ROCSCIENCE

RocFall2

Simplified Input Parameters for Fragmentation Analysis

Theory Manual

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Introduction

The original fragmentation module proposed by Guccione et al. (2025) requires six input parameters for the rock block, four of which are estimated from Brazilian tensile tests (BT):

- Specimen diameter
- Critical force
- Weibull shape factor for force
- Critical work
- Weibull shape factor for work

and one from unconfined compression tests (UCS):

- E_i(Secant modulus).

Additionally, two optional parameters—Mode I fracture toughness and E_i(Tangent modulus)—are used to estimate energy loss during fragmentation.

In **RocFall2**, these original parameters are input via **Rock Type Library** > **Fragmentation tab** > **Advanced entry form**. The **Advanced entry form** can only be accessed by enabling **Advanced rock type entry** under **Project Settings**.

Rather than requiring the user to input all aforementioned parameters, a simplified methodology was developed because the distribution of force and work required to break discs in BT are rarely reported in standard laboratory results. The **Simplified entry form** is the default input form in the **Rock Type Library**. This simplified approach estimates the four Weibull parameters (critical force, Weibull shape factor for force, critical work, and Weibull shape factor for work) using only:

- Specimen diameter (mean and standard deviation)
- Tensile strength (mean and standard deviation)
- E_i(Intact secant modulus, mean and standard deviation)

These steps are performed internally in **RocFall2**. The two optional parameters for energy-loss estimation are not included in the simplified version.

Verification of this methodology is reported in the Verification Manual.

1. Derivation of the Weibull parameters from simplified input parameters

[RocFall2 Build 8.027]

1.1. Workflow for Simplified Fragmentation Input Parameters

The workflow can be summarized as follow:

1. **Monte Carlo Sampling**

   Generate 100,000 random normal samples for the three input variables:

   - Specimen diameter (mean and standard deviation)
   - Tensile strength (mean and standard deviation)
   - E_i(Secant modulus, mean and standard deviation)

2. **Compute Force and Work Distributions**

   For each sample, apply:

   - The standard formula for tensile strength in Brazilian tests
   - A theoretical formula to estimate disc displacement during indirect tensile tests.

     These calculations yield distributions of **force** and **work** required to break a disc.

3. **Fit Weibull Distributions**

   Use the simulated force and work data to fit Weibull distributions, obtaining:

   - Critical force and its shape factor
   - Critical work and its shape factor

1.2. Formula used for Force and derivation of the Work from tensile strength and young modulus

The tensile strength in Brazilian tests (σ_t) is given by the ISRM standard (1978):

(1-1)
$$\sigma_t = \frac{2F_{BT}}{\pi d h}$$

Where F_{BT} is the failure load, and d and h are the diameter and thickness, respectively.

Assuming $h = d/2$, the force at failure becomes:

(1-2)
$$F_{BT} = \frac{\sigma_t \pi d^2}{4}$$

The work required to break the disc (W_{BT}) is the integral of the force F_{BT} over the displacement δ_{BT}:

(1-3)
$$W_{BT} = \int F_{BT}\, d\delta_{BT}$$

Substituting (1-2):

(1-4)
$$W_{BT} = \int \sigma_t \frac{\pi d^2}{4}\, d\delta_{BT} = \frac{\pi d^2}{4} \int \sigma_t\ d\delta_{BT}$$

Hertzian contact theory provides the total deformation when a disc is compressed against a flat surface The total deformation $\delta_{BT(d)}$ for a disc compressed between steel platens can be expressed (modified from Japaridze L. 2015):

(1-5)
$$\delta_{BT(d)} = \frac{4\, F_{BT(d)}\,(1 - \nu_b^2)}{\pi\, Y_b\, h}\left[0.41 + \ln(2d) - 0.5\ \ln\left(\frac{2\ d\ F_{BT(d)}}{\pi\ h\ \tilde{Y}_{bst}}\right)\right]$$

Where:

- Y_m is the elastic modulus of the rock;
- ν_b is the Poisson's ratio of the rock; assumed equal to 0.3;
- $\tilde{Y}_{bst}$ is an equivalent modulus for the rock-steel platen system defined as:

(1-6)
$$\frac{1}{\tilde{Y}_{bst}} = \left(\frac{1 - \nu_b^2}{Y_b} + \frac{1 - \nu_{st}^2}{Y_{st}}\right)$$

Y_b and Y_{st} are the elastic moduli of the rock and steel platens (equal to 210 GPa), respectively; ν_b and ν_{st} (equal to 0.3) are the Poisson's ratios of the rock and steel platens, respectively.

Expressing $\delta_{BT(d)}$ in terms of σ_t (details omitted for brevity):

(1-7)
$$\delta_{BT(d)} = 2d\sigma_t \frac{1 - \nu_b^2}{Y_b}\left(0.41 + \ln 2 - 0.5 \ln \frac{\sigma_t}{\tilde{Y}_{bst}}\right)$$

And then differentiating:

(1-8)
$$d\delta_{BT(d)} = 2d \frac{1 - \nu_b^2}{Y_b}\left(0.6 - 0.5 \ln \frac{\sigma_t}{\tilde{Y}_{bst}}\right) d\sigma_t$$

An explicit expression of the work as a function of the simplified input parameters (specimen diameter, tensile strength, and the young modulus) can be obtained by substituting equation (1-8) into equation (1-4):

(1-9) $$W_{BT} = \pi d^3 \frac{1-\nu_b^2}{Y_b} \frac{\sigma_t^2}{2} \left(0.16 + \ln 2 - 0.5 \ln \frac{\sigma_t}{\tilde{Y}_{bst}}\right)$$

1.3. Weibull fitting

Once the simulated force and work data are obtained, the Weibull fitting is computed to obtain the critical and shape factors. The critical value (F_{BT}^{cr} or W_{BT}^{cr}) corresponds to a survival probability equal to $1/e \sim 37\%$; and the shape parameter (m_{BT-F} or m_{BT-W}) corresponds to the slope of the central part of the Weibull distribution, which increases with decreasing of variability.

(1-10) $$SP(F_{BT}) = e^{-\left(\frac{F_{BT}}{F_{BT}^{cr}}\right)^{m_{BT-F}}}$$

(1-11) $$SP(W_{BT}) = e^{-\left(\frac{W_{BT}}{W_{BT}^{cr}}\right)^{m_{BT-W}}}$$

More details of the effect of Weibull parameters and other parameters on the fragmentation module can be found in Guccione et al 2021a, 2021b and 2022.

References

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