Fracture elasticity influenced by surface roughness distributions

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Introduction

There exists an implicit linkage between fluid flow properties – resulted from the opening and connectivity of apertures, and elastic properties – contributed from contacted asperities [Pyrak-Nolte & Morris, 2000]. Previous study has illustrated that various aperture distribution could result in distinction in fracture flow properties especially observed under different extent of compression [Ma *et al.*, 2018]. Unlike flow properties which depend on both the spatial correlation and global variation of the apertures, elastic properties should be predominantly controlled by the former factor [Swan, 1983]. An understanding of associations between aperture distributions and fracture stiffnesses would further enable an inference for statistical description of fracture surface roughness, which is of interest for subsurface reservoir characterization.

Methodology

We investigate the effect of normal stressing on the single fractures with numerical simulations. Consider fracture exist in a square domain of horizontal length L = 100m and assume that the fracture aperture size follows a log-normal distribution, we synthesize the random aperture maps in 128 x 128 pixels [Ruan & McLaughin, 1998], with autocorrelation length λ from L/64 to L/16 and a fixed standard deviation of L/250. Neglecting the change in surface topography change due to asperity interactions during fracture compression, we assume a Poison's ratio of 0.25 and bulk modulus of 70 GPa for the hosting rock. The nodal force exerted on each contact point, and thus the corresponding effective pressure on fracture, for a given compression displacement is found with a linear dependence with the compressed asperities [Giroud, 1968], The averaged relation between effective pressure and compression displacement obtained over 50 realizations for each λ, and interpolated with Chebyshev polynomials, are then used to derive the fracture compliance for each roughness distribution.

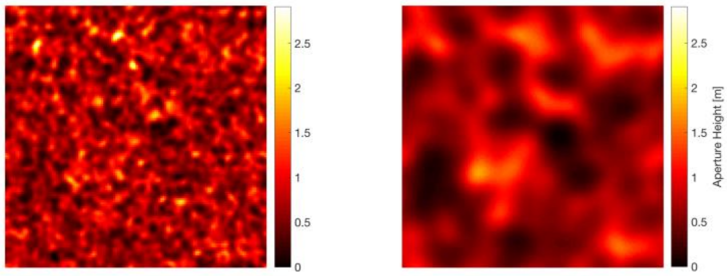
Results

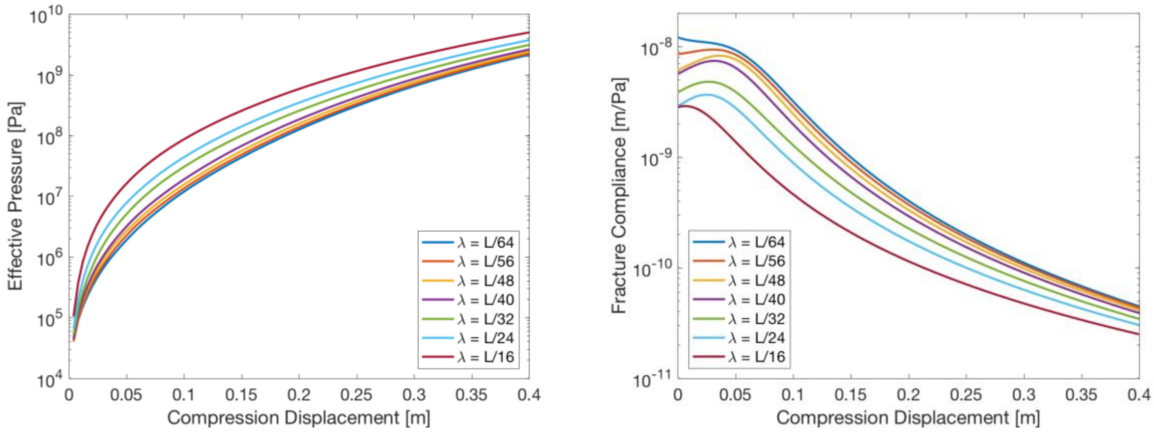
Figure 1 illustrates the fractures with shorter λ tend to have denser but smaller contact area. Figure 2a suggests that shorter λ fractures require higher pressure to be compressed compared to longer λ ones. Therefore they behave as stiffer fractures, as shown in Figure 2b for lower values for fracture compliance. Nevertheless, Figure 2c suggests that the distinction in fracture compliance between different distributions is more apparent under low effective pressure (~10MPa), before the background stiffness of host rock becomes an increasingly significant contributor than the contacts.

Conclusions

The fracture stiffness properties are controlled by surface contact distribution. We have illustrated, from numerical simulations, the dependency of fracture compliance on the spatial correlation of fracture apertures. The results show that an estimation of fracture compliance is possible by knowing the roughness distribution and stressing state of the fracture.

Figure 1: One of the realizations for aperture distribution with (a) $\lambda = L/64$ and (b) $\lambda = L/16$ respectively. Dark regions represent smaller apertures, which are more prone to contact and closure.





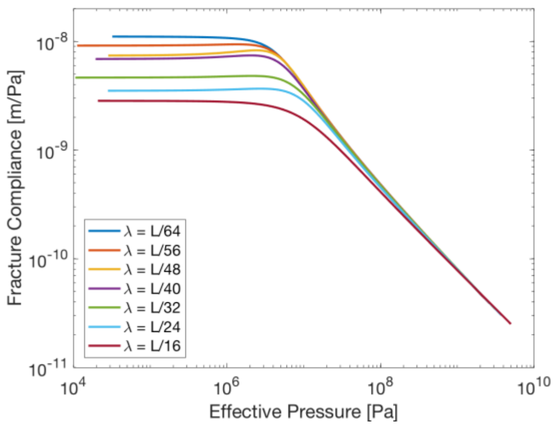


Figure 2: The simulated relation between (a) effective pressure and compression displacement, (b) fracture compliance and compression displacement, and (c) fracture compliance and effective pressure on single fracture with various aperture distribution autocorrelation lengths.

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References

1. *Giroud, J-P., 1968, Settlement of a linearly loaded rectangular area, J. Soil Mech. Found. Div. Am. Soc. Civ. Eng., 94, 813-831.*
2. *Ma, J.H.Y., Li, Y.E., Cheng, A., 2018, Dependency of flow and transport properties on aperture distributions and compression states. Geophysical Prospecting.*
3. *Pyrak-Nolte, L. J., & Morris, J. P., 2000, Single fractures under normal stress: The relation between fracture specific stiffness and fluid flow. International Journal of Rock Mechanics and Mining Sciences, 37(1-2), 245-262.*
4. *Ruan, F., & McLaughlin, D., 1998, An efficient multivariate random field generator using the fast Fourier transform. Advances in water resources, 21(5), 385-399.*
5. *Swan, G., 1983, Determination of stiffness and other joint properties from roughness measurements: Rock Mechanics and Rock Engineering, 16, 19–38.*