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**GRAĐEVINSKI FAKULTET U PODGORICI**
***FACULTY OF CIVIL ENGINEERING, PODGORICA***


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6TH INTERNATIONAL CONFERENCE
CIVIL ENGINEERING - SCIENCE AND PRACTICE
ŽABLJAK, 7-11 MARCH 2016

*Zlatko Zafirovski[1], Darko Moslavac[2], Zoran Krakutovski[3], Milorad Jovanovski[4]*

# ANALYSIS OF INTERACTION BETWEEN ROCK MASS AND LINING SUPPORT FOR ROAD TUNNEL

***Summary***

The principle of the method "interaction of rock and tunnel lining support", widely used for designing tunnel constructions is presented in this paper. The reaction curve of the rock which shows the connection between the pressure of the tunnel lining support and the tunnel convergence, as the tunnel deformation versus the strength ratio of the rock mass and the local exerting is being considered. These analyses for the reaction curves of the tunnel lining support and the rock are made for a road tunnel in Macedonia, using the software package ROCSUPPORT.

***Key words***

Tunnels, analysis, rock mass, ROCSUPPORT, tunnel lining support

# ANALIZA INTERAKCIJE IZMEĐU STIJENSKE MASE I PODGRADNE KONSTRUKCIJE DRUMSKIH TUNELA

***Rezime***

U ovom članku su prikazani principi metoda "interakcije stijenske mase i tunelske podgradne konstrukcije" koji se široko koristi pri projektovanju tunela. Razmatrana je kriva reakcije stijene koja prikazuje vezu između pritiska u tunelskoj podgradi i konvergencije tunela, kao i deformaciju tunela prema odnosu čvrstoće stijenske mase i lokalne napregnutosti. Ova analiza reaktivne krive tunelske podgradne konstrukcije i stijenske mase je provedena kod drumskih tunela u Makedoniji, korišćenjem softverskog paketa ROCSUPPORT.

***Ključne riječi***

Tuneli, analiza, stijenska masa, ROCSUPPORT, podgradna konstrukcija

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# 1. INTRODUCTION

Although there are no clearly defined rules for tunnel support and lining design at the present time, three general methods have emerged over recent years. These can be described as:

1) Closed form solution methods that are based upon the calculation of the extent of plastic failure in the rock mass surrounding an advancing tunnel and the support pressures required to control the extent of the plastic zone and the resulting tunnel deformation.

2) Numerical analysis of the progressive failure of the rock mass surrounding an advancing tunnel and of the interaction of temporary support and final lining with this failing rock mass.

3) Empirical methods based upon observations of tunnel deformation and the control of this deformation by installation of various support measures.

Each of these methods has advantages and disadvantages, and the optimum solution for the given tunnel design, may involve a combination of different methods, at different stages of the design. For example, a preliminary analysis of temporary support requirements could be carried out with RocSupport, and detailed final design, including plastic failure of the rock mass, and yielding support, can be carried out with Phase2.

# 2. THE USE OF THE SOFTWARE ROCSUPPORT IN ESTIMATING SUPPORTS IN WEAK ROCK MASSES

The analysis method used in RocSupport is often referred to as “rock support interaction” or “convergence-confinement” analysis. This analysis method is based on the concept of a “ground reaction curve” or “characteristic line”, obtained from the analytical solution for a circular tunnel in an elasto-plastic rock mass under a hydrostatic stress field.

Each of these methods has advantages and disadvantages, and the optimum solution for the given tunnel design, may involve a combination of different methods, at different stages of the design. For example, a preliminary analysis of temporary support requirements could be carried out with RocSupport, and detailed final design, including plastic failure of the rock mass, and yielding support, can be carried out with Phase2.

## 2.1. APPLICABILITY OF METHOD

The main assumptions in the analysis method are as follows:

- tunnel is circular
- in-situ stress field is hydrostatic (i.e. equal stress in all directions)
- rock mass is isotropic and homogeneous. Failure is not controlled by major structural discontinuities.
- support response is elastic-perfectly plastic
- support is modeled as an equivalent uniform internal pressure around the entire circumference of the circular tunnel.

This last assumption in particular (that support is uniform around the entire circumference of the tunnel), should be carefully considered by the user, when comparing actual tunnel behavior, and calculated results using RocSupport.

The assumption of uniform support pressure implies that:

– shotcrete and concrete linings are closed rings

– steel sets are complete circles

– mechanically anchored rockbolts are installed in a regular pattern which completely surrounds the tunnel.

Because this will not usually be the case, actual support capacities will be lower, and deformations larger, than those assumed in RocSupport.The analysis method used in RocSupport is often referred to as "rock support interaction" or "convergence-confinement" analysis. This analysis method is based on the concept of a "ground reaction curve" or "characteristic line", obtained from the analytical solution for a circular tunnel in an elasto-plastic rock mass under a hydrostatic stress field.

## 2.2. GROUND REACTION CURVE

At the heart of the "rock support interaction" analysis method used in RocSupport, is the "ground reaction curve" or "characteristic line", which relates internal support pressure to tunnel wall convergence.

Assume that a circular tunnel of radius ro is subjected to hydrostatic in-situ stress p0 and a uniform internal support pressure pi, as illustrated in the margin figure.

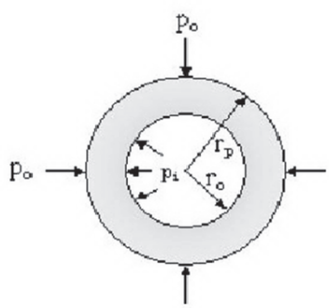


*Figure 1. Plastic zone around the tunnel*

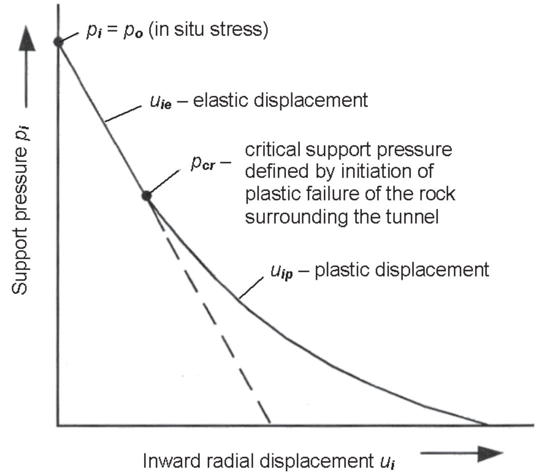


*Figure 2. A typical ground reaction curve*

Failure of the rock mass surrounding the tunnel occurs when the internal pressure provided by the tunnel lining is less than a critical support pressure $p_{cr}$. If the internal support pressure *pi* is greater than the critical support pressure $p_{cr}$, no failure occurs, and the behavior of the rock mass surrounding the tunnel is elastic.

When the internal support pressure *pi* is less than the critical support pressure $p_{cr}$, failure occurs and a plastic zone of radius $r_p$ is formed around the tunnel. A typical ground reaction curve is shown in Figure2.This plot shows:

– zero displacement when the support pressure equals the hydrostatic stress ($p_i = p_o$)

– elastic displacement $u_{ie}$ for $p_o > p_i > p_{cr}$

– plastic displacement $u_{ip}$ for $p_i < p_{cr}$

## 2.3. SUPPORT REACTION

The support reaction is a function of three components:

1. The tunnel wall displacement that has occurred before the support is installed.
2. The stiffness of the support system.
3. The capacity of the support system.

Once the support has been installed and is in full and effective contact with the rock, the support starts to deform elastically as shown in Figure 1-4. The maximum elastic displacement which can be accommodated by the support system is usm and the maximum support pressure psm is defined by the yield of the support system.

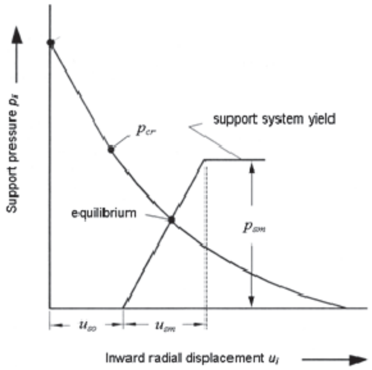


*Figure 3. Response of support system to tunnel wall displacement, resulting in establishment of equilibrium*

Equilibrium is achieved if the support reaction curve intersects the rock mass displacement curve before either of these curves have progressed too far. If the support is installed too late (i.e. uso is large in Figure3), the rock mass may have already deformed to the extent that loosening of the failed material is irreversible. On the other hand, if the capacity of the support is inadequate (i.e. psm is low in Figure3), then yield of the support may occur before the rock mass deformation curve is intersected. In either of these cases the support system will be ineffective, since the equilibrium condition, illustrated in Figure3, will not have been achieved.

## 2.4. FACTOR OF SAFETY FOR THE SUPPORT

The definition of the Factor of Safety in RocSupport is as follows:

– A Factor of Safety GREATER THAN 1 is calculated as shown in Figure4. In this case the Factor of Safety is simply the ratio of the Maximum Support Pressure psm to the Equilibrium Pressure peq (the pressure at the intersection point of the Ground Reaction and Support Reaction curves). Figure4-a.

– A Factor of Safety LESS THAN 1(Fs<1) is calculated as shown in Figure4-b. This occurs when the Ground Reaction curve intersects the Support Reaction curve after the elastic limit of the support has been exceeded. A “projected” equilibrium pressure p'eq is calculated by projecting the elastic support reaction curve until it intersects the Ground Reaction curve, and this value is used in the denominator of the Factor of Safety equation.

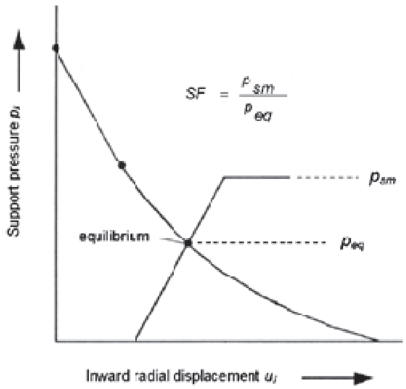


*Figure4-a. Factor of safety Fs>1*

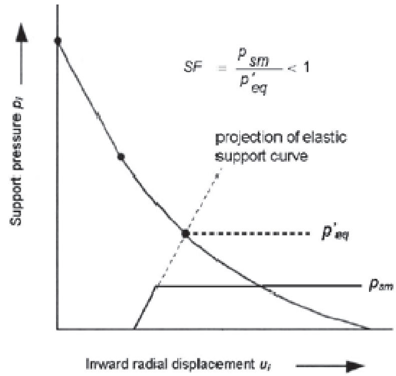


*Figure4-b. Factor of safety Fs<1*

## 3. ANALYSIS OF INTERACTION FOR ROAD TUNNEL

The deterministic technique is shown by the example of the express road tunnel Raec-Drenovo for two distinctive zones of rock masses. In the zones are present limestone whose thickness is 1-5 meters, and in some places more. The RMR parameter in this area is about 56 points.

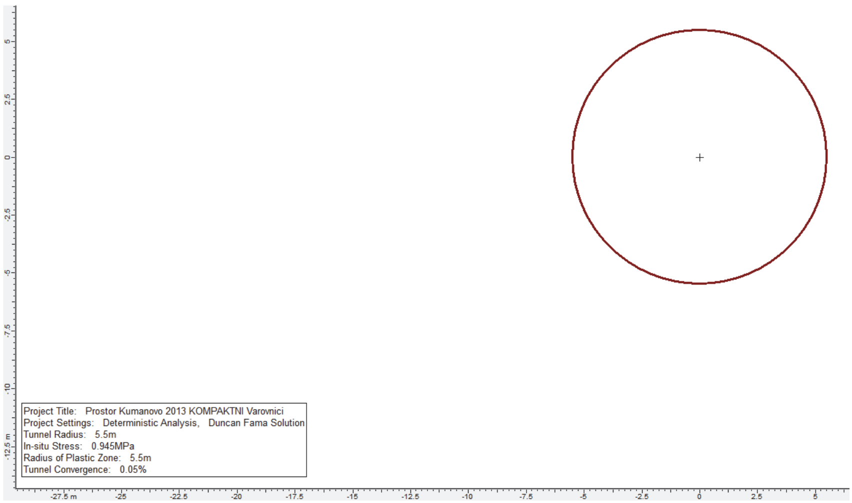


*Figure5. There is no plasticity of the rock mass (original results from software)*

If primary support is used:

– shotcrete d=15cm, concrete grade -25;

– SN Rockbolts ∅25mm, L=4.0m, al/ac=2.0/2.0m.

As can be seen, the picture shows the following data:

– The radius of the plastic zone (without support) is 5.5m;

– The final tunnel convergence is 0.05%.

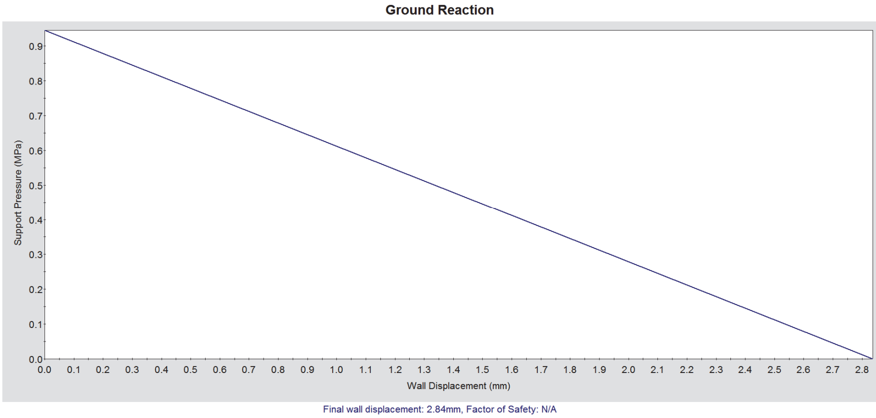


*Figure6. Rock reaction curve (original results from the software)*

Unsupported tunnel convergence of 0.05%, shows us the necessity of using shotcrete and rockbolts support.

The image shows that we have a linear relationship deformation/bearing of the support, which means that the tunnel is in a state of elastic stresses and no problems are expected in its emergence. The possibility of relegation of potential unstable blocks which could be formed by cutting in the systematic cracks in the area of excavation will be stabilized with primary support of shotcrete, rockbolts and steel sets.

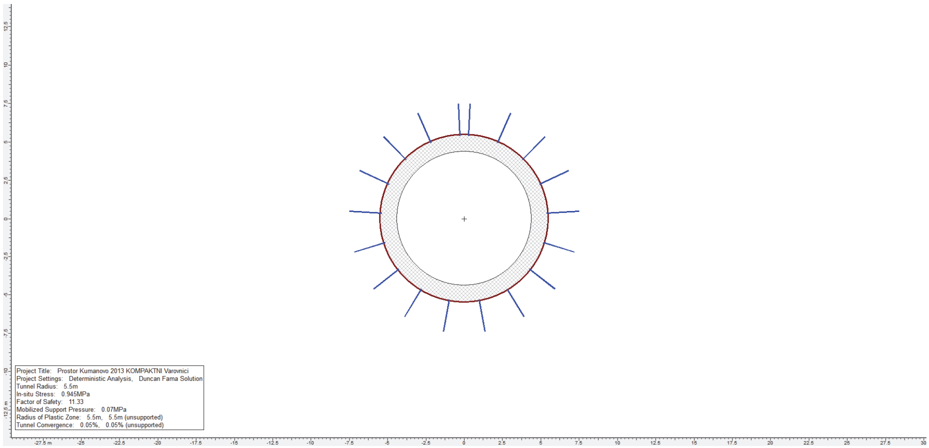


*Figure7. Analysis of the tunnel with support (original results from software)*

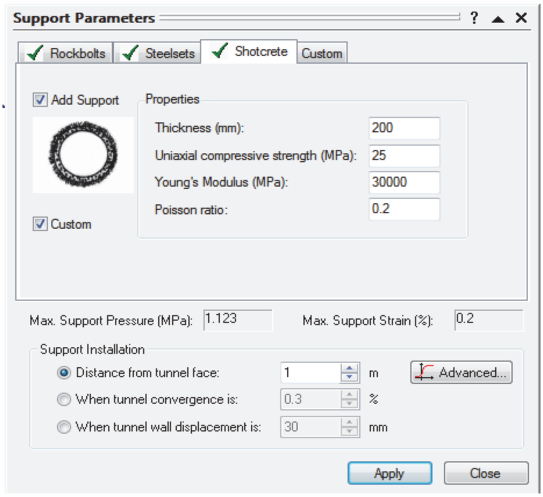


*Figure8. Input parameters of the rock*
*(window where we input the parameters for the tunnel)*

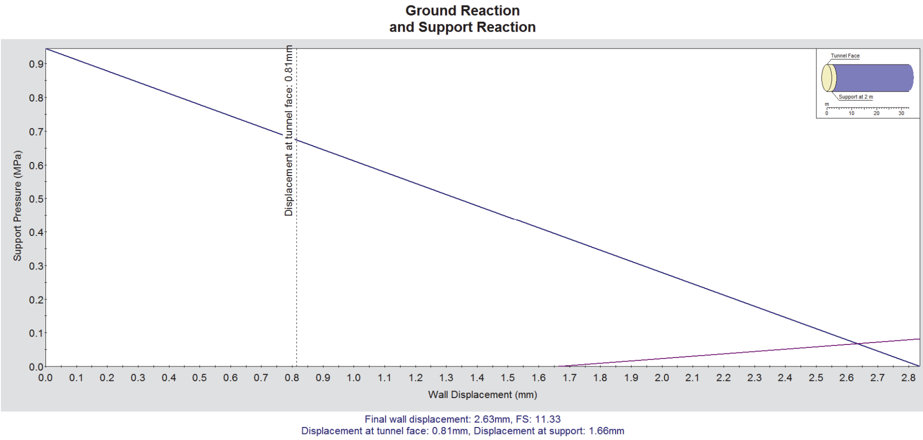


*Figure9. Reaction curves for the rock and support (original results from the software)*

The following should be noted for the reaction curve of the support:

– Origin of the support reaction curve on the horizontal axis (tunnel convergence) is determined by the distance of the tunnel face depending on the longitudinal deformation profile;

– Slope of the elastic part of the support reaction curve is equal to the maximum pressure on the support;

The intersection of the two curves determines the portable pressure of the support, the final tunnel convergence and the radius of the plastic zone.

It may be noted that the support of shotcrete has little effect on the radius of the plastic zone, the tunnel convergence and the mobilized pressure on the support, and great effect on the safety factor.

This is because the capacity of the shotcrete support moves the intersection point between the curves from the two reactions from the rock and the support, where this values are obtained.

It should be noted that the strength used is for 28 days old concrete. The strength of the shotcrete in the beginning is significantly lower than the one after 28 days and it must be noted that the actual combined factor of safety changes during the hardening (aging) of the concrete.

The rockbolt support does not reduce the radius of the plastic zone. Although the length of the rockbolts is not included in the RocSupport calculations (because the support is calculated as the equivalent of the internal pressure), the radius of the plastic zone gives an indication of the rockbolts length for effective support. For the rockbolts to be effective, they must be anchored in the uninterrupted rock. That means they should extend behind the plastic zone.

## 4. CONCLUSION

The RocSupport software package in which the method "rock support interaction" is implemented, represents a very effective and simple tool to assess tunnel convergence and the size of the plastic zone. These indicators on the other side are very important to assess the stability of the tunnel and the type of the support to be applied to ensure the necessary safety of the staff and tunnel machines. Certainly, the theoretical assumptions should be taken into account when using the software, and if they are not fully satisfied the results should be carefully analyzed and approved.

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