ABSTRACT

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Rock masses may present remarked geostatic stress anisotropy and anisotropic material properties; thus, the tunnel alignment with the geostatic principal stress directions and with the axes of material anisotropy is unlikely. Nevertheless, tunnel design often neglects those misalignments and; yet, the misalignment effects were unknown. In this doctoral research, tunnels under complex anisotropic conditions were modelled analytically and numerically with 3D nonlinear Finite Element Method (FEM). When the tunnel misaligns with the geostatic principal stress directions, anti-symmetric axial displacements and shear stresses are induced around the tunnel. Analytical solutions for misaligned shallow and deep tunnels in isotropic elastic ground are provided. The analytical solutions were validated with 3D FEM analyses. Near the face, the anti-symmetric axial displacements are partially constrained by the tunnel face, producing asymmetric radial displacements and stresses. The asymmetric radial displacements at the face can be divided into a rigid body displacement of the tunnel cross-section and anti-symmetric radial displacements. Those asymmetries may affect the rock-support interaction and the plastic zone developed around the tunnel. In anisotropic rock masses, the tunnel misalignment with the axes of material anisotropy also produces anti-symmetric axial displacements and stresses around the tunnel. It occurs because when the tunnel is not aligned with the principal material directions, the in-plane stresses are coupled with the axial displacements (i.e. the compliance matrix is fully populated). Thus, tunnels in anisotropic rock mass not aligned with the geostatic principal stresses and with the axes of material anisotropy are substantially more complex than tunnels not aligned with the principal stress directions in isotropic rock mass. An analytical solution for misaligned tunnels in anisotropic rock mass is provided. It was observed that the relative orientation of the geostatic principal stresses with respect to the axes of material anisotropy plays an important role. The axial displacements produced by far-field axial shear stresses and by the rock mass anisotropy

may compensate each other; thus, axial and radial displacements around the tunnel are reduced. On the other hand, those anti-symmetric axial displacements may be amplified; thus, the ground deformations are increased. Asymmetric radial and axial deformations, and asymmetric spalling of the tunnel walls are commonly observed on tunnels in anisotropic rock masses. The tunnel misalignment with the geostatic principal stress directions and with the axes of material anisotropy could be associated with those phenomena that, so far, are not well comprehended.