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The buckling failure of tunnels induced by high horizontal stress in jointed rocks

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ABSTRACT: The buckling failure of tunnels in jointed rock by high horizontal stress is illustrated and numerically investigated. In simulating the buckling failure, the homogenous model is applied in combination with the discrete modeling of some key joints near the tunnel wall. Using the proposed procedure, a mouth-shaped, unlined tunnel driven in jointed rock with a family of horizontal joints is numerically computed.

1 INTRODUCTION

Under certain circumstances, stability problems, such as buckling and bulging, are of significance in rock engineering and mining practice. This phenomenon has been observed in situ, see e.g. Stille et al (1981). Fairhurst & Cook (1966) investigated this problem theoretically under some postulations, whereas model tests were conducted by the Australian Coal Industries Research Laboratory for simulating the structural and stress conditions in the coalfields near Sydney/Australia. In Fig. 1b), the buckling of slabs in the roof and floor of an excavation in a high horizontal stress field is illustrated, from Hoek & Brown 1982.

The essential loading and boundary condition for the buckling failure is the uniaxial compressive stress along to thin rock slabs containing discontinuities parallel to free boundary surface of underground openings. Until now, it is a common way to evaluate the safety against the buckling failure by using stability theory. Rock slab is seen as plate under axial compressive loading. This approach can only be applied, when the real axial stress is determined. This is, however, not always the case. The secondary stress in rock mass is dependent on the geometric profile of openings, the E-modul of rock slabs, the shear strength in rock and along discontinuities as well as the primary stress state. The strength failure in rock and on discontinuities due to underground opening lead to the further stress redistribution in rock mass and may have a significant influence on the failure mode. Therefore, it is important to consider all these factors in analyzing such problems.

In this paper, a procedure is illustrated investigating the buckling failure of a mouth-shaped, unlined tunnel driven in jointed rock. The primary stress state is assumed to be anisotropy, and has a higher horizontal stress arising from geological effect and rest tectonic stress. For simulating the buckling failure of the tunnel, the homogeneous model is applied in combination with the discrete model, where the material and geometric nonlinear behavior is taken into consideration by using finite elements and joint elements.

2 DETAILS OF THE PROBLEM

The statistical results of in situ stress measurements in various parts of the world, as Hoek & Brown reported (1982), indicate that in general the vertical stresses in rock mass can be determined considering the overlying weight of rock at corresponding depths. Compared to this, the measured horizontal stresses may not be predicted using elastic theory. Furthermore, the horizontal stresses are often larger than the vertical stresses at depths of less than 500 m, see Fig. 1 a). The construction of underground openings under such primary stress state may lead to the strong stress concentrations at the roof and at the invert. On the assumption that the encountered rock mass contains a family of horizontal discontinuities, buckling failure may occur at roof and floor slabs (see Fig. 2).

Fig. 2 illustrates a mouth-shaped, unlined tunnel having a height of 10 m and a width of 14 m. The tunnel is driven in a rock mass containing a family of horizontal joints. The primary horizontal stress is 4 MN/m² and the vertical stress 2 MN/m². The joints have an average spacing of 0.3 m. Rock is assumed to be elastic and strength failure is only possible along joints.