UNDERSTANDING STRENGTH, DEFORMABILITY, STRESS STATE AND ROCK BREAKAGE

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Abstract

This paper introduces a new failure criterion for rocks, addressing the limitations of traditional unconfined compressive strength (UCS) testing and its associated parameters. Our research explores the mechanisms of rock breakage under compressive loads, highlighting the formation of tension fractures and the significant role of friction in stress distribution. We propose a revised interpretation of the stress-strain curve and emphasize the need for direct tensile testing to achieve more precise measurements of tensile strength and elastic modulus. By presenting a novel failure criterion that accounts for these factors, this study aims to enhance the reliability of rock strength assessments, ultimately improving the safety and stability of underground engineering projects.

Keywords: Failure Criteria; Unconfined Compressive Strength; Rock Deformability; Elastic Modulus; Tensile Strength;

1 INTRODUCTION

The unconfined compressive strength of rock or rock mass is a crucial and unavoidable parameter for evaluating the stability of underground structures. This strength is determined by a standardized test in which a cylindrical rock specimen is loaded until it fails. The normal compressive stress within the specimen at the moment of failure is recorded as the compressive strength of the tested rock. However, this method equates the compressive load on the specimen with normal compressive stress, which is not entirely accurate.

During the test, the stress-strain curve is recorded and used to determine the elastic modulus, whether tangent or secant. However, these values do not accurately represent the true deformability of the rock. The elastic modulus is used to estimate the deformation of the rock, which in turn determines the support requirements for underground openings. Since both the compressive stress and elastic modulus are inadequately defined, the assessment of support stability is also inadequate.

For certain failure criteria, the stability of a structure is determined by understanding the compressive load. Most failure criteria assume that failure occurs due to shear stress, but in reality, only tensile failure occurs.

2 ROCK BREAKAGE AS A CONSEQUENCE OF COMPRESSIVE LOAD

The unconfined compressive strength of rock is determined by a standardized test following ISRM procedures. The specimen must be adequately prepared before being subjected to loading and deformation, as illustrated in Figure 1.

During loading, the specimen deforms in both axial and lateral directions. This means the specimen is compressed in the direction of the load (σ_0) and contracts while expanding in the radial or lateral direction. At a certain point, the specimen fails and appears as shown in Figure 2.

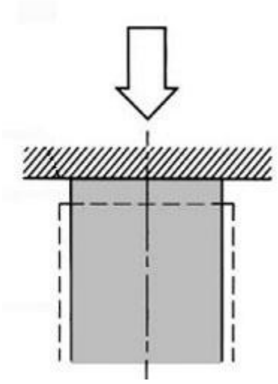

Figure 1 Loading and deformation of the specimen

Figure 2 Granite specimen after failure [1]

If there are no preexisting fractures within the specimen, vertical tension fractures form as a result of failure. These tension-induced fractures occur due to the repacking of rock particles, as illustrated in Figure 3. In this process, particle A is compressed between particles B and C, causing their separation. During this process, particle A slides along its contact areas with particles B and C.

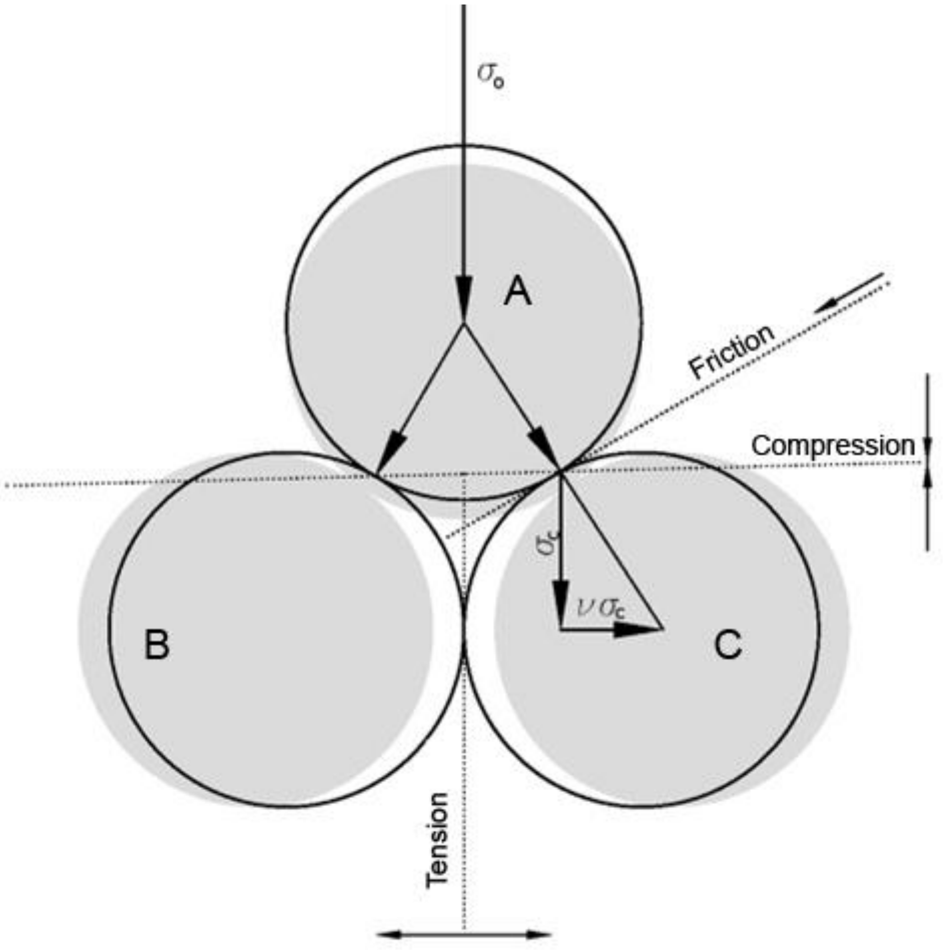

Figure 3 Mechanism of vertical tension fracture formation in specimen under compression

Due to this, the specimen is subjected to compression in the direction of the applied load and tension in the lateral direction. Considering that the ratio between lateral (transverse) and axial strain is equal to Poisson's ratio, and assuming the elastic modulus is the same for both compression and tension, the same ratio applies to the corresponding stress components or forces. At the moment of failure, the radial compression force driving the particles laterally is equal to $(\nu \cdot \sigma_{\mathrm{o}})$.. This force is opposed by cohesion (tensile strength σ_t) and friction ($\sigma_t tg\varphi$).

Therefore:

$$\nu\sigma_o = \sigma_t + \sigma_t\, tg\varphi, \text{ which simplifies to}$$

$$\sigma_o = \frac{\sigma_t}{\nu}(1 + \ tg\varphi), \text{ and finally,}$$

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

Where:

σ_o - axial compressive stress,

σ_t – tensile strength,

$tg\varphi$ *- tangent of the friction angle,*

ν - Poisson's ratio.

This expression is related to the unconfined compression test and applies to the rock mass at the boundary of an underground opening. In the general case:

$$\sigma_1 = \frac{\sigma_t + \sigma_3}{\nu}(1 + \ tg\varphi)$$

Where σ_1 and σ_3 are maximum and minimum principal stresses.

An idealized stress-strain curve is presented in Figure 4, illustrating the relationship between strain and the load applied to the specimen. However, this curve can be misleading when interpreting results and drawing conclusions from the unconfined compression test.

Figure 5 provides a suggested interpretation. Typically, in Figure 4, the lateral (transverse) strain curve is placed in the second quadrant of the chart, correlating lateral strain to the axial load applied to the specimen. By placing it in the third quadrant, it correlates to the tensile stress, thus representing the elastic modulus more accurately.

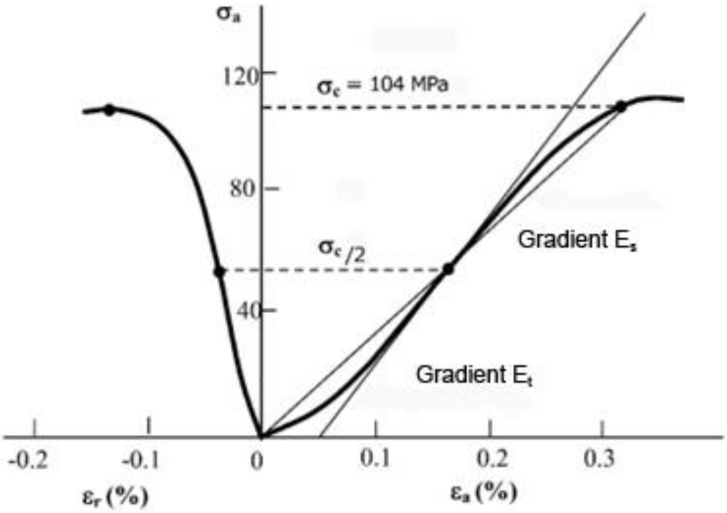

Figure 4 Idealized stress – strain curve from unconfined compression test

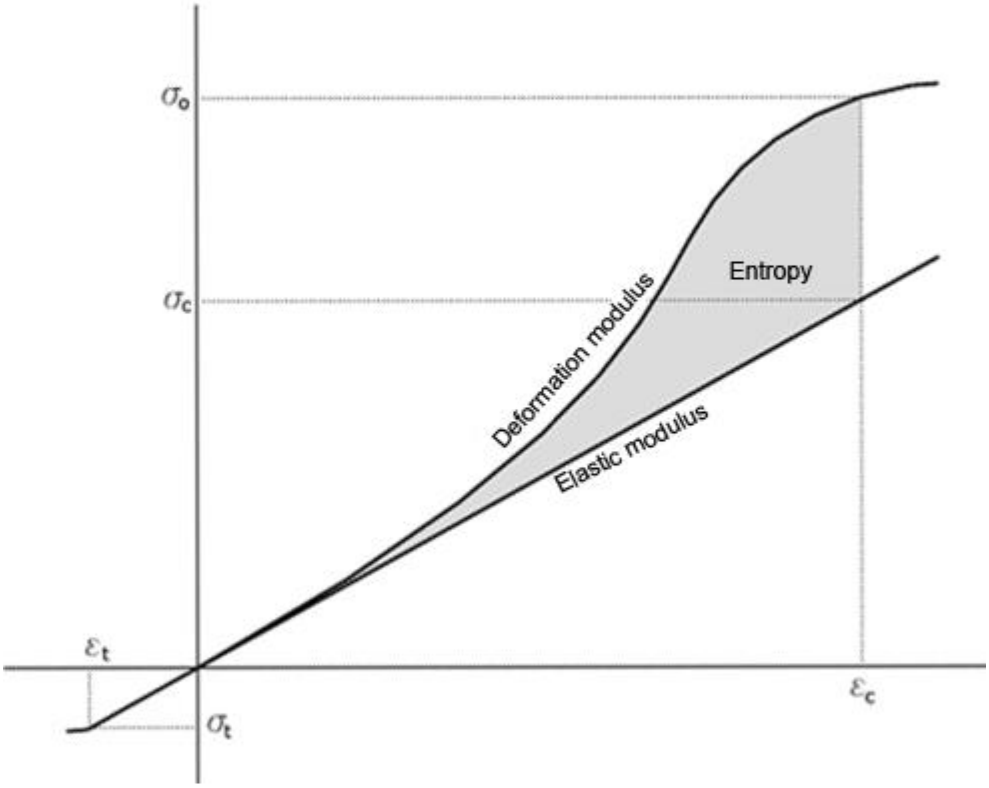

Figure 5 Suggested stress – strain curve interpretation

The elastic modulus is linear and should remain so. In contrast, the deformation modulus of rock mass is nonlinear, increasing with friction. Friction, in turn, increases with tensile stress due to increased tensile strain, all in accordance with Hooke's law. The elastic modulus represents the initial modulus when the friction impact is minimized.

Using the stress-strain curve, and assuming we can reliably determine the elastic modulus, provides a direct approach to determining the tensile strength of the tested specimen. However, performing direct tensile testing is more representative for determining tensile strength and elastic modulus, as no friction is activated during this process. This method allows for a more accurate assessment of these properties.

Following the proposed failure criterion, we can determine the internal friction angle and Poisson's ratio. The internal friction angle can be determined by the following expression:

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

The Brazilian test is essentially similar to the unconfined compression test, but it involves a significantly smaller contact area. The tensile strength obtained from the Brazilian test is always greater than the true tensile strength because the influence of friction is not accounted for. Performing the expensive triaxial test is unnecessary, as the direct tensile test is the only reliable method for determining true tensile strength.

Specimen load (σ_0) becomes compression (σ_c), tension (σ_t) and friction ($\sigma_t tg\varphi$):

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

Strain energy is recoverable, while deformation work or dissipated energy due to friction is essentially entropy.

3 CONCLUSION

In conclusion, this study emphasizes the complexities and critical considerations involved in evaluating the unconfined compressive strength and deformability of rock specimens. The conventional method of testing compressive strength is shown to have limitations, particularly in accurately representing the true deformability of the rock. The research highlights that the elastic modulus and tensile strength, as obtained through standard tests, can be misleading due to the inherent friction and stress distribution within the specimen. To enhance the reliability of these measurements, direct tensile testing is recommended as it eliminates friction effects, thereby providing a more accurate representation of the rock's tensile properties. Understanding these is vital for reliably assessing the stability and support requirements of underground openings.

4 REFERENCES

[1] Zhang, Y., & Yu, D. (2019). Comparative study on the test method for tensile elastic modulus of rock materials. *Advances in Civil Engineering*, *2019*.