Dynamic rock properties

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1 Introduction

Geotechnical constructions and geological processes comprise a quite large range of strain rates and durations as shown in fig. 1. The impact and blasting region are characterized by pronounced increased dynamic strength and stiffness values. Fig. 2 illustrates corresponding strain rates applied in different geotechnical lab test devices.

Depending on the loading velocity one can distinguish static (or quasi-static) and dynamic rock properties. Most important are the following relations:

- Increasing loading velocity → increasing strength
- Increasing loading velocity → increasing stiffness

In general three stages can be distinguished in respect to strength as shown in fig. 3. The transition between these stages can be characterized by the following values:

$$\dot{\varepsilon}_1 \approx 10^0\,\mathrm{s}^{-1} \ldots 10^2\,\mathrm{s}^{-1} \qquad \dot{\varepsilon}_S \approx 10^3\,\mathrm{s}^{-1} \qquad \dot{\varepsilon}_2 \approx 10^4\,\mathrm{s}^{-1}$$

Another classification scheme is shown in fig. 4.

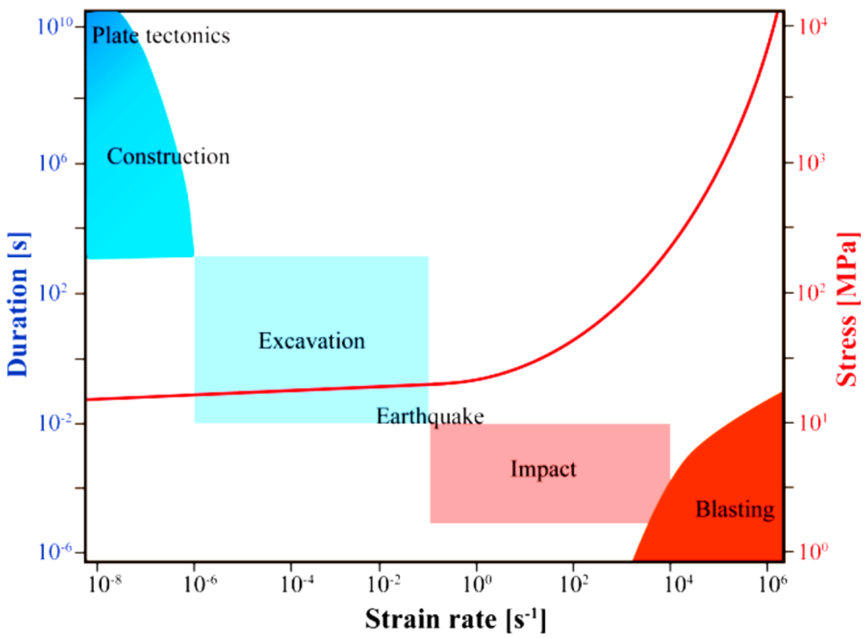

Fig. 1: Typical strain rates and durations in geotechnical engineering (Zhang, 2014)

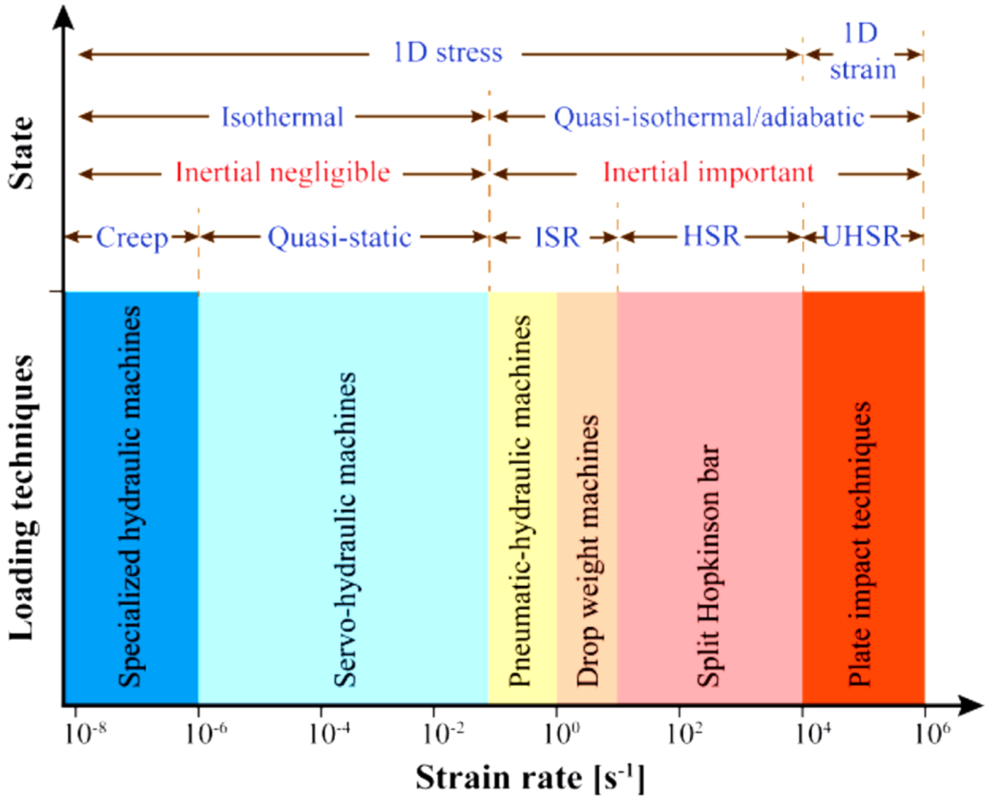

Fig. 2: Typical strain rates applied in different geotechnical lab test approaches (Zhang, 2014)

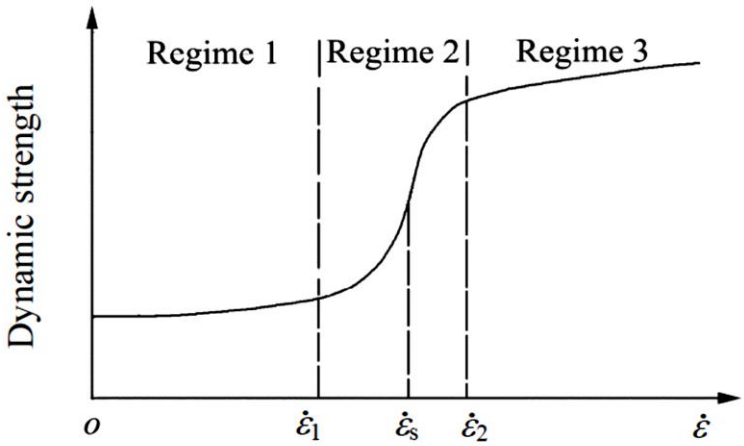

Fig. 3: General relation between dynamic strength and strain rate (Qian et al., 2009)

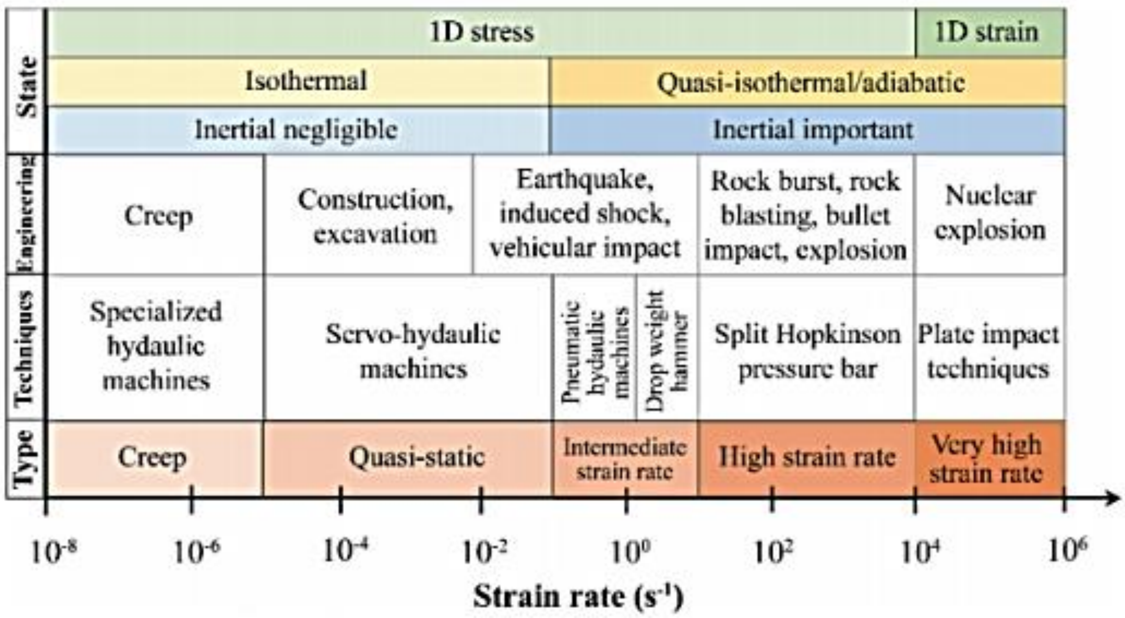

Fig. 4: Classification scheme according to strain rates (Li et al., 2018)

2 Dynamic rock properties

The change in material properties can be characterised by the so-called Dynamic Increase Factor (DIF). Figures 5, 6 and 7 show DIF values obtained from testing of quite different rocks (sedimentary, plutonic and metamorphic). They all show a distinct increase in strength (both, compressive and tensile) beyond a strain rate of app. 10 s^{-1}. Corresponding general formulas to predict dynamic strength are also given in fig. 5 and 6 for the regime 1 and 2 (see also Zhang & Zhao, 2014).

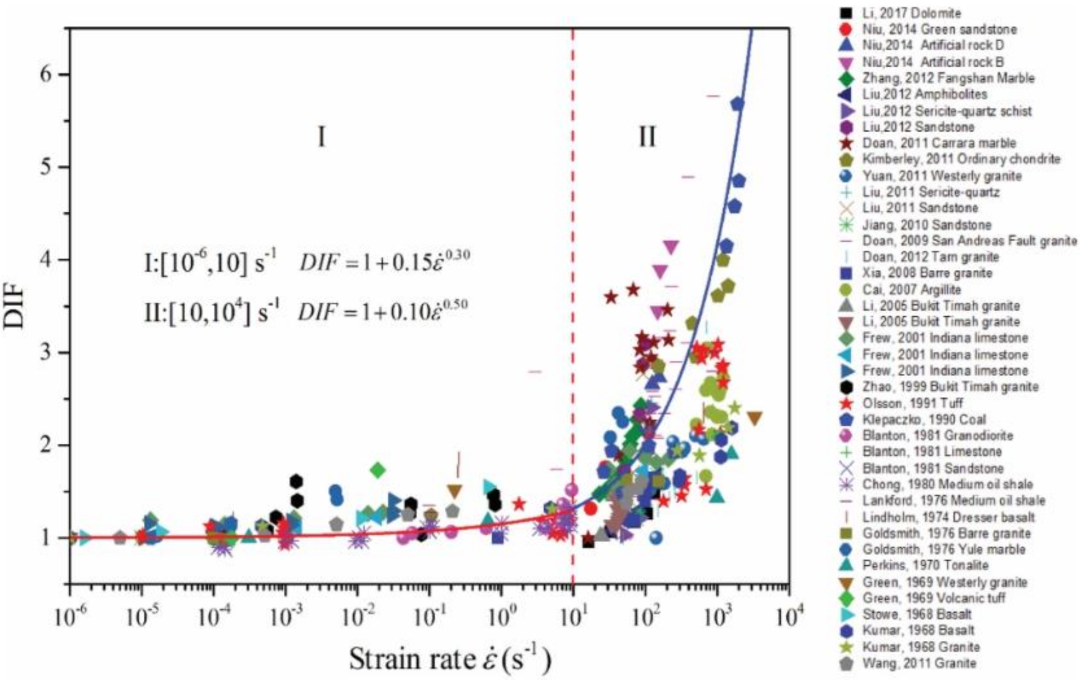

Fig. 5: DIF vs. strain rate for compressive strength (Li et al., 2018)

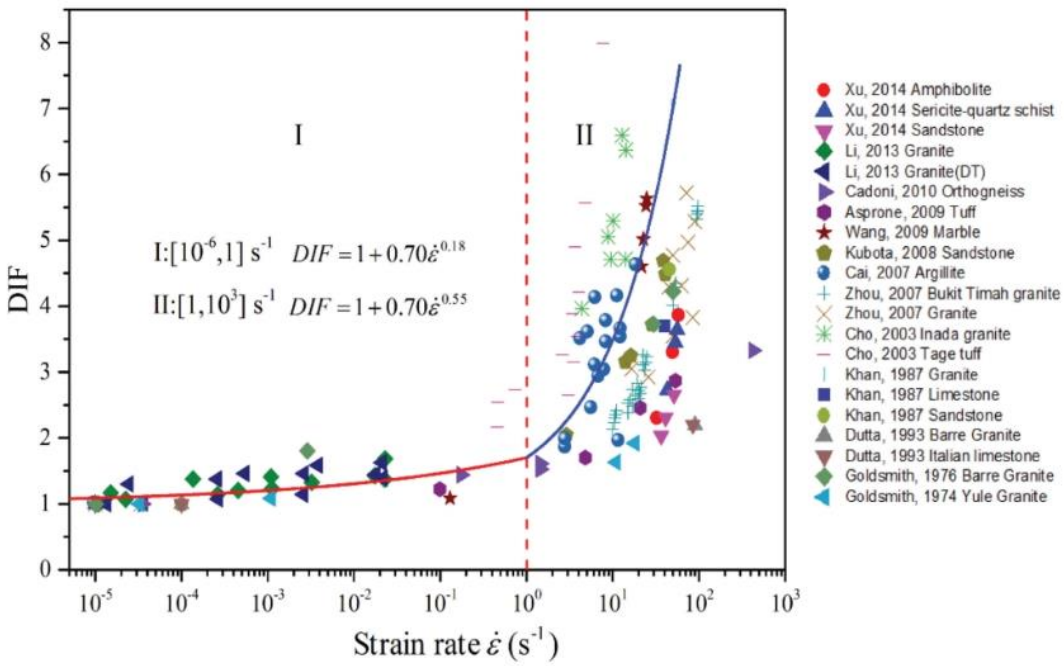

Fig. 6: DIF vs. strain rate for tensile strength (Li et al, 2018)

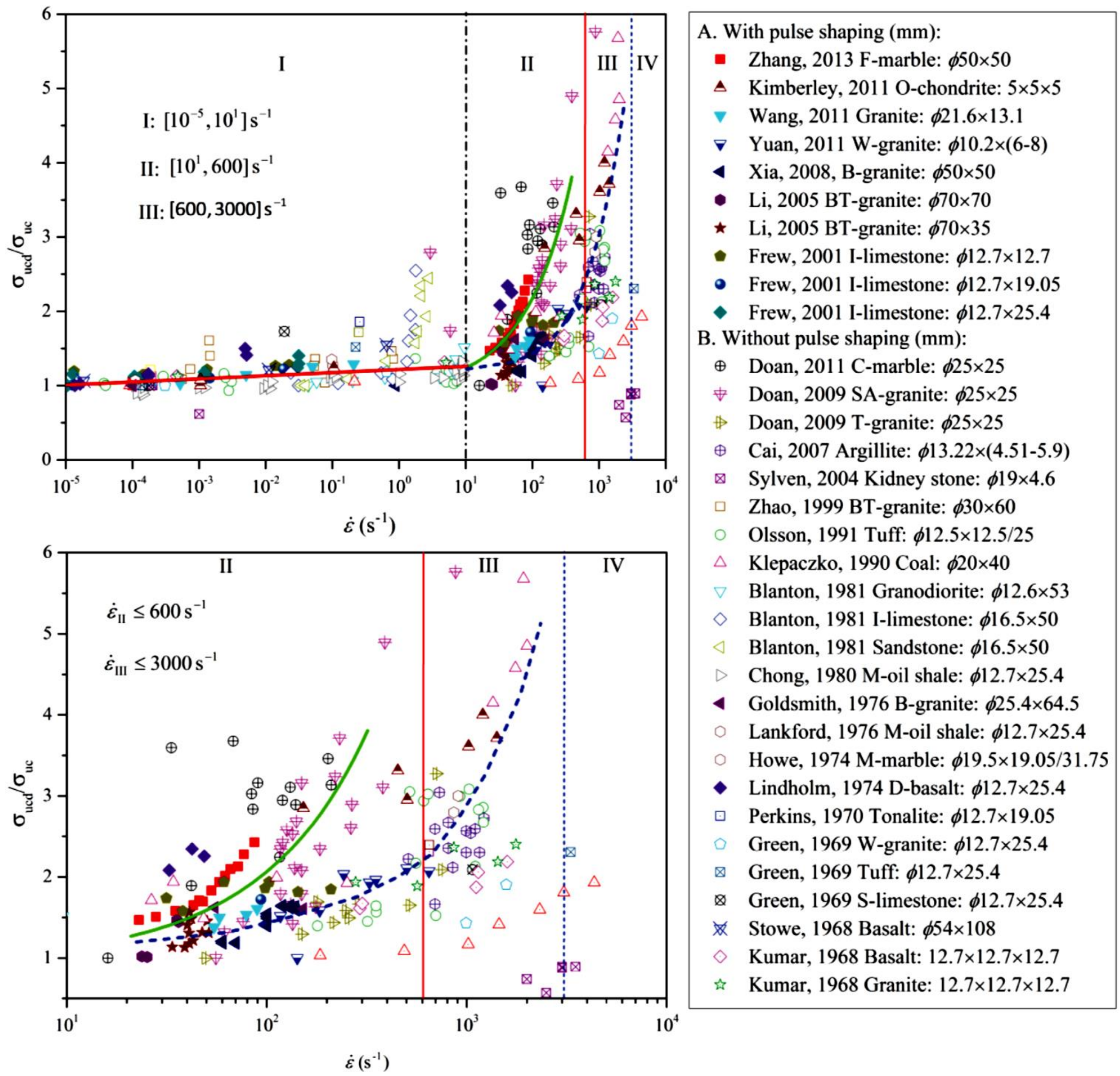

Fig. 7: Ratio between dynamic and static uniaxial compressive (top) and tensile strength values (bottom) for different rocks (Zhang & Zhao, 2014)

Similar relations are obtained considering different loading rates like shown in fig. 8, 9 and 10. In terms of fracture mechanics one has to pay attention to the fact, that increasing loading or deformation rate will lead to a transition of single to multiple fracturing due to the excess of kinetic energy as illustrated in fig. 11.

Besides the increase of strength the stiffness shows also an increase with increasing deformation rate as illustrated in fig. 12. Exemplary, the increase in stiffness with increasing strain rate for rock-like material (especially concrete) is shown in fig. 13.

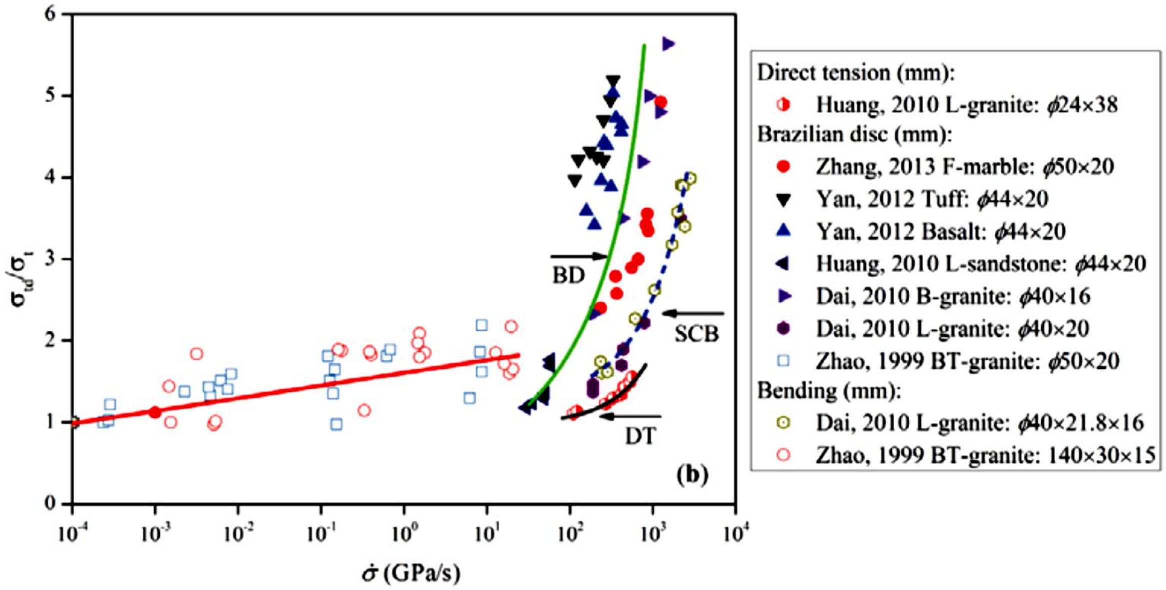

Fig. 8: Ratio between dynamic and static tensile strength for different loading rates (Zhang & Zhao, 2014)

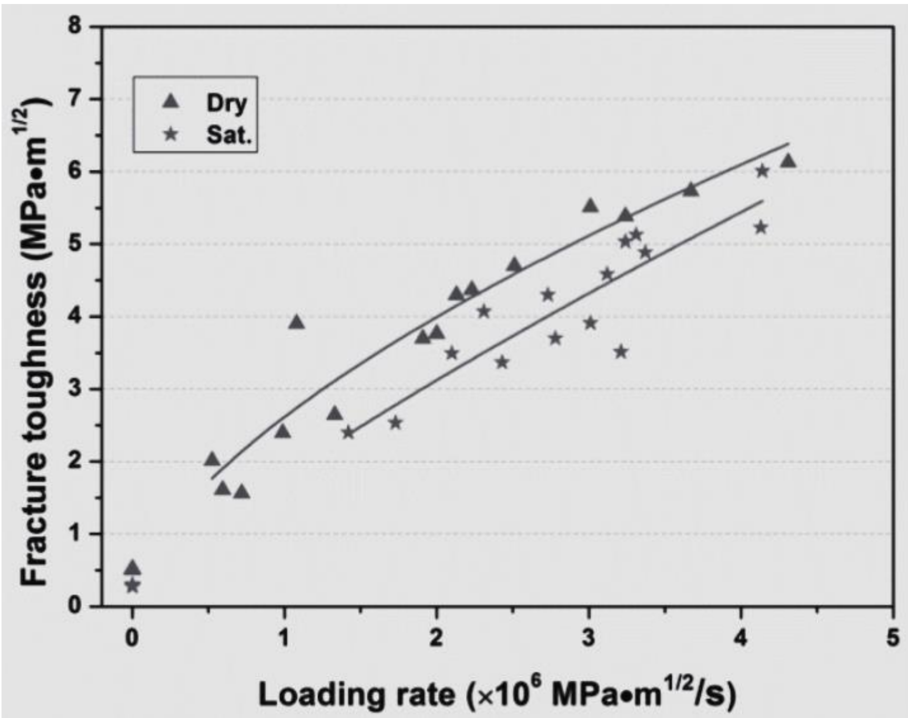

Fig. 9: Mode-I fracture toughness for dry and wet sandstone as function of loading rate (Cai et al., 2018)

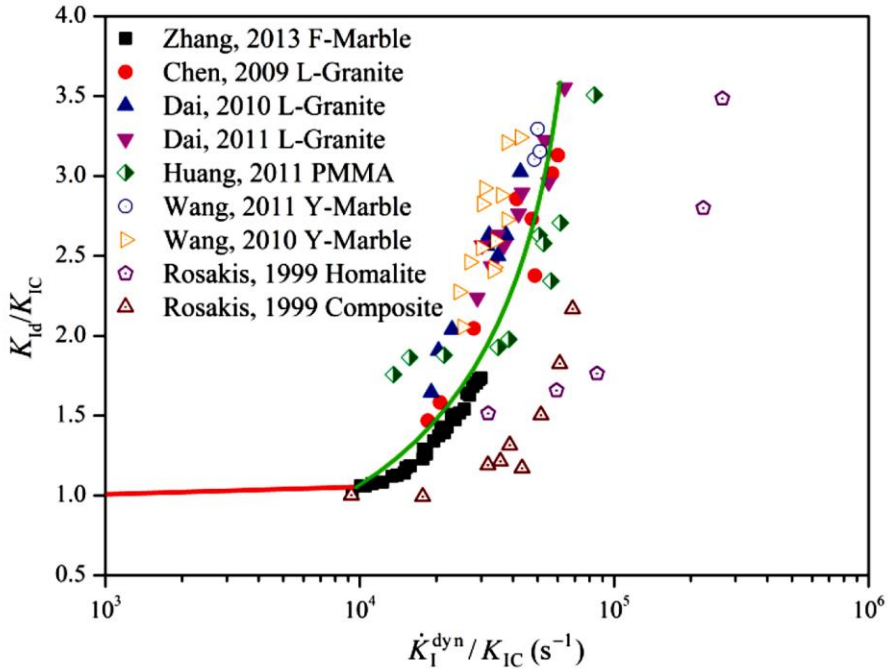

Fig. 10: Ratio between dynamic and static fracture toughness (Mode-I) depending on loading rate (Zhang & Zhao, 2014)

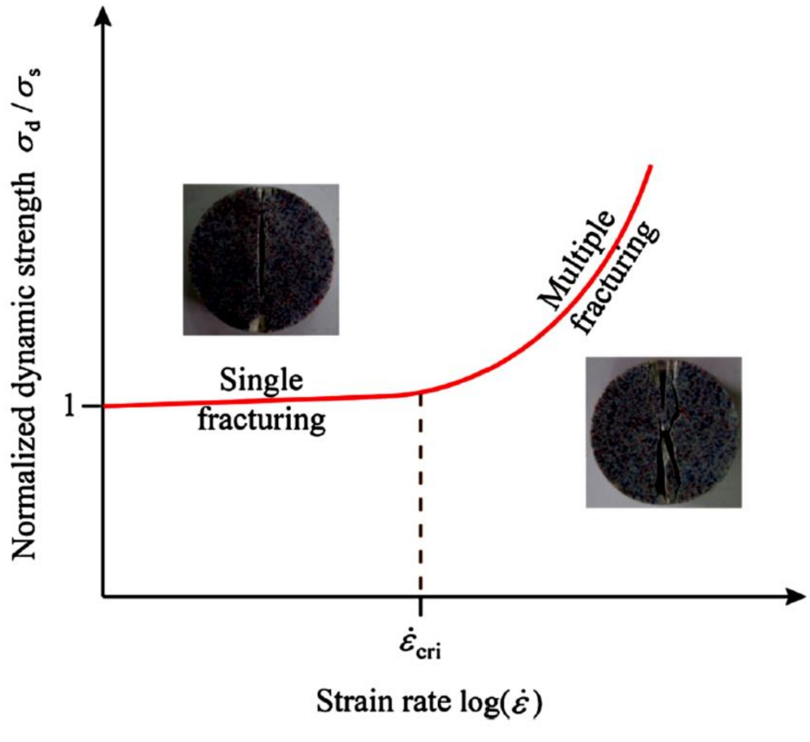

Fig. 11: Principal sketch of normalised dynamic tensile strength as function of strain rate illustrating the transition between single and multiple fracturing (Zhang & Zhao, 2018)

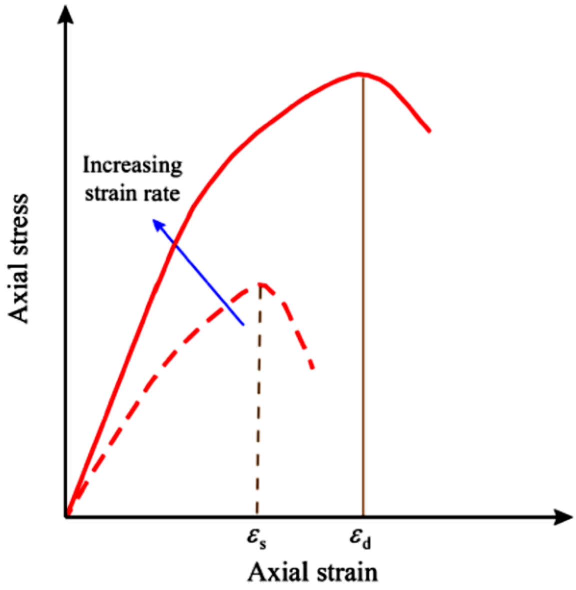

Fig. 12: Stiffness increase with increasing loading rate (static vs. dynamic)

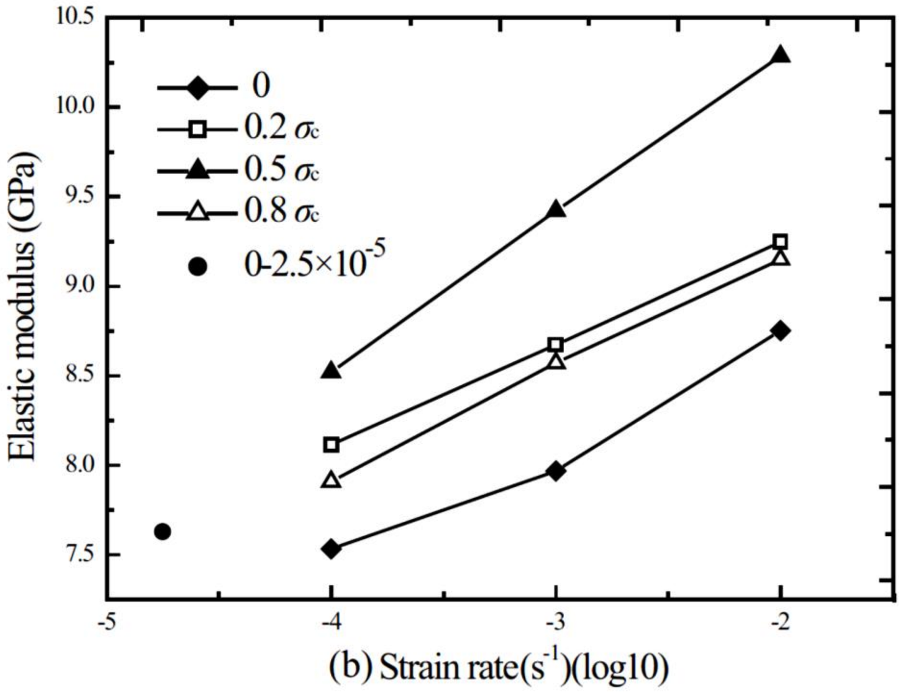

Fig. 13: Young's modulus vs. strain rate for fissured rock-like material (Feng et al., 2018)

The most popular and suited devices to determine strength parameters at high strain rates are the Split-Hopkinson-Bar (SHB) device (Zhou et al., 2012; Tawadrous 2010) and the Plate Impact device (Zhang & Zhao, 2014). These devices can be extended to perform tests at high temperatures as well as under biaxial or triaxial stress states (Zhang & Zhao, 2014).

3 References

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