

Stability analysis of underground openings for extraction of natural stone

Stabilnostna analiza podzemnih prostorov za pridobitev okrasnega kamna

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Kratka vsebina

Pridobivanje naravnega kamna s podzemnimi komorami je v svetu in pri nas še vedno v zelo nizkem deležu v primerjavi s površinskim odkopavanjem. Ob omejenih ekonomskih zalogah naravnega kamna in ostrejših ekoloških zahtevah je podzemno pridobivanje aktualna alternativa.

Dimenzije podzemnih prostorov se določijo na osnovi stabilnostnih analiz. Bistvenega pomena je, da se ugotovi mehanizem možnih porušitev v podzemnem prostoru. Na podlagi tega se izbere primerna stabilnostna analiza. V mehaniki hribin se zelo pogosto uporablja numerična zvezna analiza. Slabost analize je v tem, da ni možno simulirati sistemov prelomov. V zadnjih letih je velik razvoj doživela numerična analiza ločenih elementov, ki omogoča stabilnosti izračun podzemnih prostorov v zmerno razpokani hribini. V predstavljenem primeru izgradnje podzemnih prostorov kamnoloma Hotavlje so podani rezultati obeh analiz. Ugotovljeno je, da je zvezna analiza primerna za preverjanje globalne stabilnosti podzemnega prostora, z nadaljno analizo pa dobimo natančnejše izračune o stabilnosti blokov v okolici izkopa. Za preverjanje stabilnosti posameznih blokov in podpornega sistema za posamezen blok, pa je še vedno dovolj natančna analitična blokovna analiza. Prvi pogoj za zanesljivo stabilnostno analizo je dovolj vhodnih podatkov o geomehanskih lastnostih hribine. Za to so potrebne terenske in laboratorijske preiskave in geotehnične meritve. Na podlagi večjega števila izdelanih stabilnostnih analiz je bila za podzemne prostore kamnoloma Hotavlje ugotovljena največja širina podzemnih prostorov 12 m.

Abstract

Extraction of natural stone is usually carried out in surface quarries. Underground excavation is not a frequently used method. Due to the restrictive environmental legislature and limited stores of natural stone, underground extraction has become quite an interesting alternative. Dimensions of underground openings are determined with stability analyses. Prior to starting a numerical analysis of a large underground opening it is very important to determine the mechanism of failure and set up a proper numerical model. The continuum method is usually used in rock mechanics. A disadvantage of this calculation is that it cannot be applied to a large number of joints. Other methods are preferred, such as the numerical discrete method, which allows joint systems to be involved into calculations. The most probable failure of rock with several joint systems is block sliding. In the example of the marble of Hotavlje both methods were used. It was established that the continuum method is convenient for the global stability prediction of the underground opening. Further discrete method enable the block stability calculation. The analytical block analysis is still accurate for the a stability calculation of single block. The prerequisite for a good numerical analysis is sufficient quality data on geomechanical properties of rock. In-situ tests, laboratory tests and geotechnical measurements on the site are therefore necessary. Optimum dimensions of underground chambers in the Quarry of Hotavlje were calculated by using several numerical models, and the maximum chamber width of 12 m was obtained.

1. INTRODUCTION

Extraction of natural stone in underground chambers is quite rare in Slovenia and also in other countries of the world. Surface excavation is still in the majority everywhere. Underground excavation becomes more and more interesting because of limited stores of natural stone and rigorous environmental regulations.

There always exists a possibility that rock is not appropriate for underground excavation. Therefore, the decision for such technology shall be based on geotechnical investigations of a rock massive. In the first stage, maximum dimensions of chambers and galleries shall be estimated using a preliminary analysis. Usually RMR and Q rock mass classification are used. In this paper the term gallery is used for an underground excavation of a height of 4m and the term chamber for a higher one. The jointed system of rock shall be identified and mapped during the engineering geological work on the field. Several in-situ and laboratory geotechnical investigations shall be carried out to evaluate geotechnical properties of rock.

In the next stage a research gallery shall be excavated and various geotechnical equipment installed in it. The use of extensometers, measuring anchors, crack-meters, convergence profiles and 3D measurement devices is recommended in our experience. Geotechnical measurements in a gallery can supply a very important information on the deformation and stress field and provide input data for the stability analysis.

2. NUMERICAL METHODS

The most commonly applied numerical methods in rock mechanics are continuum method and discrete method. The choice of methods depends on many specific problems, mainly on the problem scale and fracture system geometry.

2.1 Continuum method

Several numerical programs are available for the continuum calculation. One of them, FLAC 2D, is presented in the paper. It is an explicit finite difference program (FDM) that performs Lagrangian analysis. The general calculation sequence embodied in this

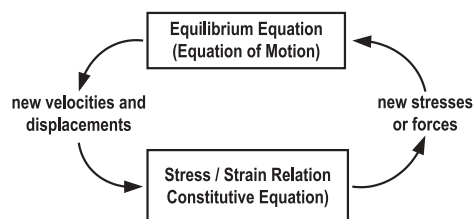


Figure 1. Basic explicit calculation cycle

program is illustrated in Figure 1. This procedure first invokes the equations of motion to derive new velocities and displacements from stresses and forces. Then strain rates are derived from velocities and new stresses from strain rates. One timestep is taken for each cycle. It is important that the timestep is small enough. Deficiency of such calculations lies in the structural analysis. It is almost impossible to consider a moderately number of joint systems. For jointed and fissured rock, the geomechanical properties for the numerical model should be reduced.

2.2 Discrete method

The discrete approach is most suitable for moderately fractured rock mass. Recent programs are described as distinct element method (DEM). The program UDEC is presented in the paper. In a distinct element method, a rock mass is represented as an assembly of discrete blocks, and joints as interfaces between distinct bodies. Contact forces and displacements at interfaces are obtained through a series of calculations which are tracing the movement of blocks, the movement being induced by applied loads or body forces in a dynamic process. The dynamic behaviour is represented numerically by a timestepping algorithm.

The distinct method is based on the concept that the timestep is sufficiently small to prevent the propagation of disturbances between discrete elements. Calculations performed by the distinct element method alternate between the application of the force-displacement law to all contacts and Newton's second law to all blocks. The force displacement law is used to find out contact forces from known displacements. Newton's second law gives the motion of blocks resulting from known forces acting on them. If

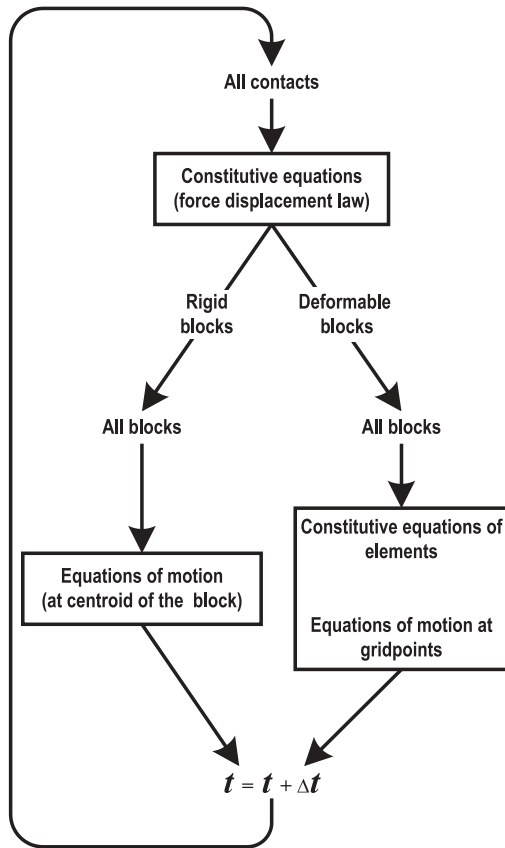


Figure 2. Calculation cycle of the distinct element method

blocks are deformable, the motion is calculated at gridpoints of triangular finite strain elements within blocks. Figure 2 shows schematically the calculation cycle for the distinct element method.

3. CASE HISTORY: THE QUARRY OF HOTAVLJE

The Quarry of Hotavljewas the first Slovene quarry which started the underground extraction of natural stone. This natural stone is known as the “Marble of Hotavljje”, although it is actually limestone in a lithological sense. Hotavljje quarry is located in the narrow valley of Volaška stream, a few hundred meters north from

the village Hotavljje in the Poljanska valley. The quarry is built in the cordevol limestone (Vesel, Senegačnik, 2000). First investigations were started in 1993. According to preliminary analyses, the largest width of an underground opening with a semi-circular ceiling was estimated to 20 m (Petkovšek, 1993). Investigations were performed systematically till 2001. Several numerical models, supplied with geological and geotechnical data, were used for calculations. Optimum and safe dimensions of chambers were calculated at the end of the research project. The position of galleries in the middle of the year 2001 is shown on Figure 3. Three galleries, 8 wide and 4 m high, were excavated until that time. The length of the longest gallery was 45 m. The west gallery (G3) and middle gallery (G1) were connected with crossbar (P2). Also the middle gallery and east gallery were connected with another crossbar (P1).

3.1 Investigations performed

3.1.1 Engineering geological mapping

Joint systems were identified by means of the engineering geological mapping. The limestone of Hotavljje was found to be fissured by two systems of joints and additional random fissures on some locations. Open joints or joints with clay were crucial for the possibility of a block failure. There were great variations in the strike and quality of joints. The fact that joints were not continuous throughout the quarry, had a positive effect on underground openings. Although a failure of a separate block might occur in such cases, the underground opening would remain structurally stable.

3.1.2 In situ investigations

Several pressuremeter measurements were carried out during the research project. Very high elastic moduli of 21-60 GPa were calculated in the intact rock. They were confirmed by laboratory dynamic ultrasound investigations which gave values of 58-66 GPa. Elastic moduli of fissured rock were much lower, their values dropping down to 5-10 GPa.

Laboratory geotechnical tests

The weakness of geotechnical laboratory tests lay in the fact that intact specimens were tested. The limestone of Hotavljje showed quite a high uniaxial compressive

strength of 15–93 MPa. Its tensile strength was between 5 and 10 MPa. Triaxial laboratory tests performed on five samples showed that their angle of friction was 33° and cohesion 46 MPa. The cohesion value was very high. But as the limestone of Hotavlje is very fissured in reality, a lower cohesion value had to be used for the stability analysis.

3.1.3 Geotechnical measurements

Geotechnical measurements are used for the observation of the deformation field around an excavation. In this way, they are very important for the monitoring of stability and safety of underground excavations. The following geotechnical equipment was installed into galleries:

- convergence profiles for measuring relative displacements between the sides and between the ceiling and the floor of a gallery. They were installed on portals and close to extensometer profiles.

- extensometer profiles for measuring deformations around the excavation. Two extensometer profiles were installed. The lengths of extensometers were 1.5, 3 and 6 m.

- crack-meters for measuring distances between the sides of joints. Five crack-meters were installed across the largest joints running through a gallery.

The results of convergence measurements showed that the maximum displacement between the two sides of a gallery amounted to 1.5 mm. The maximum displacement was observed at the portal of the west gallery and at the crossbar P2. Deformations obtained from extensometers and crack-meters

did not exceed 0.5 mm. The last measurements of all profiles in the middle of 2001 confirmed the stability of galleries.

3.2. Stability analysis of underground openings of the Quarry of Hotavlje

Several numerical analyses were made on the basis of laboratory tests, field investigations and geotechnical measurements. It is recommended to make a numerical back-analysis for a model to calibrate it according to the real situation on the field. Numerical back-analyses were carried out for the existing galleries. In the next step, extension and deepening of the excavation was simulated.

Preliminary analyses were made on the basis of two rock classifications, the RMR (Bieniawski, 1989) and the Q (Barton et al., 1974) rock classification. The quality of rock was estimated by considering parameters of uniaxial strength, RQD index, water conditions, joint system and quality of joints. The limestone of Hotavlje was classified into the group II, which means that rock was of a good quality for underground (with RMR classification).

As already mentioned, several numerical models are available for the calculation. In the paper the finite difference model will be presented as a continuum method and the distinct element model as a discrete method.

3.2.1 Finite difference method (FDM)

The finite difference method with the Mohr-Coulomb calculation was used in the first step. The method is one of the most popular numerical methods in rock engineering.

The ratio k between the horizontal stress field and vertical stress field depends on depth and tectonical conditions of a region. Data from measurements in different depths and different parts of the word present the value of the coefficient k between 1 and 2.5 (Hoek & Brown, 1996). In our calculations, the value of $k=1$ was adopted, because the best results were calculated in comparison with measured results..

In first numerical simulations, several calculations were done for massive - unfractured rock. As its geomechanical properties are high, the results of calculations showed that openings were stable at

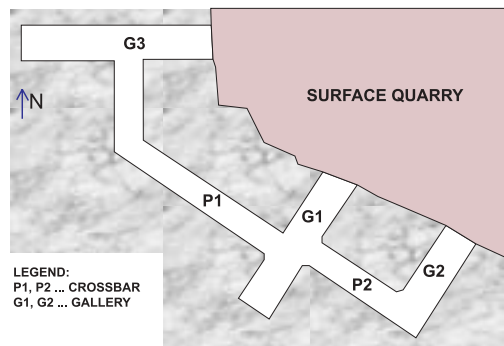


Figure 3. Plan of the underground galleries

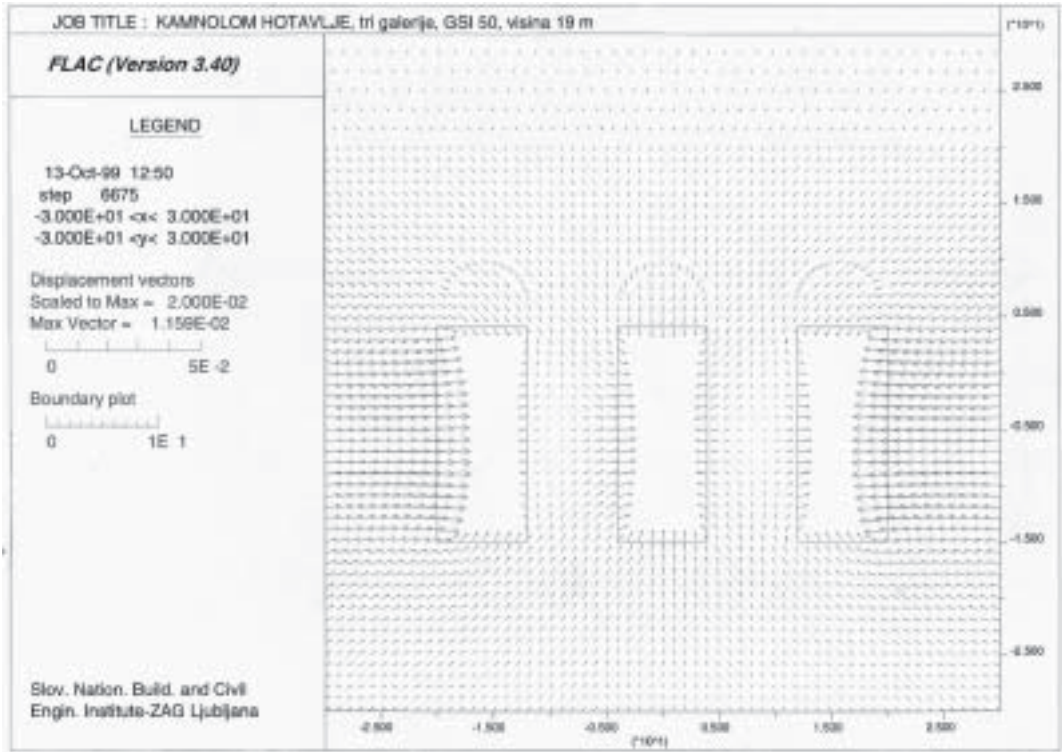


Figure 4. Displacements around galleries (continuum method)

relatively great dimensions. A chamber with the semi-circular ceiling was stable even at the width of 16 m. However, the limestone of Hotavlje is fractured in reality. Consequently, geomechanical properties of fractured rock were reduced in the next step by using the GSI index (Marinos & Hoek, 2000). GSI is a new classification method very appropriate for fractured rock. The GSI index can be estimated from diagrams for different types of rock, fracture systems and fracture qualities. Geomechanical properties were then calculated on the basis of the GSI index and lithological parameters. The value of the GSI index estimated from the engineering geological mapping amounted to 50. The following geomechanical properties, were used in the numerical model:

E (elastic modulus)	6.32 GPa
ν (poisson's ratio)	0.22
γ (unit weight)	0.24 KN/m ³
ϕ (angle of friction)	29°
c (cohesion)	1.23 MPa

Vectors of deformations for three chambers, for example, are presented in Figure 4. The height of the respective chambers was 19 m and the width 8 m. The maximum calculated deformation was 12 mm. Chambers with the width of 16 m were stable to the depth of 30 m too, but only in the case their ceiling was semi-circular.

3.2.2 Distinct element method (DEM)

The calculation based on the distinct element numerical method can provide block deformations and deformations in joints between blocks. The limestone of Hotavlje is jointed into several large blocks. And every single block is further divided by close fissures or fissures filled with silicates. These fissures are not dangerous for the stability of the whole excavation, but they bring about lower geomechanical properties of individual blocks. The GSI value of 68 was estimated for the blocks. The following geomechanical properties, based on the GSI

calculation, were used in the numerical model:

E (elastic modulus)21.8 GPa
 ν (poisson's ratio)0.22
 γ (unit weight)0.27 KN/m³
 ϕ (angle of friction)31°
 c (cohesion)1.5 MPa

The Mohr-Coulomb calculation was used for blocks and joints. This mathematical model enables only a two-dimensional calculation. Accordingly, joints have to be projected on the plane perpendicular to the gallery. It is impossible to consider all joints and fissures in the calculation. The problem must be simplified by considering only joints which are relevant for the stability of an underground excavation. In addition, all joints are highly variable with respect to dimensions, strike and quality. Continuous joints without breaks shall be used for the numerical method. It is a conservative cal-

culation, because more blocks are formed in this case and more of them are critical for sliding into the excavation. Joints parallel and perpendicular to the dinaritic strike shall be simulated in the numerical calculation. Beside two system of joints, several random joints exist too.

A bigger problem is the estimation of geomechanical properties of joints. Laboratory tests of jointed rock are limited. Some theoretical and empirical equations exist for the normal stiffness (K_n) and shear stiffness (K_s). The best way, to our opinion, is the numerical back-analysis. Numerical back-analyses were applied to the convergence profiles which had been installed into the galleries. Geomechanical properties required by the numerical models were changed systematically until the measured displacements were calculated. By using this procedure, the following geomechanical properties were obtained for the joints:

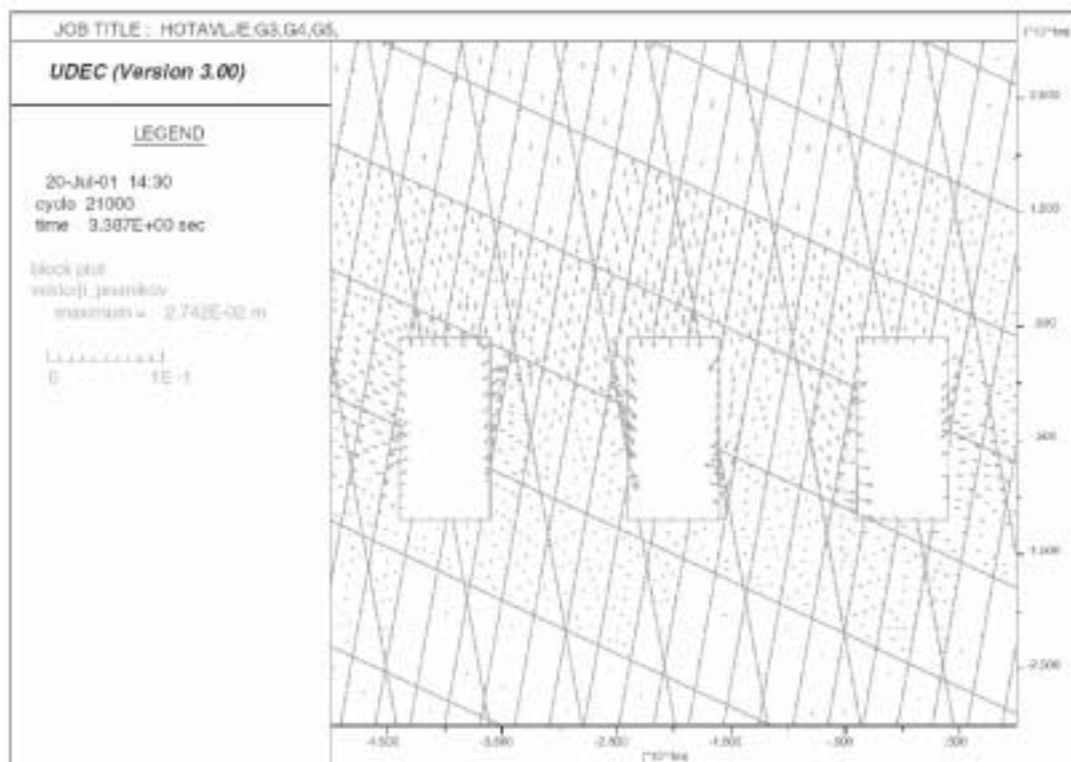


Figure 5. Displacements around galleries (discrete method)

Kn (normal stiffness)	2.5 GPa
Ks (shear stiffness)	2.5 GPa
φ (angle of friction)	25°
c (cohesion)	0

As in previous calculations, the value of the coefficient k equal to 1 was adopted.

In the case of unstable blocks a support system with anchors shall be foreseen. The orientation and number of anchors depend on the individual block. The anchors of 8 m length with the following properties were used in calculations:

l (length)	8m
ϕ (diameter)	38 mm
E (elastic modulus)	200 GPa
γ (yield tension)	300 KN

The ratio of width to depth is very important for the stability of a chamber. Data of known underground openings all over the world were collected in a special database (Kaiser, 2000). The results indicated that the majority of large underground openings was stable, provided the width-to-depth ratio was 2. These results were confirmed by our calculations too. Chambers in the limestone of Hotavlje were stable up to the width of 12 m. In the west side of the quarry, there is a higher density of joints and their orientation more unfavourable for the gallery. In that region the greatest width of chambers was 8 m. In all simulations the greatest displacements occurred in joints between blocks. Maximum displacements were about few centimetres there. An example of three galleries having the width of 8 m is presented on Figure 5. Maximum displacements were calculated on the sides of unstable blocks which were local supported by anchors.

3.2.3 Analytical block analysis

More information on block stability of single block can be obtained from the block analysis based on the block theory. The geotechnical stability of a block is calculated from the strike, dip and geotechnical properties of joints. Joint systems observed in the excavated galleries were used in these calculations. Several simulations were made for galleries of different dimensions. Almost all blocks could be stabilized by using long enough anchors.

After having performed calculations with the mathematical model and block analysis,

it became clear that the most probable type of failure would be the block failure.

3.3 Comparisons of the continuum method and the discrete numerical method

Several numerical analyses were carried out with different models. Calculations showed that stability could be expected in cases of underground chambers of 12 m width and depth of 2 times the width. In all calculations, the safety factor of 1.5 was taken into consideration. The comparison between the continuum (FDM) and the discrete method (DEM) was of interest for the detection of regions with greatest deformations. In the first case, the greatest deformations were obtained on both sides of a chamber. When the continuum method is applied to fissured rock, lower properties of rock shall be considered, because they are calculated by using the GSI index. The whole rock massive is acting as a solid body and consequently, the greatest deformations are calculated on critical places of excavation, i.e. on the ceiling or on the sides. Numerical results indicate the possibility of the collapse of the sides or the ceiling of a chamber, if the latter is too wide.

The calculation using the discrete model is closer to reality. Several joint systems are forming a region divided into several blocks. The rock is a high quality one, but joints are open or filled with stiff clay. Unstable blocks might fail under such geological conditions. Maximum deformations are calculated on the sides of chambers too, but only in the region of unstable block. However, an optimum support system can be provided in this case too. The discrete method enable detailed prediction of the block stability around the underground opening.

4. Conclusions

Based on practical experiences gained by underground excavation in the Quarry of Hotavlje, the following conclusions can be drawn:

- The prerequisite for a good stability analysis is the input of quality data. Laboratory and in-situ measurements are necessary to obtain them.
- The most important is to detect the mechanism of failure
- In the first stage the global stability is calculated with numerical continuum

method and in the next stage the stability of blocks with discrete method.

- The best method for the evaluation of geomechanical properties of joints is the numerical back-analysis. In order to calibrate this calculation model, geotechnical measurements shall be carried out.

- It is utterly important to perform the geological mapping during the chamber excavation. The aim of the mapping is to record any new joints which might affect the chamber stability. Such joints are open and clay-filled joints. Special attention shall be paid to continuous joints running through the top and the sides of a chamber. If a block can be formed, its stability shall be analysed by means of the analytical block analysis. The block analysis shall be used to calculate the optimum supporting system for the individual block.

- Continuous geotechnical measurements are very important for the safety of excavation. In the case of greater deformations as predicted from calculations, the stability of a chamber shall be checked by using new data.

Safety is of the utmost importance for the excavation of underground chambers. On the other hand, dimensions of chambers should be appropriate for the economic extraction. The optimum and safe dimensions of the underground openings can be achieved by

detailed geological mapping, systematical geotechnical measurements and proper numerical calculations.

References:

- Bieniawski, Z.T. 1989: Engineering rock mass classifications. New York:Wiley.
- Barton, N.R., Lien, R. & Lunde, J. 1974: Engineering classification of rock masses for the design of tunnel support. *Rock Mech.* 6(4), 189-239.
- Carvalho, J. & Hoek, E. 1992: Unwedge user's Guide, ver.2.3, Rock Engineering Group, University of Toronto.
- Hoek, E. & Brown 1996: Underground Excavation in Rock. E&FN Spon, London.
- Itasca, 2000: Fast Lagrangian Analysis of Continua - User's Manual. Itasca Consulting Group, Minneapolis.
- Itasca, 1996: Universal Distinct Element Code - User's Manual. Itasca Consulting Group, Minneapolis.
- Kaiser, P.K., Diederichs, M.S., Martin, C.D., Sharp, J. & Steiner, W. 2000: Proceeding of the Internations Conference on Geotechnical & Geological Engineering, Melbourne, Australia. Balkema.
- Marinos, P., Hoek, Evert, 2000. GSI: A geologically friendly toll for rock mass strength estimation. Proceeding of the Internation Conference on Geotechnical & Geological Engineering, Melbourne, Australia. Balkema.
- Petkovšek, B. 1993: Geotehnična ocena širine podzemnega prostora za kamnolom Hotavlje. Arhiv GeoZS, Arhiv ZAG, Ljubljana.
- Vesel, J. & Senegačnik, A. 2000: Raziskave naravnega kamna na širšem območju Hotavelj. Arhiv GeoZS, Ljubljana.

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V letošnjem letu so se tri velika združenja s področja geofizikalnih ved, ved o Zemlji in planetih prvič dogovorila za skupni evropski kongres. Kongres, ki so ga organizirali Evropsko geofizikalno združenje, Ameriška geofizikalna unija in Evropska geološka unija, je potekal v Nici med 6. in 11.4.2003. Ta kongres naj bi postal tradicionalen in je za nekaj prihodnjih let že napovedan v istem času, prav tako v Nici.

Kongres, ki je za nami, je kongres presežkov. Na kongresu je bilo registrirano okoli 11000 udeležencev, iz 90 držav, ki so svoje delo predstavili v več kot 14000 prispevkih, od tega je bilo okoli 8000 posterjev, preostalo pa so bile predstavitve v številnih sekcijah. Sekcije so potekale hkrati v 31 dvoranih, skupaj pa se je odvijalo kar 393 sekcij. Program kongresa je skupaj z indeksom avtorjev obsegal 850 strani in izbira sekcij, ki si jih želel poslušati, je terjala podroben študij programa. Urnik kongresa je bil zelo natrpan, odmori med sekcijami so bili kratki. Za udobje udeležencev kongresa je bilo poskrbljeno le toliko, kolikor je bilo nujno potrebno, poudarek je bil le na stroki in izmenjavi informacij, vse drugo je bilo močno podrejeno. Zaradi velikega števila udeležencev se je pogosto zgodilo, da je bila kakšna od dvoran tako zasedena, da varnostniki vanjo niso spustili nikogar več in veliko poslušalcev je ostalo pred vrati. K vtisu o velikosti kongresa so dodatno prispevali še zelo strogi varnostni ukrepi, saj je bilo potrebno pred začetkom vsakega dne zasedanj, za vstop v kongresni center čakati v vrsti tudi do pol ure.

Kongres je bil razdeljen na posamezne simpozije, ki bi jih lahko označili kar kot manjše kongrese znotraj velikega kongresa. Ti simpoziji so bili posvečenim strokam, ki delujejo znotraj združenj, ki so organizirala kongres. Simpoziji na kongresu so bili posvečeni vedam o atmosferi, klimatologiji, geodeziji, vedam o notranjosti Zemlje, hidrologiji, vedam o oceanih, nelinearnim procesom, naravnim tveganjem, planetarnim vedam, solarnim vedam, biogeoke-miji, vedam o kriosferi in energiji. Poleg teh specialnih simpozijev so bila organizirana tudi skupna posvetovanja na nivoju celotnega kongresa. Ta so obravnavala splošne teme, kot je na primer izobraževanje geologov ali informiranje javnosti o dejavnostih na področju ved o Zemlji. Skupna posvetovanja so bila namenjena tudi nekaterim aktualnim temam znotraj tematskega kroga kongresa, tako so bile na primer obravnavane poplave v Evropi, raziskave planetov in monoge druge teme.

Poleg simpozijskih predstavitev v sekcijah, so vzporedno potekale tudi številne delavnice, sestanki in pa predavanja ob podelitvah različnih nagrad. Skoraj vsi nagrajenci so predstavili svoje poglede na stroko, s katero se ukvarjajo, hkrati pa to niso bila le ozka strokovna in znanstvena predavanja, temveč v veliki meri epistemološki pregledi posameznih znanstvenih vej. Predavanja v okviru teh dejavnosti so bila izredno zanimiva, saj so predstavljala zgoščen povzetek trenutnega dogajanja in razvoja. Tako bi tudi pri nas veljalo razmisliti o tem, da bi nagrajenci, ki so jim podeljene nagrade znotraj strok, predstavili svoje delo.

Kongres so spremljale tudi številne komercialne predstavitve, od prodajnih razstav založb knjig do predstavitev komercialnih laboratorijev in podjetij, ki prodajajo merilno opremo. Razstavljene so bile številne revije, nove in zanimive knjige. Med drugim je bilo na policah zaslediti veliko regionalnih geoloških pregledov posameznih pokrajin in območij, pa tudi posameznih držav, kot na primer Madžarske in Albanije. Pri tem pa ni šlo le za površne preglede, temveč za obsežna in sistematična dela. Žal nikjer ni bilo zaslediti ničesar o geologiji Slovenije in skrajni čas je, da se to belo liso prekrije z objavo knjige v angleščini. Če je ne bomo prekrili sami, nam jo bodo zapolnili drugi.

Kongres je bil preobsežen, da bi ga lahko zajel in pregledal en sam človek. Tudi posamezni simpoziji so se odvijali v več vzporednih sekcijah. Dogajanje na kongresu je bilo tako obsežno, da si je bilo komajda mogoče ustvariti vtis o njem. Iz celotnega dogajanja kongresa pa sledi, da so raziskave in razvoj na področjih, ki jih je obravnaval kongres zelo intenzivne, razvejane in pestre. Hkrati pa to pomeni, da je odprto še veliko vprašanj in da so na voljo še številni izzivi.

Avtor pričujočega zapisa se je udeleževal predvsem sekcij, ki so se nanašale na hidrološke vede in znotraj njih na podzemne vode in hidrogeologijo. V okviru številnih sekcij kongresa se je izkazalo, da študije, ki se ukvarjajo s podzemno vodo, segajo na zelo široka področja. Tako je bilo preučevanje podzemne vode zaslediti na tradicionalnih hidroloških področjih kot tudi na drugih področjih, ki prvenstveno niso v domeni hidrogeologije. Če se naslonimo le na dva ekstremna primera lahko ugotovimo, da je podzemna voda tudi predmet obravnave paleoklimatologije in klimatologije. Ta obravnava sloni predvsem na pomenu vloge podzemne vode v hidrološkem krogu in na prizadevanjih po rekonstrukciji komponent in razmerij znotraj nekdanjega hidrološkega kroga. Drug ekstrem pri obravnavi podzemne vode predstavljajo planetarne vede, kjer se veliko energije posveča interpretaciji erozijske zgodovine Marsa in vlogi podzemne vode pri tem. Seveda brez špekulacij o aktualnem obstoju podzemne vode in njenih zalogah ne gre. Na tradicionalnih področjih hidrogeologije se veliko energije posveča preučevanju in analiziranju širjenja onesnaženja v podzemni vodi. Veliko sredstev se vlaga v razumevanje interakcije med onesnaževali in litološkimi komponentami vodonosnika ter saniranju onesnaženj v vodonosnikih. Hkrati s tem se številni avtorji osredotočajo na karakterizacijo heterogenosti vodonosnikov. Če so se v preteklih letih raziskave lotevale predvsem sanacij, pa so v zadnjem času postale pomembne tudi ekonomske analize teh postopkov ter tehtanje stroškov in dobrobiti. Nekaj sekcij je bilo namenjenih tudi interakciji podzemne vode in površinske vode. Te sekcije so bile razdeljene na tiste, ki so obravnavale te interakcije predvsem s stališča hidrodinamike in na tiste, ki jih je problematika zanimala s stališča vodooskrbe in vpliva površinskih voda na podzemne vode. V okviru hidrologije podzemnih voda velja omeniti tudi vadozno cono. Analizi razmer v nezasičeni coni je bilo posvečeno nekaj sekcij, od karakterizacije in meritev do modeliranja in interpretacij.

V okviru opisa hidrologije podzemne vode velja omeniti tudi nekatera prizadevanja na področju hidrologije površinskih voda. Veliko raziskav se usmerja v možnost napovedovanja in modeliranja odnosa med padavinami in odtokom na povodjih, kjer se redni hidrološki monitoringi ne izvajajo. Nekaj sekcij je obravnavalo modeliranje odnosa med padavinami in odtokom. Številne raziskovalne skupine po svetu razvijajo kompleksne hidrološke modele v katere skušajo vključiti najraznovrstnejše komponente hidrološkega kroga. Znotraj teh prizadevanj je veliko naporov posvečenih prav karakterizaciji odnosa med različnimi komponentami odtoka. S pojavom katastrofalnih poplav tudi v razvitih delih sveta, kot so bile na primer poletne poplave v Srednji Evropi v letu 2002, se je povečalo tudi zanimanje za napovedovanje klimatskih ekstremov. Številna predavanja in posterji so prikazali različne scenarije razvoja klime in padavinskih procesov ter njihov vpliv na odtok in s tem na morebitno pojavljanje poplav.

Čeprav je bil kongres zelo obsežen in ga kot celoto ni mogoče zaobjeti in opredeliti, pa se kljub temu pokažejo nekatere splošne značilnosti dogajanja na kongresu. Obstoj številnih in raznolikih kongresnih sekcij kaže na zelo ozko specializacijo raziskovalcev. Pozornemu opazovalcu pa ni moglo uiti, da je bilo med udeleženci kongresa zelo malo kroženja med sekcijami in da so znotraj strok oblikovane posamezne interesne skupine. Te skupine, navkljub intenzivnemu razvoju komunikacijske tehnologije, komunicirajo le znotraj ozkega kroga. Obiskovalec teh sekcij se ni mogel znebiti občutka, da so se avtorji prispevkov, ki so sodelovali na teh sekcijah, dogovorili za srečanje na kongresu in da so pozornost posvetili predvsem svojemu interesnemu krogu in le njemu dopustili tudi predstavitev. Hkrati s tem pa je bilo opaziti tudi to, da so se nekatere sekcije po tematiki in vsebini v veliki meri prekrivale z nekaterimi sekcijami znotraj drugih simpozijev, ki so bili pogosto istočasni. Takšen razvoj je verjetno predvsem posledica obilice raziskav in številnih raziskovalnih skupin, ki zaradi preobsežnosti znanstvene produkcije med seboj niso več sposobne komunicirati. To pa seveda privede do prekrivanja raziskav in rezultatov.

V slovenski geologiji le redko zasledimo delo večjih skupin raziskovalcev, ki so kasneje tudi soavtorji prispevkov. Sistem vrednotenja znanstvenoraziskovalnega dela s strani financirjev pa takšno sodelovanje posredno tudi deprivilegira, saj točkovanji za delo v večjih skupinah in individualno delo nista ločeni. V nasprotju s tem je bilo na kongresu prisotno veliko raziskovalnih skupin, ki so po številu svojih članov presegale nekaj deset raziskovalcev. Te skupine so pogosto nastopale kar pod imeni skupine, v programu kongresa pa so bili navedeni člani teh

skupin. To kaže na svojevrsten razvoj tudi znotraj geofizikalnih ved, in ne le drugih ved, kot na primer pri biokemijskih vedah, ko posameznih problemov ni več mogoče reševati na enem mestu in z omejenimi finančnimi sredstvi. Tako smo priča na videz paradoksalni situaciji, po eni strani imamo opraviti z ozkimi in dokaj zaprtimi skupinami, ki sicer delujejo na globalni ravni, po drugi strani pa z velikimi skupinami, ki se povezujejo in razdružujejo po potrebi.

Takšno združevanje raziskovalnih moči nam odkriva tudi to, da pojavi, ki jih obravnavajo geofizikalne vede niso več le v domeni posameznih strok temveč, da so predmet interdisciplinarnega preučevanja, v središču pa je le poznavanje in razumevanje pojava in ne le stroka. To pa je premik, ki ga bodo morali storiti tudi slovenska geologija in druge vede o Zemlji.

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