Effect of rock stiffness change on acoustic emission

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ABSTRACT: It is known that the ratio of rock stiffness around the mine workings and the stiffness of the surrounding strata has a crucial meaning for rock stability in the close vicinity of the underground excavation. Significant resources were invested for the research aiming to understand the failure mechanism using acoustic emission (AE) to evaluate the relationship between the parameters of AE and crack/fracture dimension/scale to determine statistical regularity of AE appearance before oncoming rock collapse and features of acoustic wave attenuation during its propagation via rock massive. However, the methodology of the rock stiffness assessments based on the AE parameters is still lacking.
The paper considers the physical basis for applying AE for stiffness assessment in underground conditions.

Keywords: acoustic emission, rockburst, rock stiffness.

1 INTRODUCTION

The rockburst understanding and assessment of their occurrence is in the mainstream of rock mechanics since the violating collapse of rocks towards the space of underground openings is a great cause of accidents during mining (Zhang et al. 2017a, He et al. 20017). Moreover, strong seismic events are largely responsible for the general community's increasingly declining acceptance of mining (Alber et al. 2009).

There are different approaches in the assessment of the probability of rockburst proneness (Zhang et al. 2017b) including local stress assessment at the wall/face of underground openings or/and in boreholes, using acoustic emission (AE) (Muhammad et al. 2021, Plenkers et al. 2022) or/and electromagnetic radiation (EMR) caused by rock fracturing (He et al. 2017, Lockner and Rehez 1994, Guha 2001, Thompson et al. 2009, Johnson et al. 2013, Goebel et al. 2014, McLaskey & Lockner 2016, Gibowicz & Kijko 1994, Frid & Mulev 2018). AE or seismic acoustic excitation is known to be induced by rock fracturing (Kim et al. 2015).

2 STIFF LOADING

Stiffness is defined as the ability of the system to resist deformation in response to an applied load (Mendetsky 2016). It scales positively with the ratio of the applied stress to the induced strain. Variations in shear stiffness in the shear zone contributed to the emergence of a high slip potential, leading to seismic events (Sainoki & Mitri 2014). The effect of stiffness changes on instability in the underground opening was studied by Qin et al. (2006), who showed that the instability leading to coal bump depends mainly on the system stiffness ratio. Generally, the criterion of stiff loading can be written as follows (Kocheryan et al. 2016):

$$K_{\mathrm{m}} > K_{\mathrm{F}} \tag{1}$$

Where K_m and K_F are stiffness coefficients of the loading system (rock mass) and fractured zone near the underground opening, respectively. If Eq.1 is invalid, the rock failure occurs in an abrupt and blast-wise form (so-called rockburst).

The expression for K_F can be written as follows (Fletcher & McGarr 2006):

$$K_F = \begin{cases} \dfrac{16G_F}{7\pi l} \\ \dfrac{7\pi G_F}{16l} \end{cases} \quad (MPa/m) \tag{2}$$

where G_F and l are the values of the shear modulus and the radius of the failure zone, respectively. Note that the first expression is for the asperity failure while the second is for the crack creation (Fletcher & McGarr 2006).

The expression for rock mass is known to be written as follows:

$$K_m = \frac{G_m}{\lambda} \quad (MPa/m) \tag{3}$$

where G_m and λ are the values of shear modulus and block size which load the rock near the mine opening. Following Coudurier-Curveur et al. (2020) the size of such a block is related to the fault length L via the following expression:

$$\lambda = (0.1 - 1)L \tag{4}$$

Superimposing Eqs. 1-3 yields the stiffness ratio:

$$\frac{G_m}{G_F}\frac{l}{k\lambda} > 1 \tag{5}$$

where k is equal to 16/7π either for asperity failure or to 7π/16 for crack creation (Fletcher & McGarr 2006). Eq. 5 means the conditions for stiff loading/failure and hence the lack of abrupt blast-wise failure. Note that the asperity model corresponds to stiffer loading than the crack model.

The relation Eq. 5 can be written using the corner frequency of the acoustic emission or seismic-acoustic emission as follows (Gibowicz & Kijko 1994, Cai et al. 2001, Shearer 2009, Fletcher & McGarr 2011):

$$\frac{G_m}{G_F}\frac{1}{k\lambda}\frac{0.21V_s}{f_0^c} > 1 \tag{6}$$

where V_s and f_0^c are the values of shear wave speed and the corner frequency, respectively.

3 RESULTS AND CONCLUSION

Figure 1 shows the results of calculating the stiffness ratio for the following values of parameters included in Eq. 6.

$$0.1 < \frac{G_m}{G_F} < 10,\ 10m < \lambda < 1000m\ 2000\ m/s < V_s < 5000\ m/s$$

$$0.1 < f_0^c < 1000\ Hz \text{ and } k = \frac{7\pi}{16} \tag{7}$$

Figures 1 a-d portray the values of stiffness ratio for the values of shear wave speed 2,3,4 and 5 km/s, respectively. It is seen that an increase in the ratio of shear modulus ratio G_m/G_F from 0.1 to 10 increases the stiffness ratio, which is consistent with the stiffness theory (Hudson et al. 1972). Note that the case G_m/G_F =1 (the dashed lines in Figure 1) corresponds to the case of mining within a big ore body when the rocks near the underground opening and in the loading system are the same. The G_m/G_F >1 implies that the loading system is stiffer than the rocks surrounding the underground opening (e.g., when the stiffer layers in the crown overlay coal layer). The opposite case (G_m/G_F <1) means the loading system is softer than the rock near the underground opening.

An increase in the value of shear wave speed V_s in the rock in the close vicinity underground opening induces an increase in the value of stiffness ratio (Fig. 1a-d). A similar relationship can be noted for the size of the loading block, the decrease of which causes an increase in the value of the stiffness ratio.

The analysis of the relationship between the corner frequency f_0^c and the stiffness ratio exhibits that the smaller the ratio $1/(\lambda f_0^c)$, the stiffer the loading process. Note a reverse relationship between the value of corner frequency f_0^c and the value of source radius l (Eqs. 5-6), which can be interpreted as the parameter characterizing the size of the area of maximal/concentrated stress in the rock surrounding the underground opening. The smaller the value of l, the less the area where the stress concentration exists. Hence, the decrease in the value of ratio l/λ follows with the decrease in loading stiffness due to an increase in stress concentration. The last conclusion is consistent with the previously known observations (Hudson et al. 1972).

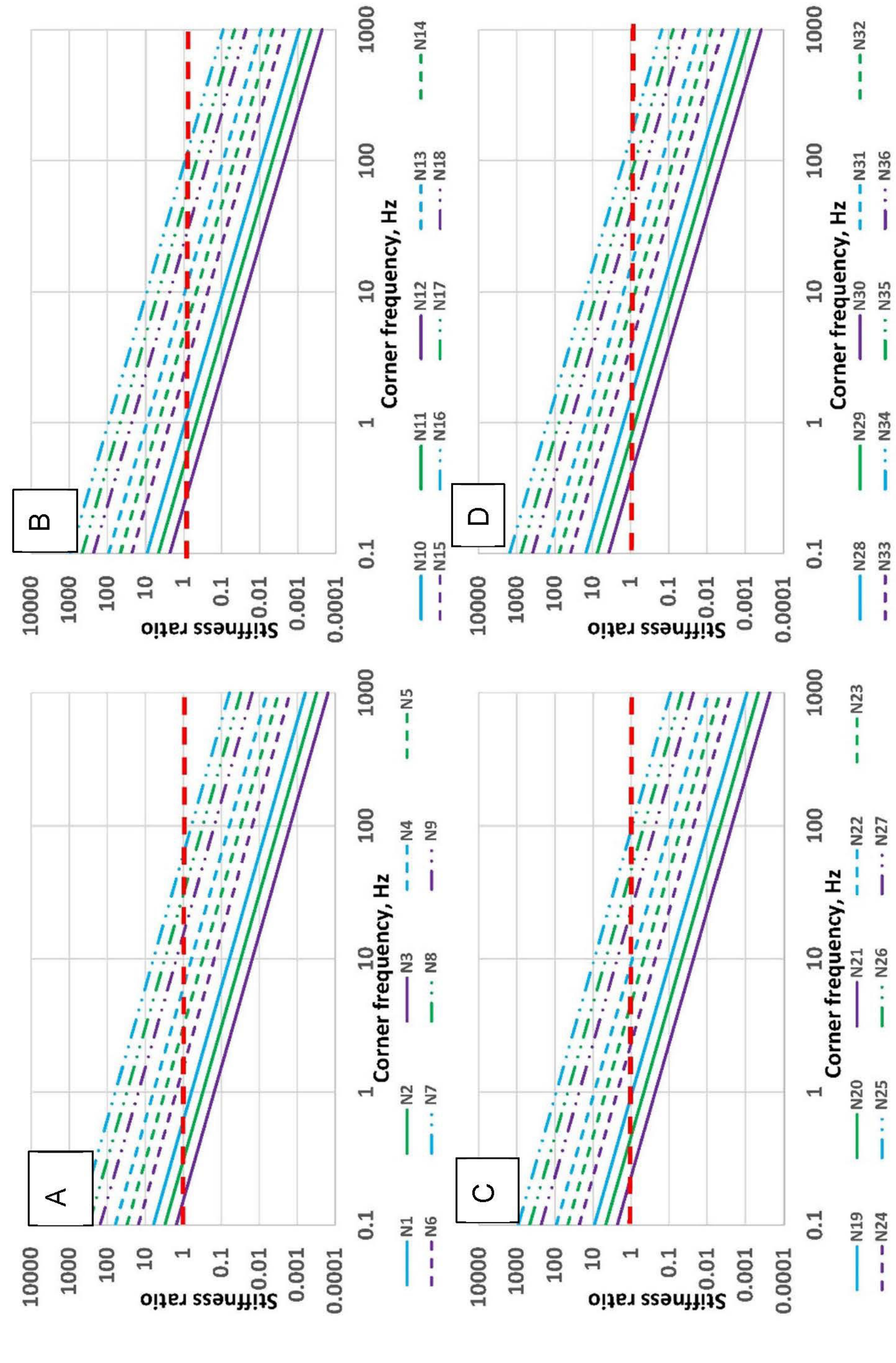

Figure 1. The relationship between the stiffness ratio and the corner frequency.
A. Vs=2km/s, λ=100m for N1-N3, λ=10m for N4-N6, λ=1m for N7-N9, G_m/G_F =10 for N1, N4, N7; G_m/G_F =1 for N2, N5, N8; G_m/G_F =0.1for N3, N6, N9. B. Vs=3km/s, λ=100m for N10-N12, λ=10m for N13-N15, λ=1m for N16-N18, G_m/G_F =10 for N10, N13, N16; G_m/G_F =1 for N11, N14, N17; G_m/G_F =0.1for N12, N15, N18. C. Vs=4km/s, λ=100m for N19-N21, λ=10m for N22-N24, λ=1m for N25-N27, G_m/G_F =10 for N19, N22, N25; Gm/GF=1 for N20 N23, N26; G_m/G_F =0.1for N21, N24, N27; D. C. Vs=5km/s, λ=100m for N28-N30, λ=10m for N31-N33, λ=1m for N34-N36, G_m/G_F =10 for N28, N31, N34; G_m/G_F =1 for N29,N32, N36; G_m/G_F =0.1for N30, N33, N36.

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