Are trigger levels useful for tunnels at high rock pressure?

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ABSTRACT: For rock tunnels under high overburden and/or squeezing ground stable conditions may be obtained at a wide range of displacements depending on the support stiffness and rock mass characteristics. The ground reaction curve (Fenner-Pacher curve) depends on complex geologic and surrounding conditions which may never be known beforehand. It may also be noted, that once the rock mass strength is exceeded, the rock mass curve is changed. This has rarely been noted in the literature. The fracture processes within the rock mass determines if critical situations may occur. Therefore, rock bolting is most important in order to control the development of failure surfaces. As long as displacements tend to cease, a stable condition is approached. Because displacements depend on excavation rate and sequence (heading/bench/invert) as well as on the stiffness of support including deformation slots and/or yielding elements, displacements are not decisive as trigger values.

Keywords: Rock pressure, trigger levels, fracture process, displacements, monitoring.

1 INTRODUCTION

For tunnels with high overburden during tunnel driving stress redistribution processes result in extensive deformations of the opening. Therefore this process is not being a stress problem but a problem of deformations (G. Vavrovsky 2013). It is important to allow deformations via stress reduction thereby respecting the compatibility of deformations between support and rock mass.

This process makes it difficult to predict radial deformations. Longitudinal deformations are seldom included in predictions. In the past discussions have been taken place especially in the Far East to define so-called admissible or critical deformations. This of course is misleading in case of the application of a deformable lining.

2 FRACTURE PROCESS

2.1 Fracturing of rock in the laboratory

The fracture process of rock specimens investigated in uniaxial compression indicates, that avoiding an abrupt rupture by using a stiff testing machine, fracturing results in decreasing elasticity with decreasing strength (Bieniawski 196), see Figure 1.

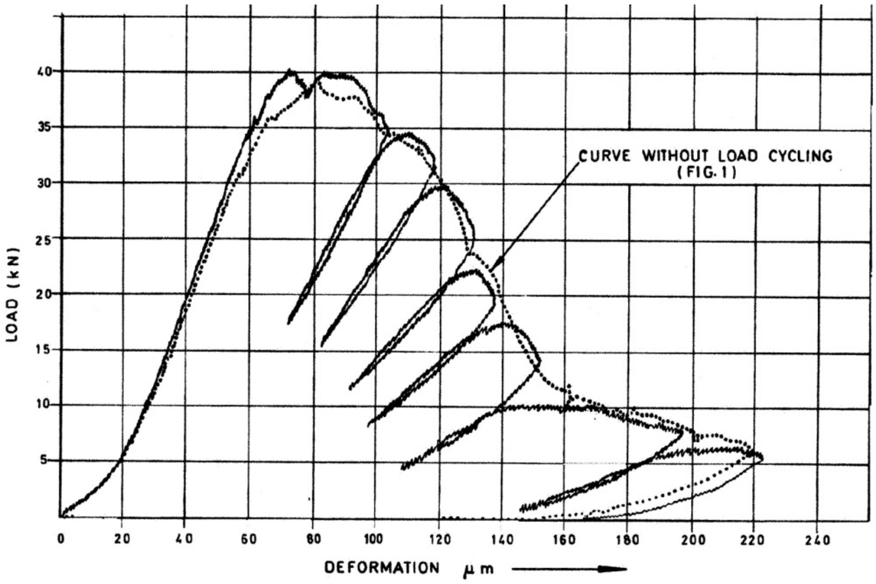

Figure 2. Complete stress-strain curve in uniaxial compression including loading cycles (Bieniawski 1967).

Triaxial compression tests show, that during the process of fracturing the angle of friction may be reduced slightly, however the cohesion gets lost, as seen in Figure 2 and 3.

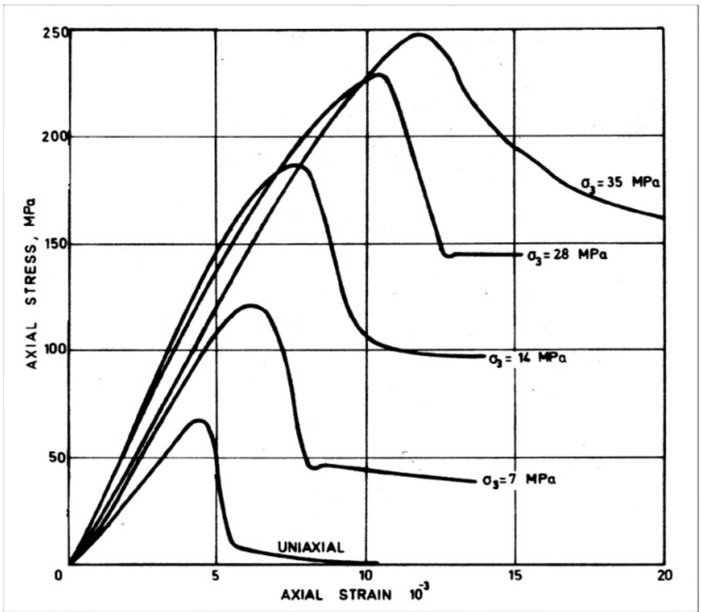

Figure 2. Complete stress -strain curve in triaxial compression for sandstone (Bieniawski 1967).

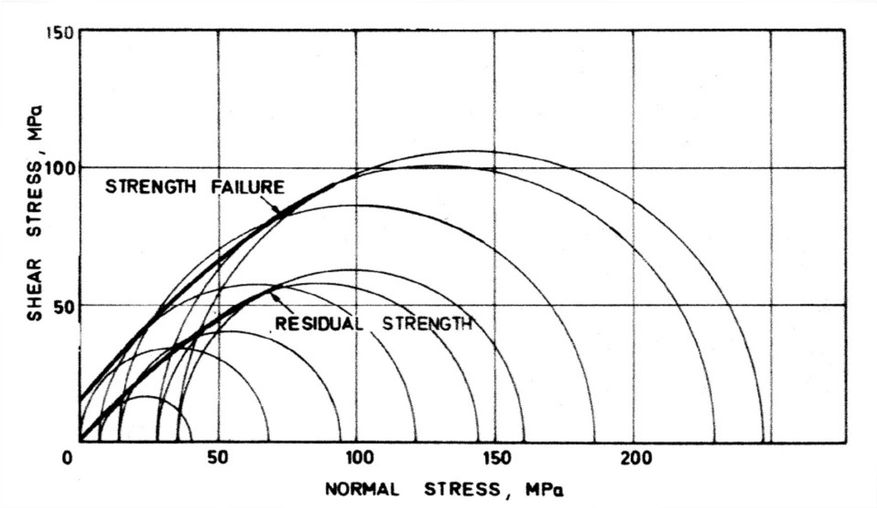

Figure 3. Mohr`s strength failure criterion for sandstone (Bieniawski 1967).

2.2 Fracture process for deep tunnels

The dependency of the ground reaction curve on the fracture process - represented by decreasing cohesion - has been shown by Vavrovsky (HL-AG), see Figure 4.

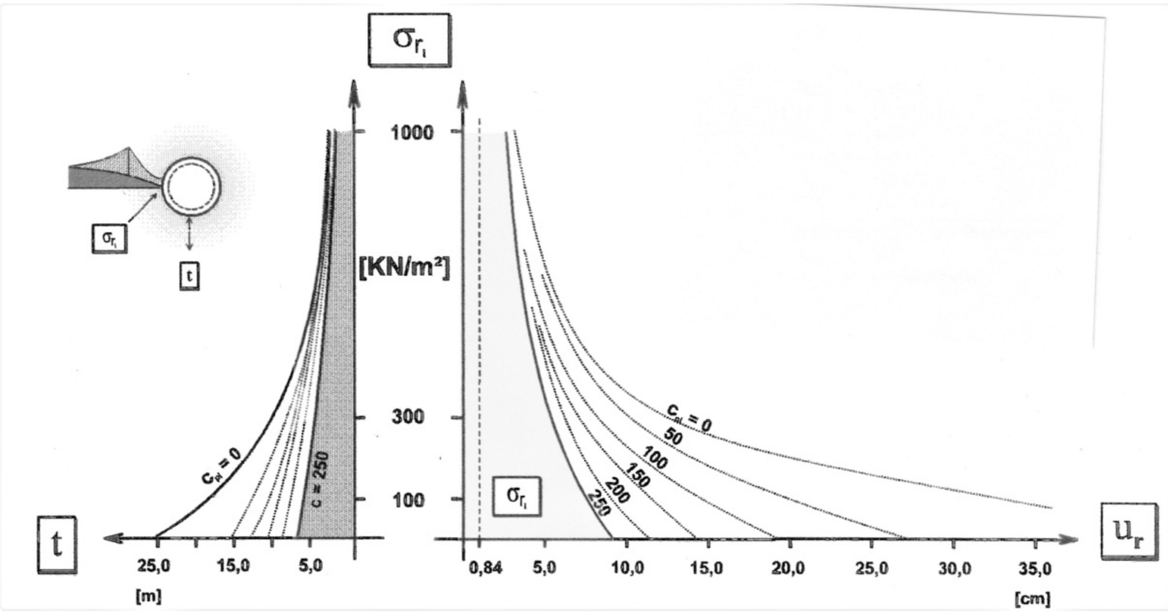

Figure 4. Relation between ground reaction depending on fracturing (reduction of cohesion), radial displacements u_r and failure zone t (Vavrovsky HL-AG).

According to Vavrovsky (HL-AG) it is to be noted, that contact stresses resulting from the distortion energy during radial reduction of stresses of the surrounding ground tend to reach a small or zero value. This means that an increase of the contact stresses with increasing displacements is not possible except for small loosening weights or fracture processes (Vavrovsky HL-AG), see Figure 5.

Regarding the application of the ground reaction curve it has to be noted, that a plane model is the basis and the complex three dimensional stress redistribution process cannot be taken into account (Rokahr 1995).

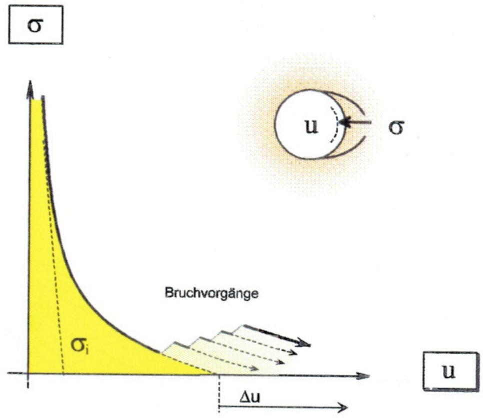

Figure 5. Ground reaction curve regarding fracture processes (Vavrovsky 2013).

The impact of the resistance of support in case of the high stress level for deep tunnels is comparatively low. Therefore the fracture process cannot be influenced considerably by a shotcrete lining. Deformations due to fracturing will cause a stiff shotcrete lining to be sheared for which reason slots in the shotcrete lining with or without yielding elements are to be used. The impact of rock bolting is generally underestimated because it cannot be equalized to a radial resistance only. Pöttler 1972 investigated the effect of rock bolting considering its effect on the cohesion of the rock mass. Although his basic considerations capture the shear resistance of rock bolts from experience it is found that the continuous process of fracture development, which is not regarded, results in underestimating the effect of rock bolting.

2.3 Deformations

Another important aspect for deep tunnels subject to high rock pressure is the fact that mostly shear planes or fault gauges are the origin of large deformations which obviously result in asymmetric deformations. This complicates the application of the ground reaction curve in addition, see Figure 6.

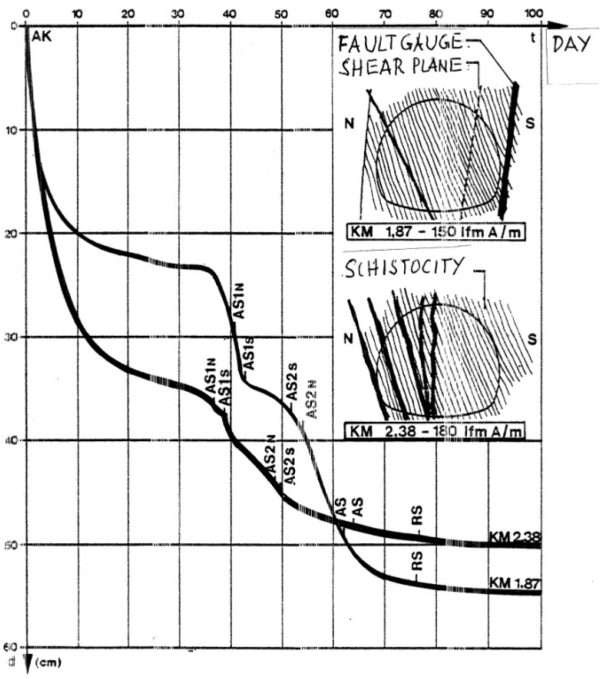

Figure 6. Convergency measurements results at the Arlberg Road Tunnel Lot West (John 1979).

Deformations can be studied especially in case of successive excavation procedures. At the Arlberg Road Tunnel excavation was subdivided in excavation of heading (AK), bench1 ($AS1_{N+S}$), bench 2 (AS_{N+S}), invert (AS) and ring closure (RS). Depending on the location of schistosity, shear planes and fault gauges fracturing is generated either mostly during heading excavation or during bench excavation resulting in equivalent final deformations, see Figure 6.

Obviously for this reason the prediction of expected deformations on the basis of the ground reaction curve is questionable. Furthermore at high stress levels the ground reaction curve decreases markedly and small changes of contact stresses result in increased deformations depending on the fracture development and thus reduction of cohesion, see Figure 4.

At the Arlberg Road Tunnel a relationship of deformation rates v1 (deformation rate of heading) + v_2 (deformation rate of bench 1) + v_3 (deformation rate of bench 2) to the support resistance represented by rock bolting was found, see Figure 7.

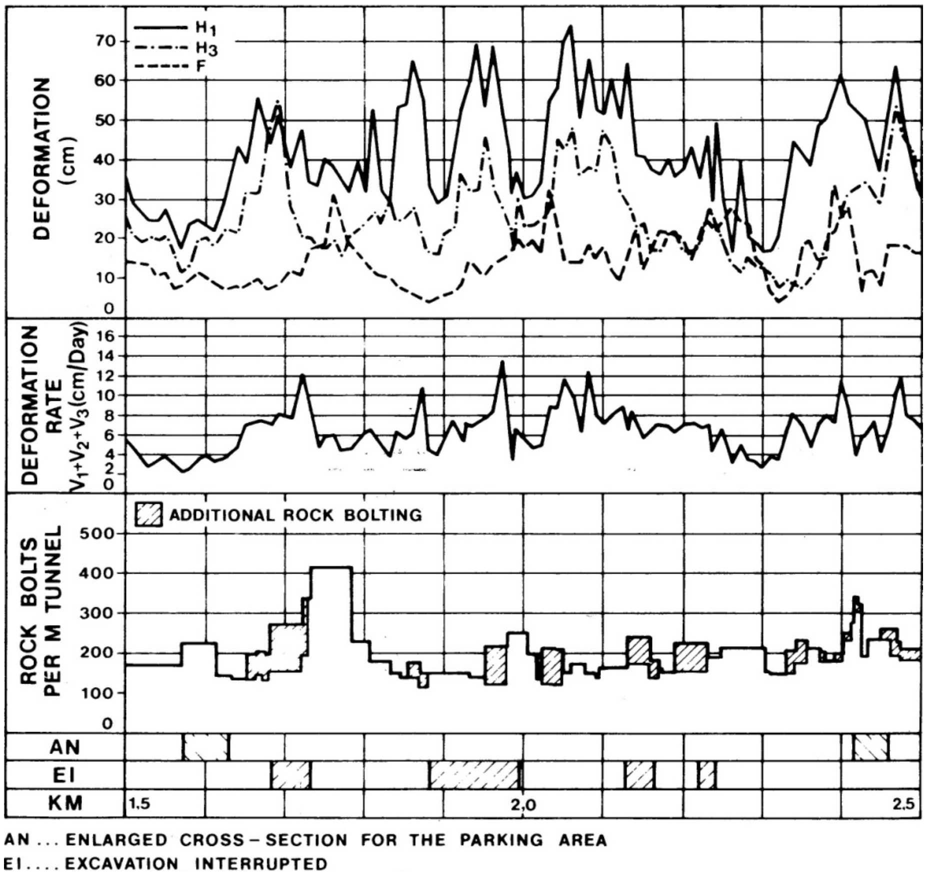

Figure 7. Arlberg Road Tunnel Lot West: Total deformations (F…Heading, H_1…Bench 1, H_3…Bench 2), sum of v_1 (deformation rate of heading) + v_2 (deformation rate of bench 1) + v_3 (deformation rate of bench 2) and sum of rock bolting (John 1979).

This evaluation resulted in the conclusion that the deformation rate is decisive for the choice of rock bolting. Also it has been concluded that as long as deformation rates decrease a stable condition is approached. Increasing deformation rates are leading to unstable conditions except they are caused by additional excavation processes. These situations are therefore most critical because it is difficult to differentiate between controlled fracture processes or uncontrolled ones developing fractures leading to failure as the well-known from an example of the Arlberg Road Tunnel (John 1977).

Rokahr 1995 confirmed that "the only possibility for a safe assessment is to use deformation rates".

3 TRIGGER LEVELS

A prediction of deformations may be required for the definition of support requirements, however they shall not be used as trigger of emergency measures.

Trigger levels shall be defined as follows:

- Green level: Deformation rates cease and/or no signs of overstressing of rock bolt plates
- Amber level: Deformation rates are constant and/or signs of excessive deformed rock bolt plates
- Red level: Deformation rates increase except due to a following excavation process and/or rock bolt plates are thorn off

REFERENCES

Bieniawski, Z.T., 1967. Mechanism Of Brittle Fracture Of Rock, *CSIR Report MEG,* Aug. 1967.

John, M., 1977. Adjustment Of Programs Of Measurements Based On The Results Of Current Evaluation, *International Symposium on Field Measurements in Rock Mechanics,* Zürich, April 1977.

John, M., 1979. Gegenüberstellung der Ergebnisse geotechnischer Messungen beim Arlberg- und Pfänder-tunnel, *4. ISRM-Congress*, Montreux, Band 2, pp. 279 - 286.

Pöttler, R., 1972, Sytemankerung und numerische Modelle, *Felsbau 10, Heft 4,* pp. 179 - 183.

Rokahr, R.B., 1995. Wie sicher ist die NÖT, 44. Geomechanik Kolloqium

Vavrovsky, G-M. HL-AG. Die Neue Österreichische Tunnelbaumethode (NÖT) im Spannungsfeld zwischen Sicherheit und Wirtschaftlichkeit. *Published by HL-AG, Wien,* p 9.

Vavrovsky, G-M. 2013. Stellenwert statischer Untersuchungen und geotechnischer Messungen bei Tunneln mit großer Überlagerung, *Symposium 88 "Planung langer Eisenbahntunnel"5./6. Mai 1988, Fassung Februar 2013,* p 14.