Pure Tension and Effective Tensile Stress

Fracture occurs due to tension and only due to tension. Particles are held together by cohesive forces. When two particles move apart to a distance at which the cohesive force no longer acts, fracture occurs, and the particles exist as separate. This critical distance and the intensity of the cohesive forces are fundamental characteristics of the material. Cohesion is numerically equal to tensile strength.

When the fracture plane is perpendicular to the tensile force, this is a case of pure tension, and the stress at the moment of fracture is the tensile strength. In mining, especially in underground mining, cases of pure tension are nearly nonexistent.

A characteristic situation occurs in exploratory drilling with core sampling. When the core tube is filled with core material, the core is detached by stopping the rotation and pulling the entire drill string upwards. The core catcher, placed in the crown or in the coupling, fixes the core inside the tube, and core breakage or tensile fracture occurs. From the difference in pressure in the hydraulic cylinder at the moment of fracture and immediately afterward, it is easy to calculate the tensile strength. Undeniably, during deposit exploration using deep vertical boreholes, drilled vertically downwards, a vast amount of data on tensile strength can be obtained without any additional activity.

When rock is subjected to compression—which is always and without exception the case in underground structures—fracture occurs as a result of displacement, rearrangement, and separation of particles. Fracture between particles occurs when they move apart to the critical distance at which cohesive forces cease. Friction develops between moving particles, so compressive stress is opposed by tensile strength (cohesion) and frictional resistance, see Figure 1. That is, the total load (σ_0) is converted into potential energy or compressive stress (σ_c) of the elastically deformed particle, into tensile stress—also a form of potential energy (σ_t) between separated particles—and into entropy, i.e., thermal energy generated by friction between moving particles ($\sigma_t(1 + tg\varphi)$).

$$\sigma_0 = \sigma_c + \sigma_t + \sigma_t tg\varphi$$

The loaded particle is itself composed of particles (sub-particles), so the loading model of a material body, symbolically represented with 3 particles, repeats within each individual particle. Thus, the compressive stress of the particle corresponds to the tensile stress between sub-particles from which the primary particle is formed. The only stress—i.e., the potential energy of the elastically deformed material—is the tensile stress.

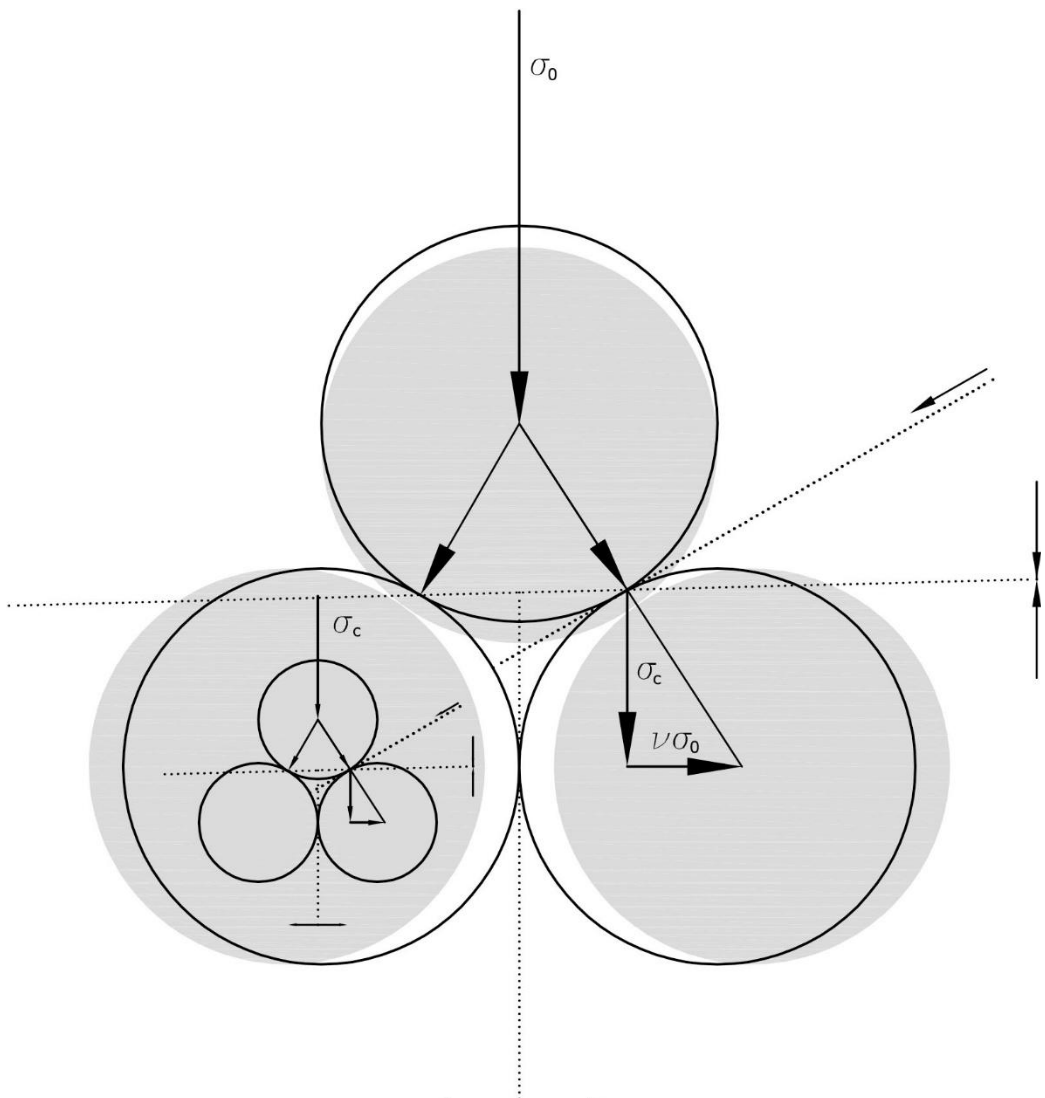

Figure 1. Material resistance to compressive loading

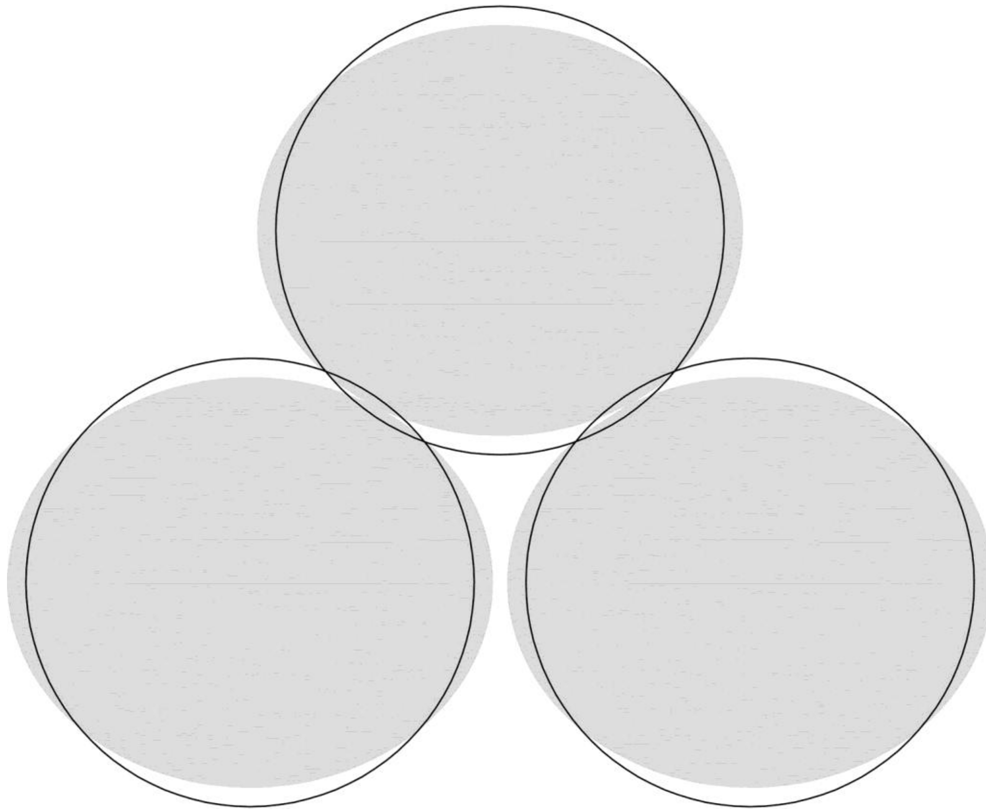

Figure 2. Dilation of deformed particles

The state of elongation (dilation) due to compression of deformed particles is shown in Figure 2. The lateral component of loading ($\nu\sigma_0$), which separates the particles, is opposed by the tensile strength or cohesion (σ_t) and frictional resistance ($\sigma_t tg\varphi$):

$$\nu\sigma_0 = \sigma_t(1 + tg\varphi)$$

Thus, the tensile stress is equivalent to the dilation, i.e., to the distance between separated particles:

$$\sigma_t = \frac{\nu\sigma_0}{1 + tg\varphi}$$

As seen in the illustrations, the sub-particles are also separated due to the compressive loading (σ_c), thus deforming the primary particles, as shown in Figure 2. Since the load (σ_c) is significantly less than the total load (σ_0), the lateral expansion of the particles takes place within the space opened by the primary dilation equivalent to the tensile stress between primary particles.

This results in a decrease in the distance between primary particles and, consequently, a reduction in tensile stress equivalent to a reduction in dilation. Therefore, we can introduce the concept of effective tensile stress ($\overline{\sigma_t}$), which is

$$\overline{\sigma_t} = \frac{\nu\sigma_0}{1 + tg\varphi} - \frac{\nu\sigma_c}{1 + tg\varphi}$$

Or:

$$\overline{\sigma_t} = \frac{\nu}{1 + tg\varphi}(\sigma_0 - \sigma_c)$$

From the previously written energy balance equation, it follows that:

$$\sigma_0 - \sigma_c = \sigma_t(1 + tg\varphi)$$

Then:

$$\sigma_0 - \sigma_c = \sigma_t(1 + tg\varphi)$$

Conclusion of this consideration could be:

Fracture occurs due to tension and only due to tension.
In the design of underground structures in rock, elements of the structure subjected to pure tension should be eliminated.
In tension caused by compressive loading, the effective tensile stress ($\overline{\sigma_t}$) is ν times smaller than the stress of pure tension, i.e., the effective tensile strength is ν times greater than the nominal.