# Design of Tunnel Support Based on the Post-Failure-Behaviour of the Rock

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Practical experience in tunnelling shows that generally the rock pressures acting on the tunnel support are of the order of magnitude of 10 tons per square meter or of few percent of the undisturbed stress field. Despite these relatively small values, most of the tunnels are not stable with time without any support structure.

Static computations, however, either by classical theories or by more sophisticated methods such as the Finite-Element-Method do not show the astonishingly high efficiency of modern light tunnel supports, e.g. of a thin gunite shell or of rock bolts.

As the computations, by themselves, are correct in most cases, the reason for the discrepancy between practical experience and mathematical results has to be looked for in the basic assumptions of the stress-strain-law chosen for the computation.

Near a tunnel, there is generally a highly stressed zone which often is even overstressed. The important point is, therefore, to know the mechanical behaviour of this rock which has been deformed beyond its failure. For it is this zone of broken rock which is in contact with the tunnel support.

Sophisticated, mostly servo-controlled testing equipment gives us indications about the post-failure-behaviour of rock specimens [1]. A biaxial testing device under construction [2] is hoped to give valuable informations about the behaviour of jointed rock models.

The complete stress-strain-diagrams show that with monotonous deformation the rock strength decreases after having reached the peak value, in a more or less rapid way (figure 1). The steepness of this falling curve depends essentially on the rock type. Together with this rock disintegration, a continuous loosening is also observed.

In a geometrically simple, axisymmetric example of a tunnel with high overburden, the influence of the post-failure-behaviour of the rock on the tunnel stability can be shown clearly [3].

It is seen that there exists a limit inclination of the post-failure stress curve (which depends also on the loosening parameter) separating "slowly" and "quickly" disintegrating rock (figure 2).

A tunnel built in a rock type with "quick" disintegration always needs a support if the theoretical stress at the tunnel perimeter, based on elastic computations, exceeds the uniaxial rock strength. The support load decreases slowly with increasing tunnel wall displacement. The design load depends, therefore, on the admissible displacements.

"Slowly" disintegrating rocks, however, behave differently if a tunnel is excavated in them. A new state of equilibrium is found with two concentric rock zones. The outer one behaves elastically as the rock stresses do not reach the failure strength. In the inner zone the state of stress is in the post-failure region, and at the unsupported tunnel wall the hoop stress is inferior to the peak uniaxial compression strength but greater than zero. Thus, even the unsupported tunnel does not collapse. But this equilibrium is not stable, because





perturbation forces (e.g. accelerations by blasting) acting in the inner rock zone towards the center of the tunnel cause irreversible displacements. In the post-failure-region, in fact, a perturbation leeds not only to a supplementary strain but also to further disintegration. If by repeated action of perturbation forces the rock at the tunnel wall is strained until the complete loss of strength, it is - at that place - without stresses and may be removed easily or falls out by gravity. In the absence of any support, a kind of retrograde erosion occurs; if there is a support permitting rock displacements at the tunnel wall which lead to the complete disintegration of the rock, the support has to bear the full weight of this shattered rock zone.

From this, it is evident that the optimal tunnel support has

a) to be built in after decompression of the rock because of the tunnel excavation, but before the rock at the tunnel wall is strained to the complete loss of its strength;

b) to be in intimate contact with the rock. It must not allow any free rock movement, i.e. displacements which do not cause reaction forces in the support.

A tunnel support fulfilling these requirements does not, theoretically, bear any rock pressure; its only but very important task is to hinder the rock to undergo supplementary displacements - and further disintegration - when perturbation forces (e.g. blasting) come to act.

Thus, the consideration of the post-failure-behaviour of the rock seems to give a better information about the stress and strain field acting near a tunnel than the orthodox theories, and is, in contrast to these theories, able to explain the frequently proved high efficiency of modern light tunnel support methods.

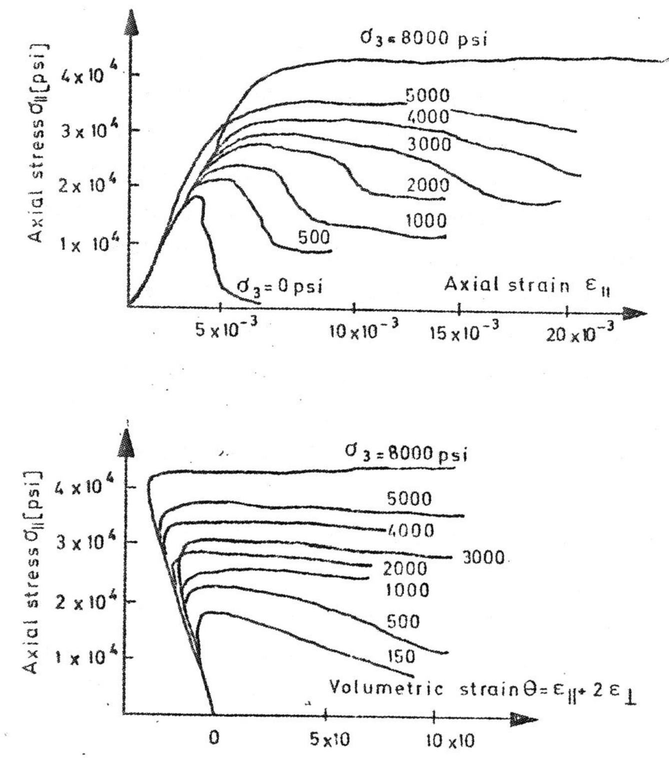


Fig. 1 Complete stress - strain - diagrams for marble (after RUMMEL)

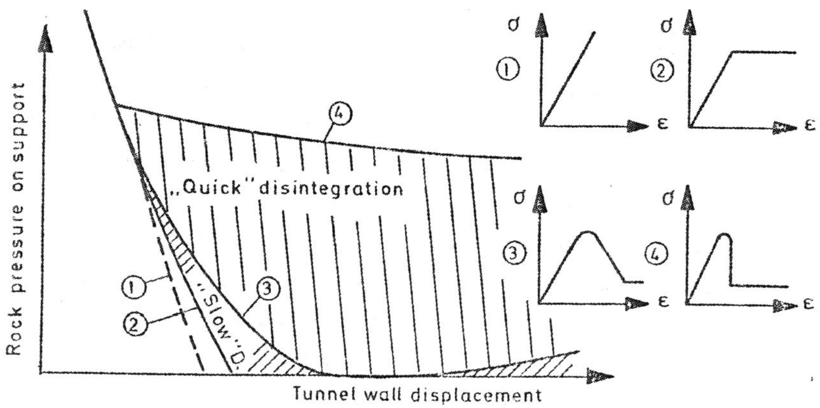


Fig. 2 Rock pressure vs. wall displacement for (1) elastic, (2) plastic, (3) progressively disintegrating, (4) brittle rock




[1] RUMMEL, F. and C. FAIRHURST: Determination of the Post-Failure-Behaviour of Brittle Rock Using a Servo-Controlled Testing Machine. Rock Mech. 2, Springer, 1970

[2] MÜLLER, L.: Herleitung von Bruchhypothesen regelmäßig geklüfteter Körper mit Hilfe zweiachsiger Druckversuche. Research Project A. 2 of SFB 77, Karlsruhe

[3] EGGER, P.: Beitrag zur Stabilitätsermittlung im Tunnelbau. XX. Geomechan. Kolloq. Salzburg, 1971