**PRINCIPLES OF ROCK MASS STABILISATION AFTER EXCAVATION OF UNDERGROUND STRUCTURES**

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**ABSTRACT**

In situ stresses occur in each rock mass disregarding the genesis and later tectonic disruptions. The field of in situ stresses is disrupted to some distance from the walls after underground excavation. Stresses occurring in the area are called induced stresses.

The paper unravels the effects that underground excavation may incur to the rock mass and the strategy of its stabilisation. Stabilisation strategy means the selection of rock support and the most appropriate time for doing it. The process establishes a new balance in the rock mass.

**АПСТРАКТ**

Кај секој карпест масив без оглед на генезата и подоцнежните тектонски пореметувања, во неговата внатрешност се јавуваат примарни напрегања. Полето на примарните напрегања се нарушува после ископот на подземниот простор и тоа до некоја оддалеченост од контурите на ископот. Напрегањата кои се јавуваат во тој простор се нарекуваат секундарни напрегања.

Во овој труд е дадено објаснување за ефектите што подземниот ископ може да ги предизвика на карпестиот масив, како и стратегијата за негова стабилизација. Под стратегија за стабилизација се подразбира избор на начин на подградување, како и одредување на времето кога е најпогодно истото да се изврши. Со оваа постапка се воспоставува нова рамнотежна положба во карпестиот масив.

1. **INTRODUCTION**

Principles of stabilisation will be analysed in two cases:

- when the induced stresses are lower than the strength of the rocks,

- when the induced stresses are higher than the strength of the rocks.

Methods of stabilisation will be analysed in two models of rock mass:

- when the rock mass behaves as a continuum,

 - when the rock mass behaves as a discontinuum.

1. **THE EFFECTS OF UNDERGROUND EXCAVATION ON THE ROCK MASS**

There are three basic effects that underground excavation causes to the rock mass (figure 1):

*Effect 1: Displacement and rock failure*

Displacement of excavation limit to remove the rock mass results in movement of the surrounding rock mass (for relaxation). Displacement of the rock mass can be allowed or limited by stabilisation measures. It is important, however, which mechanisms cause displacement:

- a block of the rock displaces during excavation,

- the rock mass is strained as a whole (elastic strain),

- dislocation is the result of rock failure.

*Effect 2*: *Disruption in the field of stresses*

There are no normal and tangent stresses at the immediate excavation surface.

Thus, the excavation limit must be the plane of main stresses. In this manner the main stress, normal to the excavation plane, equals zero. This means that the excavation will cause in situ stress redistribution according to size and orientation. The mining engineer should decide on the method of excavation that will cause the least induced stresses.

 *Effect 3: Water flow*

Water pressure at the excavation limit will drop to zero (or at the level of atmospheric pressure). Excavation will serve as drainage and water will flow from the rock mass to the excavated area until the potential is equalised. Water has a negative effect on the stability of the block mass and may also cause redistribution and swelling with some rock masses.

The goal of the engineer is not to eliminate these three in situ effects, but to secure their control.

 

Main stress directions rotate in order to become parallel and normal to unsupported area

Complex system of ground water flow

 3

 3

 1

 1

 3

1

In discontinued rocks the block will slide in the underground work

The rock will move to the underground work

 Effect 1 Effect 2 Effect 3

Figure 1. Three basic effects that underground excavation causes to the rock mass

1. **STABILISATION STRATEGY**

Two ways can be applied in rock mass stabilisation:

* *Rock reinforcement*. This process turns the disrupted mass into a load-bearing zone or the discontinued rock massif starts behaving as a continuum. Rock reinforcement can vary.
* *Rock support*. Support elements are built in the excavation in order to reduce wall displacement to a certain extent. The most common supports are sprayed concrete, steel frames, concrete, concrete blocks etc. It should be mentioned that the first thin layer of sprayed concrete is not considered as support since it only protects the rock mass surface and prevents small blocks from rock fall. Rock mass stabilisation means combined use of rock reinforcement and support for achieving balanced state.

Complex system of ground water flow

 1

1. **GROUND REACTION CURVE**

When analysing the interaction between the rock mass and rock support one needs to start with the strains occurring close to the face of the unsupported underground structure.

The radial displacements amount to (figure 2):

 - it starts at some distance before the face of the underground structure (some 2,5∙d; d - is the structure diameter),

 - reaches one third of the final value of the structure face,

 - reaches maximum distance of 4,5∙d behind the excavation face.

It is important to say that even at the unsupported structure, the face is apparent support pressure. This apparent support pressure secures stability during the time period from excavation to building in the rock support.

Figure 2. Radial displacements around the face of the unsupported underground structure

1.The radial displacements it starts at some distance before the face of the underground structure (some 2,5∙d; d - is the structure diameter),

2. The radial displacements reaches one third of the final value of the structure face,

3. The radial displacements reaches maximum distance of 4,5∙d behind the excavation face.

Apparent support pressure is (figure 3):

 - equal to in situ stresses (pi = po) at some distance (2,5∙d) before the face of the

 structure,

 - equal to one quarter of in situ stresses of the face of the structure.

 - gradually approaches zero value of some distance from the face of the

 structure.

Rock plasticity around the excavation does not mean that collapse of structures will occur. Failed material is still significantly strong enough. When the thickness of the plasticity zone is small relative to the structure radius, a small number of crackles may appear and, consequently, a small range of rock falls.

Face strain

Advancement of structure

When the plasticity zone thickness is larger, failing system in the surrounding rocks is larger and will result in inward displacement of the walls and possible excavation collapse.

The major function of the support is inward displacement of the walls in order to prevent collapse that may result in total collapse of excavation.

­pcr-critical support pressuredefined by the formation of plastic failure of rocks in the surroundings;

uip-plastic displacement

pi=p0-in situ stress

uie-elastic displacement

Radial displacement ui

Apparent support pressure pi

Advancement of structure

Radial displ.

 Plasticity zone

Figure 3.

Characteristic line of the rock mass is the relationships between the inner pressure on the rock support (apparent support pressure) and structure convergence (radial displacement of the walls).

If the structure is circular cross-section, the radius being “ro” excavated in a rock mass in which hydrostatic in situ stress prevails, “po” and uniform pressure on the support “pi” is induced on the excavation contour (figure 4).

Figure 4.

 Failure in the surrounding rock mass occurs when support load-bearing capacity is lower than the critical capacity of the support “pcr” when a plasticity zone the radius “rp” forms round the structure (radial displacement is defined by the characteristic curve between pi = pcr and pi = 0).

When the load-bearing of rock support is higher than the critical support pressure, failure of the surrounding rocks will not occur and they

behave elastically. Radial elastic displacement is given by the equation:

 ..........................(4.1)

uie- radial displacements

ν- **poisson coefficient**

E- modulus of elasticity

The shape of the characteristic curve depends on the strength and the basic properties of the rock mass. The size of radial displacements depends proportionally on the radius of the structure and reverse proportionally on the module of rock elasticity that comprise the surrounding rock massif.

1. **ROCK REINFORCEMENT**

At first sight it seems that only reinforcement of discontinued rock massif is important for the protection of individual block displacements. However, reinforcement of continued rock masses is important since it improves the mechanical properties of rocks and their behaviour in the underground work surroundings. Improving their mechanical properties makes it possible to sustain the increase of deviant stresses easily. In that way, failure is less possible. Reinforcing discontinued rock masses has a double effect:

- it improves the mechanical and structural properties of the rock mass,

- it prevents from larger displacements of the entire rock blocks.

1. **ROCK MASS SUPPORT**

Building in various elements mentioned earlier is called rock support. Its main purpose is to reduce inward displacement of the walls during excavation to the extent allowable by the activity depending on the importance, time of use and the purpose of the underground structure.

If the ground reaction curve crosscuts the diagram abscissa it means that the structure will be stable and without support. If these displacements meet the requirements of the project, the structure is left unsupported. In case of elastic behaviour of the rocks, the value amounts to 0,1% of the structure radius (1curve - figure 5). If there is stable and non-elastic behaviour of rocks, radial displacement at which the structure may remain without support, amounts to 10% of the structure radius (2 curve - figure 5). However, this displacement can be tolerated with temporal mining structures, but not with capital structures. If displacement is higher than the maximum allowed, the structure must be supported and displacement be reduced (3 curve - figure 5).

Apparent support pressure pi

Radial displacement ui

Figure 5.

Support is required in case of unstable-nonelestic rock behaviour since without support collapse is imminent.

If support must be built in, the characteristic support cruve must be drawn in the diagram. Figure 6 is the most often used elastic support curve (sprayed concrete + bolts + steel net + steel frames). The type of support is permanent load-bearing capacity after certain self strain. Of the total load-bearing of the support (Pz), the mobilised load-bearing capacity has the value of (Psm). In order to attain balance, the support is strained radially by the value (usm).

Radial support pressure

Radial displacement

1

2

Figuree 6. Ground reaction curve (1) and characteristic support cruve (2)

Figuree 6. Ground reaction curve (1) and characteristic support cruve (2)

In practice, the right shape of the ground reaction curve cannot be defined. So, radial displacements are measured, most often as structure convergence.

The ground reaction curve and the convergence curve are related since they exhibit the same phenomenon in a different way.

With convergence measurements, displacement is measured as the time between two permanent points. Measuring the displacement controls the efficiency of the built in support. If convergence, after certain period of time, comes close to the balance state, then it can be inferred that the support meets the requirements. Otherwise, it needs to be reinforced. It is worth mentioning that economically justified support cannot sustain more than 2 Mpa, whereas in situ stresses may amount to 15 Mpa in some depths which means that most of the stresses have been taken over by the rock massif. Because of this, the rock mass is the most important support element and its mechanical properties have a predominant role in the stability of the structure. Because of this all measures possible need to be undertaken during the construction so that the disruption of the rock massif is minimal.

All said so far about the ground reaction curve with continuous rocks applies to the discontinued ones as well, since the increase of rock fissuration results in increase of deformability (figure 7).

Increase of fissure density

Radial displacement

Radial support pressure

Figuree 7. Ground reaction curve in discontinuited rock mass

1. **CONCLUSION**

Construction of underground structures is a specific and important task for the mining engineer. He decides on the alignment of the structure based on data available. His task is to dimension the rock support based on the measured mechanical characteristics of the rock massif, induced stresses and the radial displacements. He needs to precisely define the time and distance from the face when building in the support. Optimising the drilling-blasting operations should disrupt the surrounding rock massif to a minimum since the rock mass sustains most of the induced stresses.

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