Construction works above cavities, investigation of an undermined area

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Abstract. Construction work above previous mining area is always a great challenge from the engineering point of view. In the southern part of Budapest, the previous mining activities resulted more than a hundred thousands of square meters of cavities. These cellars cut into porous limestone with different depth, but mostly close to the surface; nowadays, these cellars are located inside a residential area, and some part of the undermined area is planned to build because this is an empty and valuable area. For the construction of these improvements, it is necessary to perform detailed investigations and stability calculations. This paper is introducing the detailed investigation process of a significant cellar which will be involved by construction activities. Three buildings are planned to build above it. The studied cellar located in the 22nd district of Budapest, Hungary, with a depth between 4.3 – 7.7 m, with a wide range of pillars’ width between 0.73 – 7.7 m according to the studied cross-sections. The investigation starts with geometrical measurements and core drillings to map the rock mechanical properties of the host rock. Several laboratory tests were done for obtaining rock mechanical parameters for modelling. After creating the geotechnical model, it was used for FEM calculations using RS2 software. Four cross-sections were chosen across the cellar system in different locations and various directions modelling the surface load of the planned building. The stability of the cellar was studied from two different viewpoints: firstly, the factor of safety was determined, and secondly, the settlement was calculated as an effect of the surface load. A displacement measurement system was set up in several cross-sections of the cellar to compare the calculated and real displacements in the future.

Keywords. undermined area, cellar, porous limestone, FEM modelling, safety factor

1. Introduction

Geotechnical problems are one of the issues which solved nowadays with the help of numerical modelling. One of the serious problems in this field is the stability of underground cavities, both man-made and natural ones.

This article will focus on the man-made cavities called cellars; cellars are spread all around the world we can find them in China [1], in Europe: in Spain [2], in France [3] [4], in Italy: Emilia-Romagna [5] and Rome [6], and in Hungary: Miskolc [7] and Budapest [8] [9]. The constructing and using of the cellars in Hungary started in the Middle Age [10]. It has been used for a lot of purposes since that time until now.

A lot of modelling software are used to evaluate the stability of the cavities, like MATLAB [11], FLAC [12], and Rocscience software [13] [14] [15]. In some cases, the collapse of cavities located in a
soft rock under urban area happened like in Italy Marsala in 2011 [16], those collapses cause a loss in properties and lives.

Benito Olmeda et.al. [12] studied the effect of loading on the stability of a cavity. Their study covered variable values of the surface load, relative location of the load above the cavity (eccentricity), value and geometry of the load, dimensions of the cavity, rock type, and geomechanical parameters of the host rock. The vertical displacements of the cavity with increasing the load value were recorded as the main result of the investigation.

This paper is studying a cellar system in 2D cross-sections to evaluate its stability, including the effect of the cavities on the planned buildings on the surface.

2. Geological settings, description of the investigation area

The studied cellar located in Budafok south of Budapest, Hungary, where a lot of cellars were cut under this area in Miocene porous limestone. The Miocene porous limestone is one of the most important formations of the 22nd district of Budapest. The thickness of it around 50 m, and a thin layer (around 30 cm) of bentonite is also formed, which affects the cellars. According to previous studies, porous limestone is water sensitive, its strength decreases in saturated conditions [17]. The porous limestone is layered at the investigated area, the layers have different properties.

The engineering geological model of the area was set up according to the observation of the ventilation shafts. There are three layers of the limestone: weathered porous limestone where the foundation will be constructed, weak porous limestone, and good limestone; two layers of soil exist: a layer of topsoil on the surface and a bentonite layer embedded between the porous limestone. The layers from up to down are in table 1, with a range of their thickness.

| Layer name                        | Thickness range (m) |
|-----------------------------------|---------------------|
| Cover soil                        | 0.73 - 0.84         |
| Weathered porous limestone        | 0.90 – 1.00         |
| Good limestone                    | 0.39 – 3.35         |
| Weak porous limestone             | 1.00 – 1.20         |
| Good limestone                    | Till the bottom of the model |
| Bentonite (goes through good limestone layer and close to the cellar’s roof) | 0.3 |

Nowadays, the studied cellar system is using for growing mushroom, laser fighting, and as a storage place as in figure 1. The area of the site is 7218 m², and cavities below the surface cover 68% of this area. Above the cellar system 1231 m² building is planned below it the cavity covers 72% of this area. The new buildings which are planned to construct above the cellar system have an average load of 50 kN/m². Figure 2 shows the location of the buildings and the measured arrangement of the cellars. There are different types of cellar branches and pillars with different size. The cellar system has different cover which vary in a range 4.2 - 7.7 m, and a pillar’s width in range 0.73 – 7.7 m.
3. Methodology and Materials

The specimens were obtained from five places around the cellar system, samples had been obtained from the walls of the cellar system by core drilling with 3.7 cm diameter. Figure 3 shows one location of the drilling. The specimens were arranged in the laboratory to be separated into three groups according to texture: coarse, medium and fine-grained. Altogether, there were 55 specimens; the tests were done in the laboratory according to ASTM and EN codes. Apparent densities were determined according to (EN 1936:2006). The uniaxial compressive strength (UCS) tests and Brazilian tests were made according to ASTM D7012-14e1 and ASTM D 3967-16, respectively. The ultrasonic pulse velocity tests were performed on cylindrical test specimens (EN 14579:2004), and the velocities were
calculated in km/sec. The laboratory tests have been done in the natural condition regarding the moisture.

The stability calculations have been performed by Rocscience software package, with the RS2 2019 finite elements code, which allows to calculate the maximum displacements and the strength reduction factor (SRF).

Figure 3. Place of obtained specimens in the wall of the cellar.

The five obtained samples could be classified into three groups, as it is mentioned above. These three groups are distributed in the cellar in unknown way, so the used laboratory results for modelling were chosen as the average of weakest rock type, the coarse-grained porous limestone for safety, as present in table 2.

Table 2. The laboratory results used in modelling.

| Layers                  | Intact Rock | Density (kg/m3) | UCS (MPa) | Young’s modulus (MPa) | Poisson Ratio |
|-------------------------|-------------|-----------------|-----------|-----------------------|---------------|
| Coarse grained porous limestone | 1500        | 1.5             | 820       | -                     | 0.2           |
| Medium grained porous limestone | 1500        | 1.5             | 820       | -                     | 0.2           |
| Fine grained porous limestone | 1500        | 1.5             | 820       | -                     | 0.2           |

4. Results and Discussion

The models created in Rocscience (RS2) environment, four cross-sections have been chosen for modelling to cover the building area, as it is in figure 2. The maximum displacement and the strength reduction factor (SRF) were calculated and recorded for each cross-section.

The Generalized Hoek-Brown failure criterion was used to evaluate the strength of the rock layers, which is the most commonly applied strength model for modelling rock masses [18], while for soil layers Mohr-Coulomb criterion was used. The calculated strength parameter for rock layers and soil layers can be found in table 3 and table 4, respectively.
### Table 3. The parameters for rock layers for modelling.

| Layers                  | mb   | s     | a     | GSI | Deformation modulus (Erm) (MPa) |
|-------------------------|------|-------|-------|-----|-------------------------------|
| Weathered porous limestone | 0.938553 | 0.001273 | 0.511368 | 40  | 130                           |
| Weak porous limestone   | 1.91721    | 0.011744 | 0.502841 | 60  | 425                           |
| Good limestone          | 4.68201    | 0.188876 | 0.500364 | 85  | 760                           |

### Table 4. The parameters for soil layers for modelling.

| Layers            | Density ρn (kg/m³) | Internal Friction Angle (degree) | Cohesion |
|-------------------|--------------------|----------------------------------|----------|
| Cover soil layer  | 1800               | 10                               | 10       |
| Bentonite         | 2000               | 15                               | 35       |

The model of cross section D-D and E-E are in figure 4 before the construction of the building, where the layers are in different colours.

![Cross-section D-D & E-E with the layers](image)

**Figure 4.** Cross-section D-D & E-E with the layers

After the modelling of the four cross-sections, the results of maximum displacements and SRF were recorded as in table 5, the maximum displacement before the construction and after it of each cross-section are recorded.

### Table 5. The result of the modelling.

| cross Section | SRF | Max. Dis. (mm) Before adding the load | After adding the load |
|---------------|-----|--------------------------------------|-----------------------|
| B-B           | 1.83| 3.0                                  | 4.4                   |
| D-D           | 1.40| 6.1                                  | 6.1                   |
| E-E           | 1.05| 34.8                                 | 58.0                  |
| F-F           | 1.75| 3.4                                  | 7.9                   |
As we can see from the table, all the cross-sections are on safe side according to maximum displacements and SRF except cross-section E-E, which has SRF a little bit above 1.0. E-E cross-section has the highest displacement, and lowest SRF, the weakest area in the cross-section is above the widest cellar and at the same time the shallowest cover where the load is existing, as in figure 5. If the location of cross section E-E checked carefully, in the site-plan figure 2, the cellar opening between two pillars is too wide, and the pillars could be more supportive if the studied cross-section have been taken in different way like a little bit toward the north. Or we can check the cross-section B-B, which cross close the failure point in cross-section E-E, and as we can see, it is safe.

Figure 5. The location of the maximum Displacements in cross-section E-E.

In figure 6, the maximum displacements of cross-section D-D are shown, where the maximum displacement reaches 2.18 mm, and the SRF is 1.40. It is noticeable from the figure that the maximum displacement located above the wide cellar branches and thinner pillar width, while the load is located on the other side of the cross-section above wider pillar width and less width of cellar openings; because of that, we got the same maximum displacements for both steps (before and after the loading) in cross-section D-D, table 4 which means that the affection of the self-rock weight on the left side is bigger than the self-weight with the load together on the right side (above the wide pillars), which lead us to do 3D modelling to evaluate the cellar system in a better way.

Figure 6. The maximum displacements as a result of D-D modelling.

5. Conclusion
There is some risk to construct any buildings above cavities, but sometimes it is necessary to use this kind of areas. There is some example when a cavity collapsed under surface load, but many times, it is
stable. In this paper, a cellar system with medium size building above it was investigated. Field and laboratory investigations and stability calculations were made to examine the stability of it. The results proved that the host rock of the cellar, the porous limestone is a weak rock, but the rock mass of it is in good condition. That is why the calculations proved that the cellar system is stable with the applied load on the surface. The safety of the cellars needs to be proved for a long time; therefore, it is necessary to perform regular displacement monitoring during the construction and the designed life of the building. According to the results, the introduced calculations can be validated in the future to use the experience for other similar construction activities with the same host rock.

The analysis was based on the generalized Hoek Brown (GHB) failure criterion; the results showed that the SRF to be between 1.40-1.83 and the maximum displacements of the studied valid cross-sections between 4.4-7.9 mm. After the study, we can recommend the construction work to be done. To be more on the safe side, we suggest doing a 3D modelling evaluation of some parts of the cellars to understand more the behaviour of the cellar system.

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References
[1] Liu M, Tang Y, Zhao K, Liu Y, Guo X, Ren D, Yao W, Tian X, Gu Y, Yi B and Zhang X, 2017 Determination of the fungal community of pit mud in fermentation cellars for Chinese strong-flavor liquor, using DGGE and Illumina MiSeq sequencing, Food Research International, 91 80–87.
[2] Fuentes J M, Gallego E, García A I, and Ayuga F 2010 New uses for old traditional farm buildings: The case of the underground wine cellars in Spain Land Use Policy 27, no. 3, 738–48.
[3] Smeray J, Mandin D, and Chaumont J 2000 Annual variations of airborne fungal propagules in two wine cellars in French Jura Cryptogamie Mycologie, 21, no. 3 163–19.
[4] Al Heib M, Duval C, Watelet J-M, and Gombert P 2015 Back-analysis of the collapse of the Clamart chalk underground quarry - Paris (France) London 1525–30.
[5] Tinti F, Barbaresi A, Benni S, Torreggiani D, BrunoR, and Tassinari P 2015 Experimental analysis of thermal interaction between wine cellar and underground Energy and Buildings 104 275–86.
[6] Ciotoli G, Ferri G, Nisio S, and Succhiarelli C 2015 The underground cavities in the territory of Rome: typologies, distribution and sinkhole susceptibility Italy Rome 433–39.
[7] Mocsár-Vámos M, Görög P, and Török Á 2015 Engineering geological characterization of the host rocks of underground cellars in Avas hill, Northern Hungary presented at the European Conference on Soil Mechanics and Geotechnical Engineering, London.
[8] Görög P, Hangodi Á, and Török Á 2013 Stability analyses of underground structures cut into porous limestone Paris 1707–10.
[9] Hajnal G, Hydrogeological Study of the Castle Hill in Budapest. Hungary: Szinergia Ház Közhasznü Egyesület, 2006.
[10] Gálos M, Kertész P and Kürti I 1981 Engineering geological problems of cellars and caverns under historical centres of towns in Subsurface Space 119–26.
[11] Janič P, Jadlovská S, Zápac J, and Koska L 2019 Modeling of underground mining processes in the environment of MATLAB / Simulink Acta Montanistica Slovaca, 24 no.1 44–52.
[12] Benito Olmeda J. L., Moreno Robles J, Sanz Pérez E, and Olalla Marañoń C 2020 Influence of Natural Cavities on the Design of Shallow Foundations,” Applied Sciences 10 no.3, 1119.
[13] Zenah J, Török Á, Reháň N, and Görög P 2019 Investigation of the effect of construction activities to underground cavities cut into porous limestone Omiš - Split, Croatia 453–58.
[14] Bukaçi E, Korini Th, Periku E, Allkja S, and Sheperi P 2016 Reliability Analysis for Tunnel Supports System by Using Finite Element Method American Journal of Engineering Research (AJER) 5 no.9 1–8.

[15] Vlachopoulos N and Vazaios I 2018 The Numerical Simulation of Hard Rocks for Tunnelling Purposes at Great Depths: A Comparison between the Hybrid FDEM Method and Continuous Techniques Advances in Civil Engineering 2018 1–18.

[16] Fazio N L, Perrotti M, Lollino P, Parise M, Vattano M, Madonia G and Di Maggio C 2017 A three-dimensional back-analysis of the collapse of an underground cavity in soft rocks Engineering Geology 228 301–11.

[17] Zenah J, Görög P and Török Á 2020 Stability of Underground Excavation in Porous Limestone: Influence of Water Content Acta Montanistica Slovaca, 25 no.3 337–49.

[18] Hammah R E, Yacoub T E and Corkum B C 2005 The Shear Strength Reduction Method for the Generalized Hoek-Brown Criterion Anchorage, Alaska 6.