An Analysis of the Dynamic Stress Drop and Rupture Velocity for Selected Seismic Events at Rudna Copper Mine

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Introduction

Rupture process can be characterized by a few parameters which describe kinematical and dynamical aspects of the rockmass breaking process.

- static stress drop
- apparent stress
- dynamic stress drop
Static stress drop

Static (Brune) stress drop \([\sigma_0 - \sigma_1]\)

\[
\Delta \sigma_s = \frac{7}{16} \frac{M_0}{R^3}
\]
Apparent stress

\[ \sigma_a = \frac{\mu E}{M_0} \]

\[ \sigma_a \approx 1/10 \Delta \sigma_s \quad \text{(Rudna copper mine)} \]
Dynamic stress drop

\[ \Delta \sigma_f = \frac{M_0}{4\pi v_r^3 I} (1 - \xi^2)^2 \frac{dS}{dt} \]

\[ I = \int_0^T S(t) \, dt \]

- Mo - seismic moment
- \( v_r \) - constant (assumption!) rupture velocity
- \( \xi \) - geometrical (directional) factor - assumed to be 0.75
- \( S \) - STF
- \( T \) - rupture duration time
Partial stress drop/overshooting

\[ \gamma_f = \frac{\Delta \sigma_f}{\Delta \sigma_s} = \frac{\sigma_0 - \sigma_f}{\sigma_0 - \sigma_1} \]

\[ \gamma_f \begin{cases} = 1 & \text{Orowan’s model} \quad \sigma_f = \sigma_1 \\ > 1 & \text{partial stress drop} \quad \sigma_f < \sigma_1 \\ < 1 & \text{“overshooting”} \quad \sigma_f > \sigma_1 \end{cases} \]
Orowans model

Initial stress $\sigma_0$

Sliping

Final stress $\sigma_f$

Nucleation

Arresting

Time

Initial stress $\sigma_0$

Final stress $\sigma_f$

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Partial_stress_drop

initial stress $\sigma_0$

nucleation

sliping

arresting

final stress $\sigma_1$

$\sigma_f$

time
Overshooting

initial stress $\sigma_0$

time

nucleation

sliping

arresting

final stress $\sigma_f$

$\sigma_1$
Rupture velocity

“circular type”

no visible directivity

\[ V_r = 0.5V_s \]

“unilateral type”

directivity of T distribution

\[ T(\theta) = \frac{L}{V_r} - \frac{L}{V_P} \cos(\theta) \]
STF - spatial distribution
Source Time Function
Source Time Function
STW width - spatial distribution
Rupture velocity

![Graph showing the relationship between rupture velocity ($V_r/V_s$) and R(m) and $\Delta \sigma_s (Nm)$.]
Rupture velocity

![Graph showing the relationship between rupture velocity (Vr/Vs) and moment (M0) in Newton-meters (Nm).]
Stress estimates

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Correlations

\[ \gamma = \frac{\Delta \sigma_d}{\Delta \sigma_s} \]

- circular
- unilateral

overshooting

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Correlations

\[ \gamma = \frac{\Delta \sigma_d}{\Delta \sigma_s} \]

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Correlations

\[ \gamma = \frac{\Delta \sigma_d}{\Delta \sigma_s} \]

Rupture azimuth

overshooting
Correlations

\[ \gamma = \frac{\Delta \sigma_d}{\Delta \sigma_s} \]

\[ \Delta \sigma_s \text{ [MPa]} \]

overshooting
Velocity

\[ \gamma = \frac{\Delta \sigma_d}{\Delta \sigma_s} \]

\[ V_r/V_s \]

overshooting
“Overshooting” stress

\[ \sigma_f = \sigma_1 + \Delta \]
Scaling stresses with $M_0$

![Graph showing stress drops versus $M_0$]
Source size: Madariaga, Brune, or ...

![Graph showing source size comparison]

- Madariaga
- STF fit (SPE)
- STF fit (LAN)

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Conclusions

- STF calculated via Empirical Green Function approach
- Spectral analysis provides static stress drop estimates
- Rupture velocity calculated from spatial distribution of the STF widths
- $\gamma_f$ correlates ONLY with rupture velocity