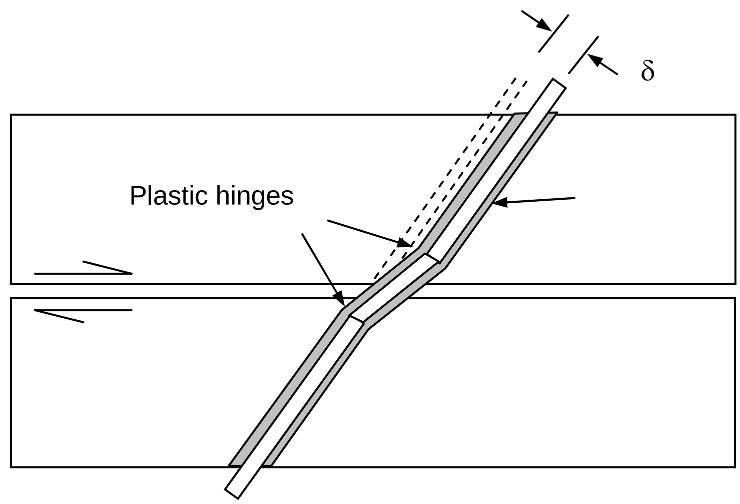
Bolt-Joint Interaction

When a bolt crosses a joint, forces will develop in the bolt to resist joint movement.

Experimental studies have shown that as fault movement occurs, bending occurs in the bolt where it crosses the joint (e.g. Graselli, 2005). At small shear displacements, plastic hinges form at a short distance on either side of the joint as shown below.



Grouted rockbolt in shear

Studies indicate that the hinges form at a distance of 1 – 2 bolt diameters on either side of the joint. In *Phase2*, it is assumed that a section of bolt spans the joint that is two bolt diameters in length. The section of bolt resists tension (and compression) just like any other segment of the bolt. When calculating the tension forces, the rotations experienced by this section of the bolt are assumed to be negligible.

The section of bolt that crosses the joint also resists joint movement through a dowel force. In *Phase2*, the formulation of Dight (1982) is used to compute this force:

$$F = \frac{D^2}{4}\sqrt{1.7\sigma_y P_u \pi\left[1-\left(\frac{T}{T_y}\right)^2\right]}$$

Where:

$$P_u = \sigma_c \left[\frac{\delta}{K\left(\pi D + 2\delta\right)}\right]^{A/2}$$

$$A = \frac{2\sin\phi}{1+\sin\phi}$$

$$K = \sigma_c\left(\frac{1-\nu^2}{E}\right)\ln\left(\frac{\sigma_c}{2p_0-\sigma_t}\right)+\frac{\sigma_c}{2p_0-\sigma_t}\left[\frac{2\nu(P_0-\sigma_t)-\sigma_t}{E}\right]$$

And where:

σ_y, T_y = yield stress and yield force in the bolt

σ_c, σ_t = unconfined compressive strength and tensile strength of the rock

ϕ = internal angle of friction of the rock

ν, E = Poisson's ratio and Young's modulus of the rock

P_0 = initial stress in the rock in the plane of the joint

δ = joint displacement perpendicular to the bolt

T = initial bolt pretension force

The equation assumes that the grout strength is equal to or less than the rock. This equation is slightly different from the original equation of Dight (1982) in that the value of δ is the joint displacement perpendicular to the bolt rather than the total shear displacement of the joint as in the original reference. The equation was modified for *Phase2* to account for the angle between the bolt and joint.

The section of the bolt crossing the joint will fail if the dowel force exceeds the shear strength of the steel section of the bolt. The shear strength is assumed to be 50% of the tensile strength. If this type of failure occurs, then it is assumed that the bolt also fails in tension and the tensile strength drops to its residual value. This residual value is substituted for σ_y in the above equation.

NOTE: Bolt-joint interaction in *Phase2* is applicable for the bonded bolt types (i.e. Fully Bonded, Plain Strand Cable, Swellex/Split Set, Tieback). Bolt-joint interaction is not considered for the End Anchored bolt model, since an end-anchored bolt in *Phase2* only interacts with the model through the bolt endpoints.

References

Dight, P.M., 1982. Improvements to the stability of rock walls in open pit mines, Ph.D. Thesis, Monash University Australia.

Graselli, G., 2005. 3D Behaviour of bolted rock joints: experimental and numerical study, *Int. J. Rock Mech. Min. Sci.*, **42**, 13-24.