*

Key words: *groundwater lowering, pit excavation, numerical model*

1. Introduction

On the premises of the cadastral parcel number 4512/1 KO Novi Sad, in Kraljevića Marka street, the construction of residential and business complex "Naselje Kraljev park" is planned. Complex consists of eight (8) residential and commercial buildings with a 2-floor underground garage under the whole complex (Figure 1). The area of the complex is approx. 1.3 ha. The constructive system of objects is reinforced concrete (RC) skeleton, with RC wall cladding and with full RC ceiling. The building is based on the RC slab.

On a wider site location, according to the geological map of Serbia, thickness of the alluvial sediments of the Danube is around 25.0 m. The lower part of alluvion zone is built of gravel and sand, and the upper part consists of the sand with individual grains of pebbles.

The morphology, geological structure and lithological composition of individual members influenced the hydrogeological characteristics of the examined terrain, as well as the anthropogenic effects. In the construction of the terrain, up to the analyzed depth, sediments of neogene and quarar are present which are mixed with humus in the surface part. Quaternary sediments are represented by sand and gravel which are characterized by porosity and represent hydrogeological reservoirs. In these sediments, an unconfined aquifer has been formed which is in direct hydraulic connection with the Danube river. Sediments of neogen are a hydrogeological isolator at the bottom of this aquifer and are made of very low permeable clay particles.

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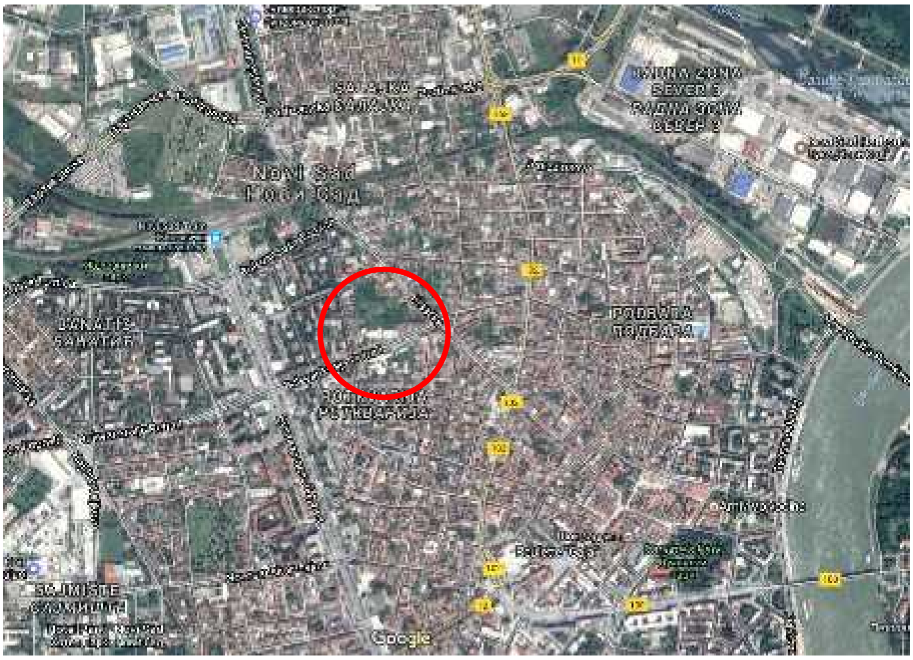

Fig. 1. *Wider view of location*

During the geotechnical examination on site (July 2016) groundwater occurred. Its level was measured at the completion of the exploration borehole and was at 75.5 meters above sea level (MASL). On the southern border of the site, a piezometer for long-term groundwater level measurement is installed.

The level of groundwater is variable seasonally and yearly and is in direct correlation with the Danube level. Based on hydrological data [1], the groundwater regime at the site is as follows:

- low water levels on the Danube: groundwater level is at 74.5 MASL or at a depth of 3.1-4.5 m from the surface of the terrain,
- mean water levels on the Danube: groundwater level is at 75.8 MASL, or at a depth of 1.8-3.2 m from the surface of the terrain,
- high water levels on the Danube: groundwater level is at 77.2 MASL, or at a depth of 0.4-1.8 m from the surface of the terrain.

Determination of hydraulic conductivity on site was performed on 10.12.2016. by pumping water from depression well B1 (Figure 2). During the pumping, water levels were measured throughout the time in three (3) piezometers at distances 6, 12 and 28 m from the well B1. The borehole size was ϕ360 mm, the well diameter ϕ225 mm, and the bottom of the well is on 57.7 MASL.

2. Objectives

Aim of the project was lowering of groundwater level from a level of 75.80 MASL to a level of 71.15 MASL for buildings 2, 3, 4, 5 and to a level of 70.40 MASL for buildings 6,7,8.

The lowering of the groundwater level is done by pumping water from the wells, from aquifer which is located below the level of 75.8 MASL at the given location. Based on the test results, hydraulic conductivity of the aquifer layer is between k=1.5x10^{-4}-1.9x10^{-4} m/s, or on average 1.7x10^{-4} m/s. The required well capacity is determined based on a hydraulic calculation – numerical simulation. The results of the hydraulic calculation give the approximate values of the required pumping capacity for the adopted parameters of the aquifer.

The hydraulic calculation is performed using numerical simulation with method of finite elements, FEMWATER.

3. Materials and Methods

FEMWATER is designed to solve the following system of governing equations along with initial and boundary conditions, which describe flow and transport through saturated-unsaturated porous media. The governing equations for flow are basically the modified Richards equation. The equation is as follows: [2]:

$$\frac{\rho}{\rho_0} F \frac{\partial h}{\partial t} = \nabla \left[K \left(\nabla h + \frac{\rho}{\rho_0} \nabla z \right) \right] + \frac{\rho^*}{\rho_0} q \tag{1}$$

$$F = \alpha' \frac{\theta}{n} + \beta' \theta + n \frac{dS}{dh} \tag{2}$$

where:

F – storage coefficient
h – pressure head
t – time
K – hydraulic conductivity tensor
z – potential head
q – source/sink
ρ – water density at chemical concentration C
ρ_0 – referenced water density at zero chemical concentration
θ – moisture content
α′ – modified compressibility of the medium
β′ – modified compressibility of the water
n – porosity of the medium
S – saturation

As a boundary condition for solving differential equations of unsteady flow, the groundwater level of 76.0 MASL is set in a radius of 900 m from the location center. Disposition of piezometric levels for the given location is obtained by simulation of pumping from well boreholes.

3. Results and Discussion

Total required flow during the pumping process depends on the construction phase of the building and was obtained by solving the differential equations of flow in the porous medium by the finite element method.

The number of active wells is harmonized with the predicted technology and dynamics of the construction works. Three (3) stages of excavation and construction works of facilities are foreseen.

- Phase-1 covers the area around the buildings 3 and 4, for which it is necessary to lower the groundwater level in the excavation pit at the level of 71.15 MASL, or 0.5 m below the bottom of excavation pit. In phase-1, five (5) borehole wells are planned: B2, B3, B4, B5 and B6, with a flow rate of 17.0 l/s, with a previously active well B1 for building 1, with a flow of 20.0 l/s. The piezometric levels for phase-1 are shown in Figure 3a.
- Phase-2, in addition to the area for the buildings 3 and 4, this phase includes expansion for the needs of founding facilities at building 2 and 5, for which it is necessary to lower the groundwater level in the excavation pit at the level of 71.15 m, or 0.5 m below the bottom of the excavation pit. For the phase-2, along the well B1 with a flow of 16.0 l/s, wells B2, B3, B5 and B6 with a flow of 16.0 l/s, it is necessary to activate well B7 with a flow of 16.0 l/s, while the well B4 can be turned off. The piezometric levels for phase-2 are shown in Figure 3b.
- Phase-3, in addition to the area for the buildings 2, 3, 4 and 5, this phase includes an extension for the needs of the foundations of the buildings 6 and 7, for which it is necessary to lower the groundwater level in the excavation pit at level of 70.40 MASL or 0.5 m below the bottom of the excavation pit. For the phase-3, wells B1 and B7 are required with a flow of 17.0 l/s and wells B2, B3, B5 and B6 with a flow rate of 16.0 l/s, while the well B4 remains switched off. The piezometric levels for phase-3 are shown in Figure 3c.

Water levels were measured in wells and in the piezometer P4, which is built in the center of the excavation pit.

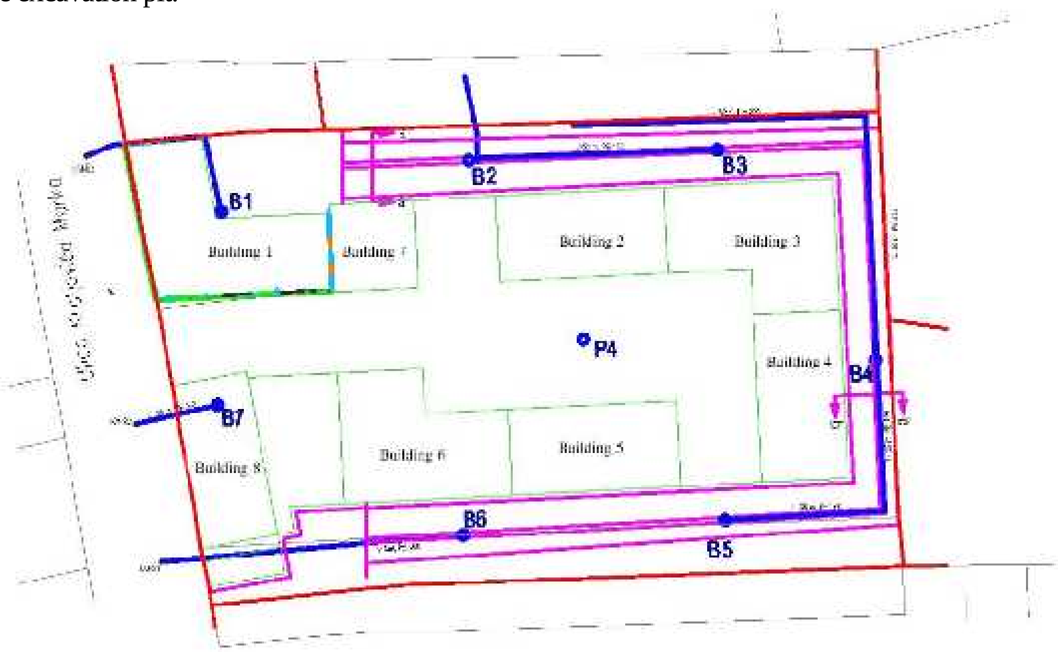

Fig. 2. *Disposition of buildings and wells*

Based on the proposed pumping plan, it is evident that there is always one well in the reserve, which can be activated if a pump failure occurs on one of the active wells.

In phase-1, the reserve well is B7, and in phase-2 and phase-3 is a spare well B4. A spare well is planned to temporarily cover the operation of one of the inactive wells until a pump replacement/repair is performed.

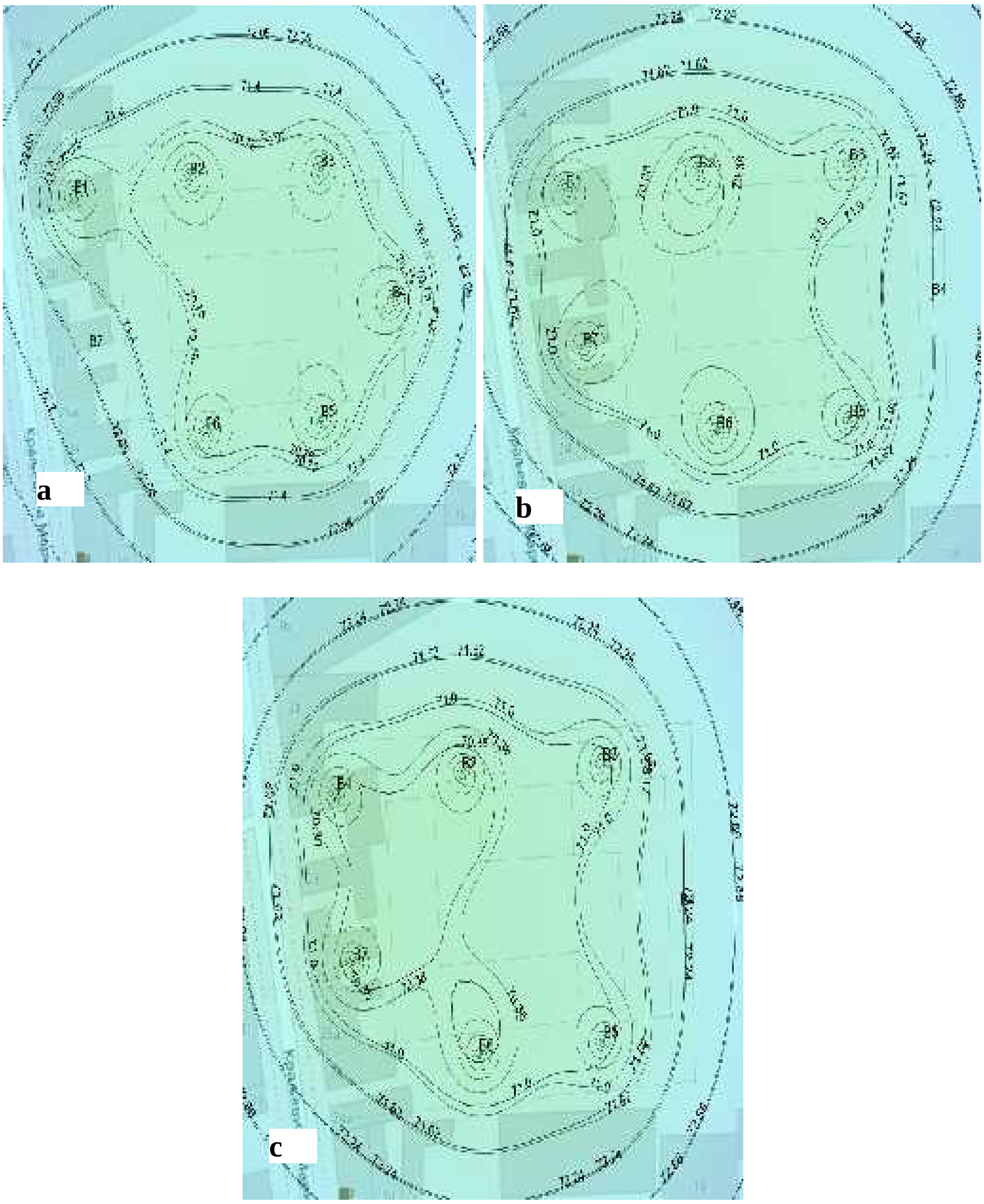

Fig. 3. *a) Phase-1, b) Phase-2, c) Phase-3*

The slope stability calculation is performed for two characteristic cross sections. Cross section a-a was adopted at the western part of the location with a terrain top level of 78.8 MASL and excavation level of 71.9 MASL, while the cross-section b-b was on the eastern part of the plot with a terrain top level of 77.5 MASL and excavation level of 71.65 MASL.

The soil strength parameters were determined based on the Elaborate [3]: ϕ'=220 and c'=10 kPa for the cover layer made of dust (ML) and ϕ'= 270 and c' = 5kPa for dust-sand-clay layer

(SF-SC). The influence of negative pore pressure (suction) in soil, due to groundwater level lowering, is neglected ($\phi_B = 0$).

The calculation was performed according to the equilibrium method, using the Morgenstern-Price [4], [5], [6] method for landslide of arbitrary shape. The adopted slope was 1: 1.25, with a berm width of 1.0 m at the level of 75.6 MASL.

Figure 4 shows the results of the calculation for the cross-section a-a, where the slope is at 1.0 m from the object, the well is in the berm at 7.5 m from the object, and the crown of the slope at a distance of 12.0 m from the object.

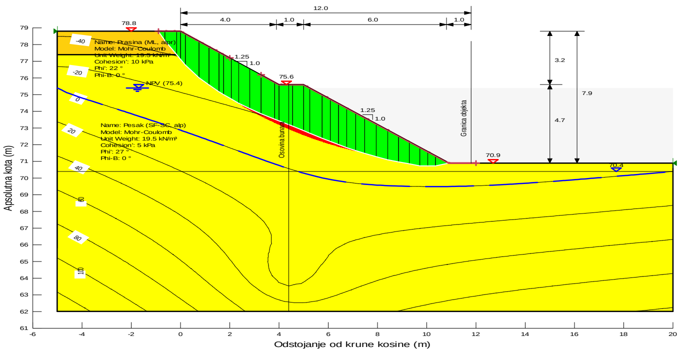

Fig. 4. *Calculated stability of cross-section a-a (minFs=1.207)*

Figure 5 shows the results of the calculation for the cross-section b-b, where the slope is at 1.0 m from the object, the well is in the berm in the distance of 6.5 m from the object, and the crown of the slope at 9.4 m from the object.

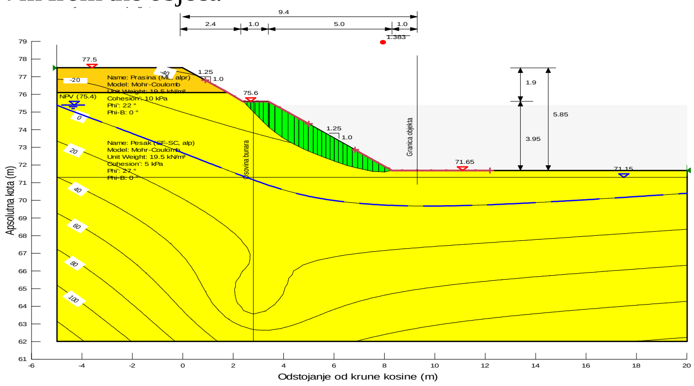

Fig. 5. *Calculated stability of cross-section b-b (minFs=1.383)*

Based on the calculation, it can be noted that slope and its geometry provide minimum safety coefficients for the temporary construction.

Groundwater lowering causes a decrease of pore pressure and an increase in effective ground tension, which causes the descending of terrain and objects. The size of the descending depends on the amount groundwater level lowering and the soil deformability parameters. Bearing in mind the difference between the volume weights of the saturated and the soaked soil, the increase in the effective tension for Π-level drop is equal to the product of the drop and volume weight of the water. The increase of the effective tension in the zone of the Kralja Petra I street is between $\Delta\sigma'_z$=43.6-16.6 kPa, and in the zone of the Kraljević Marka street between

$\Delta\sigma'_z$=44.1-29.4 kPa.

The thickness of the compressible layer, from the foundation base to the layer of marl-clay, is approximately 18.5 m, and the average modulus of elasticity of the sand in the zone of influence of the foundation is about Es≈50.0MPa. The ground descending due to groundwater lowering, can be approximated by a one-dimensional deformation method based on the following expression:

$$s = \int_{1.5}^{20.0} \pounds_z dz = \int_{1.5}^{20.0} \frac{\Delta\pm'_z}{M_s} dz \approx \int_{1.5}^{20.0} \frac{\Delta\pm'_z}{1.3E_s} dz \tag{3}$$

If the effective tension increase in the zone of King Peter I street is included in the expression above, $\Delta\sigma'_z$ = 43.6-16.6 kPa, a descending between 12.0-4.0 mm is obtained.

If the effective tension increase in the zone of Kraljević Marka street is included in the expression above, $\Delta\sigma'_z$=44.1-29.4 kPa, a descending between 13.0-8.0 mm is obtained.

Uneven descending cause the tilt of the objects to the wells. Bearing in mind the constructive systems of contemporary buildings, the estimated total and differential descendings do not compromise neighboring objects.

4. Conclusion

The paper presents the results of calculating of groundwater lowering in a wide excavation pit. This variant was adopted for economic reasons, the construction of an object in a wide excavation pit is considerably cheaper than pit with vertical sides under the protection of RC diaphragm, curtains of RC piles or sheet steel piles, for which additional construction is required. In addition to the lower price, a wide excavation variant has an additional advantage as it requires a short time to build an underground floor.

The groundwater lowering calculation was carried out according to the designed solution, with a total of 7 borehole wells ϕ360 mm and a depth of ≈25.0 m from the surface of the terrain. The time for which the groundwater level was lowered, generally coincided with the hydraulic calculation.

The descending of the control bench on a neighboring object was 6.0 mm, which is less than the maximum predicted of 12.0 mm. The descending of the other benchmarks was considerably less, and there was no significant damage on the facilities.

At the moment of writing this work, about 9 months after the beginning of the works in December 2016, the underground part of the building was successfully completed, and building the 1st floor has started.

Acknowledgements

This study was funded by the Serbian Ministry for Science; project TR37010 "Stormwater Drainage Systems as Part of Urban and Traffic Infrastructure".

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