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Interactive comment on "The Mohr–Coulomb criterion for intact rock strength and friction – a re-evaluation and consideration of failure under polyaxial stresses" *by* A. Hackston and E. Rutter

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The manuscript presents a re-examination of the Mohr-Coulomb failure criterion according to results from rock failure experiments under polyaxial stresses. Although the influence of intermediate stress on rock failure has been detected for a long time, the widely-used Mohr-Coulomb criterion is still not able to consider the effect of intermediate stress. Two-end member conditions of polyaxial stress are investigated in this paper: axisymmetric extension ($\sigma 1 = \sigma 2 \gg \sigma 3$) and shortening ($\sigma 1 \gg \sigma 2 = \sigma 3$) normal to bedding, both for intact rock fracture and frictional sliding, using sawcut samples.

The manuscript is concise, well structured and well-written. Sampling and the experimental procedure are adequately explained. Data are summarised in several tables and analysed using adequate diagrams. Discussions and conclusions are, in general, well supported by the reported results and the manuscript includes appropriate references.

There are several interesting observations that arise from the experiments: (1) experimental data fit well using the Mogi (1967) empirical criterion, (2) the friction coefficient is a stress-sate variable which shows higher values for axisymmetrical shortening than in extension, and (3) fault plane orientations vary in orientation with respect to the maximum compression in both conditions. The last two observations cannot be predicted with the Mohr-Coulomb criterion.

The manuscript is a significant contribution and the thematic is appropriate with the SE topics and the scope of the special volume. For these reasons, I recommend that the manuscript is accepted for publication after minor revisions.

From a scientific point of view I have the following general questions:

1) In Fig. 4 you show a summary of results on intact rocks for ultimate and residual strength. Friction coefficient values are relatively similar from ultimate strengths, but friction coefficients are lower for extensional tests than shortening for residual strength data. How do you explain (or reconcile) this difference between ultimate and residual strength? Are residual stress curves similar in both cases (extension/shortening)? Are there stresses associated with reboot after failure? Are they similar in both cases?

I am wondering if the differences of friction coefficient between both setups are related to the configuration of samples and the experimental device used, or alternatively indicative that the friction coefficient indeed depends on the stress configuration. Although this is partially discussed in the manuscript, I think more arguments should be given to defend this interpretation.

An additional factor that probably also influences is that the mean stresses in both conditions is different. Mean stresses are higher for extensional cases than in shortening, and from the M-C envelope we know that the increase of the mean stress produces a decrease of the friction coefficient. Can this factor explain the difference?

2) How do you reconcile the deviation of the failure envelope with respect to the tangent to the Mohr-Coulomb criterion? This deviation is higher for extensional experiments. Could you provide some explanation?

3) What is the influence of the sample geometry in your results? From uniaxial compressive strength experiments (UCS, e.g. Mogi 2007), it is well known that the ratio l/D between length (l) and diameter (D) of the sample exerts an influence on the strength. Samples with low l/D ratio tend to show higher stress failures than samples with high l/D ratios. How does l/D ratio influence the results on your experiments? And in the orientation of the fracture developed?

4) In section 4.4 there is a discussion on the role of anisotropy on the rock strength. In my opinion the results presented here cannot support the discussion on anisotropy, because the effect of strength anisotropy was not investigated in your models. Have you tested samples with shortening/extension parallel to bedding? Could you show or discuss the results? From your description of sandstones, I understand that bedding is not well developed in your samples. But for extensional settings the fracture orientation seems to be controlled by bedding. Is this right? How is resolved the potential faults and shear slip showed in the Fig. 14?

5) From my point of view, the equation 7 makes no physical. As stress is a tensor, the normal stress varies depending on the fracture/plane orientation. This variation is controlled by the differential stress and not by the mean stress, as expressed in equation 7. Perhaps this is one of the reasons that can explain the illogic negative value of the beta parameter compared to the expected one using the original Mogi (2007) criterion. A possibility is to add the differential stress in the Eq. 7 as,

r sin(2tetha)=phi (c+r cos2tetha)ˆn where r=(σ1-σ3)/2 and c=(σ1+betaσ2+σ3)/2.

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For these reasons, equation 7 needs to be reformulated, and consequently the paragraph 4.5.2 needs to be modified.

Small comments

P 3854, L25 Add in the main text the values obtained for the Mogi's equation parameters

P 3855. L4 residuals are not showed at Fig. 12

P 3855, L12-14 I do not understand this sentence. What is mean "inclined ellipses"? Do you mean that the failure criterion is not convex?

Add correlation coefficient for best fits showed in Fig 4, Fig. 9 or Fig 11. For the Mogi criterion, could you explain how was beta selected?

Figure 4 Add labels to the graphs (a to d) and indicate to the figure caption

Fig.5 Label the different diagrams (from a to d) and indicate them in the figure caption. The equation for extension in Fig. 5b is not coherent with the text (P 3850, L18)

Fig. 10 and 12 How are the dashed lines calculated? They are explained at pages 3853-3854, but the sentence is not clear. Could you please rephrase?

References

Mogi K (2007) Experimental rock mechanics. Taylor - Francis, London, p 361

Interactive comment on Solid Earth Discuss., 7, 3843, 2015.