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The stress memory in rocks: insight from the Deformation Rate Analysis (DRA) and Acoustic Emission (AE)

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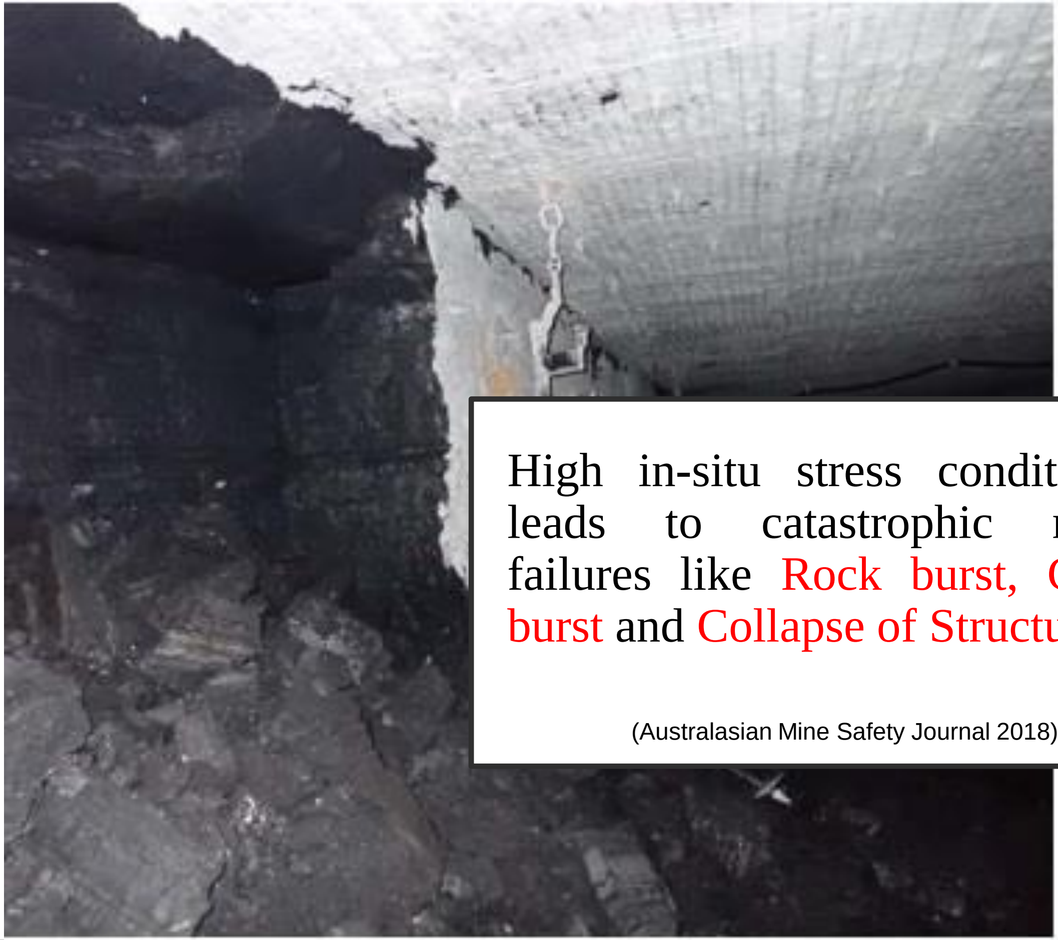
SEQUENCE

INTRODUCTION → DRA & AE PRINCIPALS → METHODOLOGY → RESULTS

Why determine in-situ stresses?

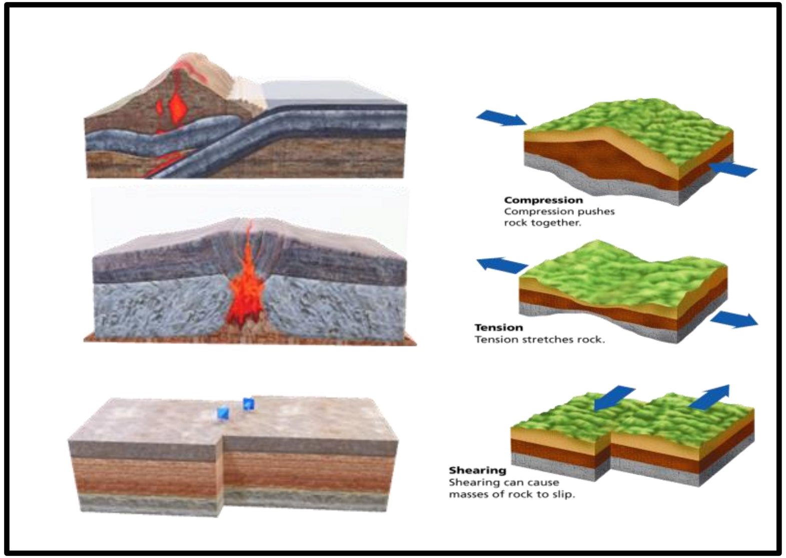


High in-situ stress conditions leads to catastrophic rock failures like Rock burst, Coal burst and Collapse of Structures

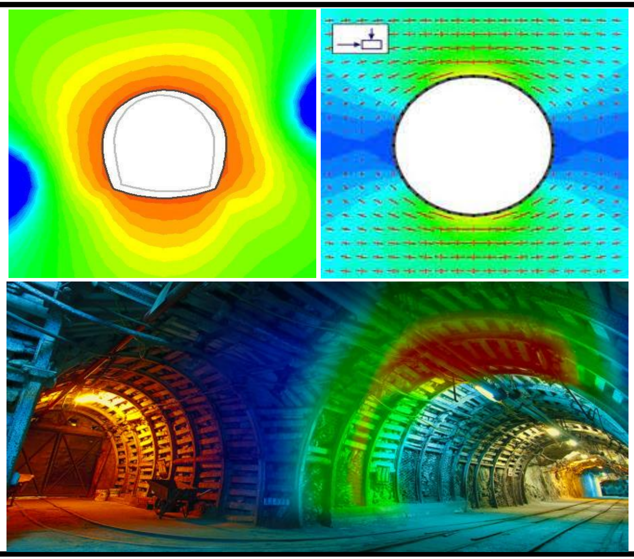
(Australasian Mine Safety Journal 2018)

Why determine in-situ stresses?

There is a pre-existing stress state in the ground and we need to understand it

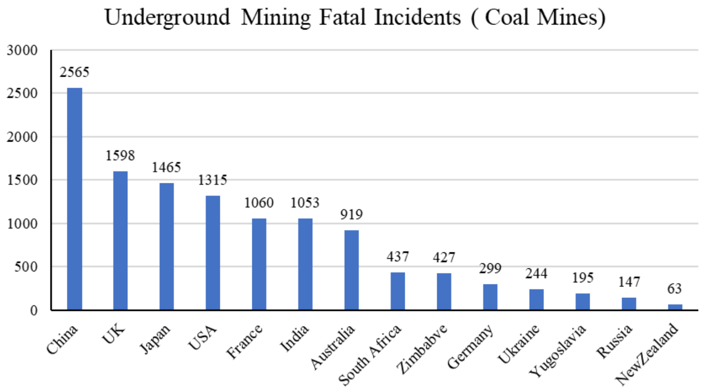


During rock excavation, the stress state can change dramatically



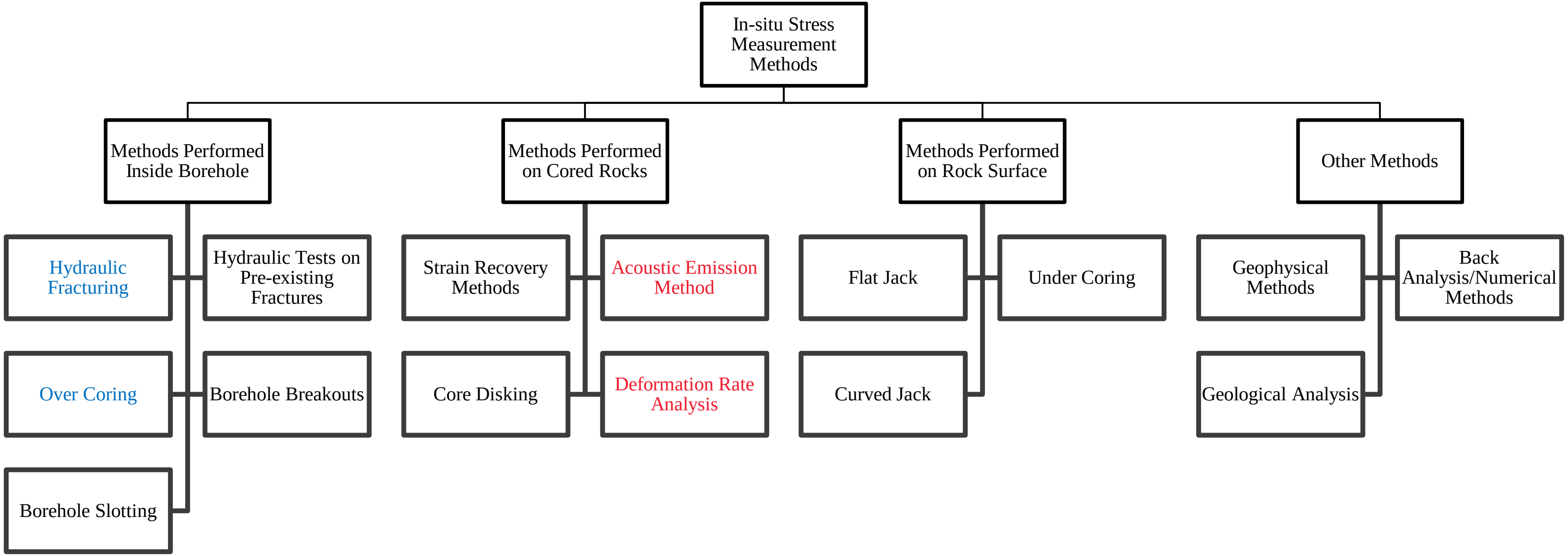
(Rocscience, 2022)

Why determine in-situ stresses?



(Kang et al. 2010)

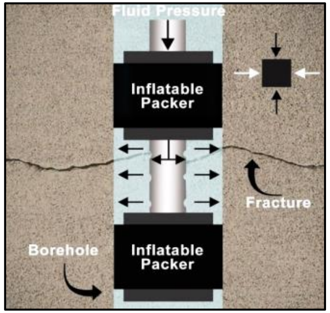
Stress Measurement Methods

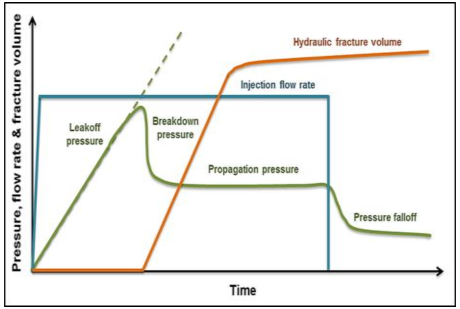


Stress Measurement Methods

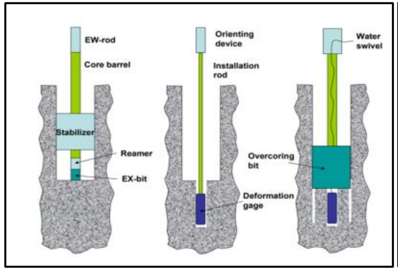
Hydraulic Fracturing

- Expensive and requires skilled technical staff
- Only 2D stress measurement
- Disturbs water chemistry





(Haimson & Fairhurst 1970)



Overcoring

- Expensive and requires drill rig and skilled technical staff
- Suitable for shallow depths
- Difficult to be applied at great depths and remote regions

(Worotnicki & Walton 1976)

Non-destructive Techniques

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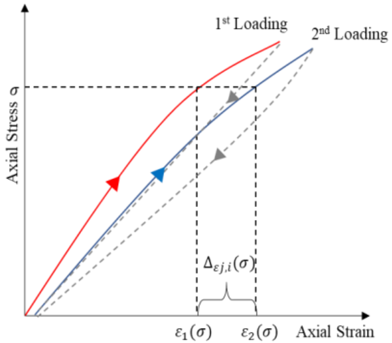
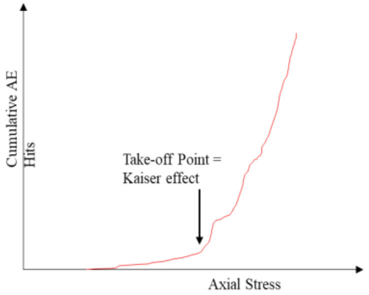
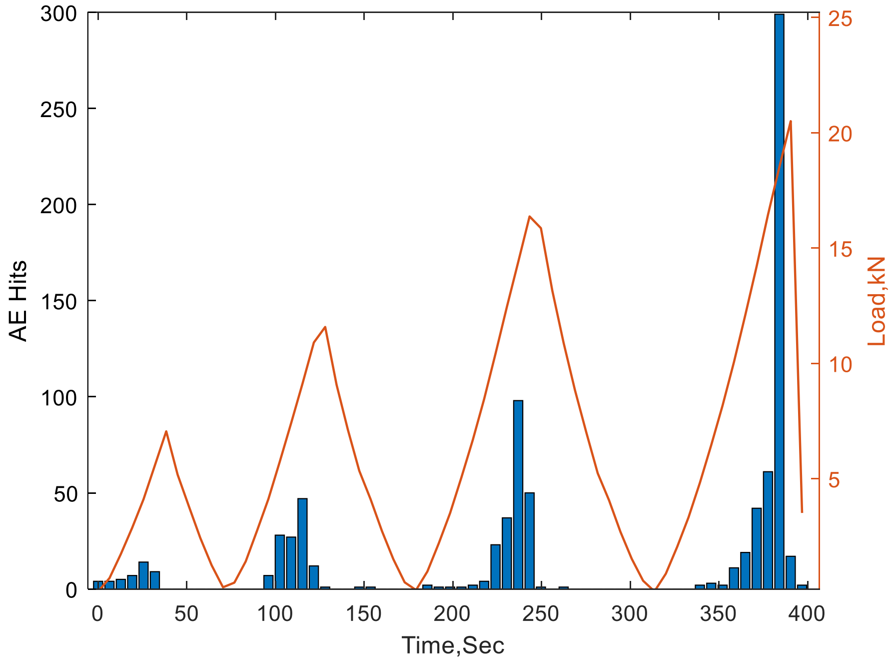
- It is an efficient, reliable and cost-effective
- Easily implemented in the laboratory with minimum cost during the mine feasibility and planning stages.
- Best suited for situations where the conventional methods are not applicable and only the exploration cores are available.
- A further advantage is that the borehole breakout data from the same boreholes can be used for cross validation of the results.

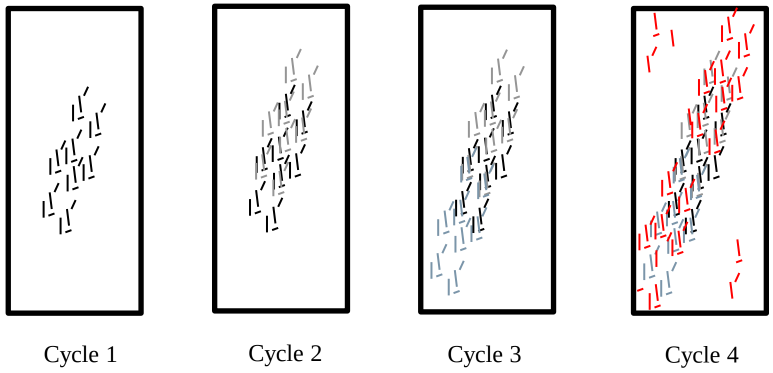




What is rock stress memory?

Rock Stress Memory





Acoustic Emission (AE) Method

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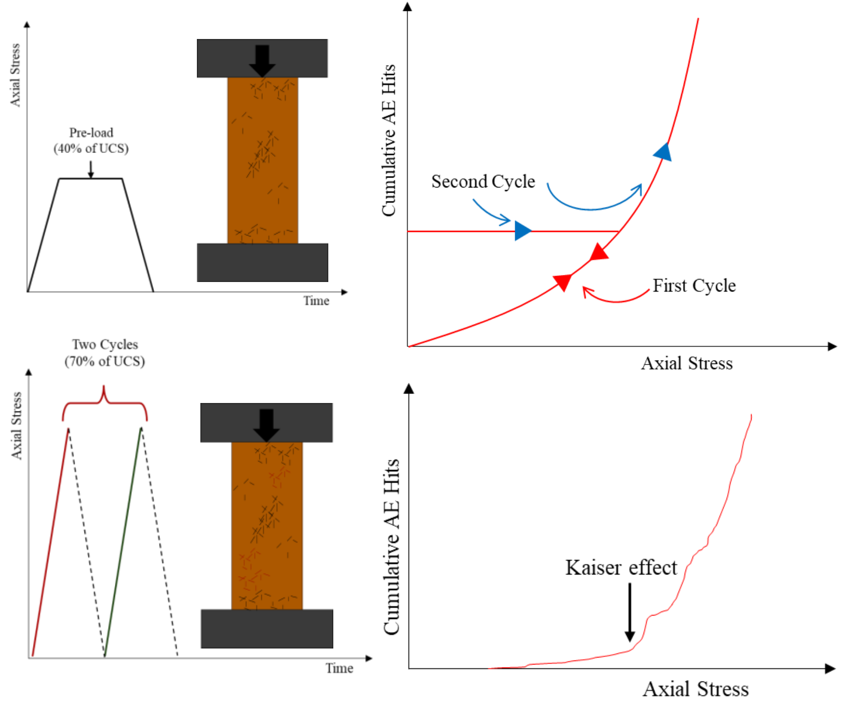
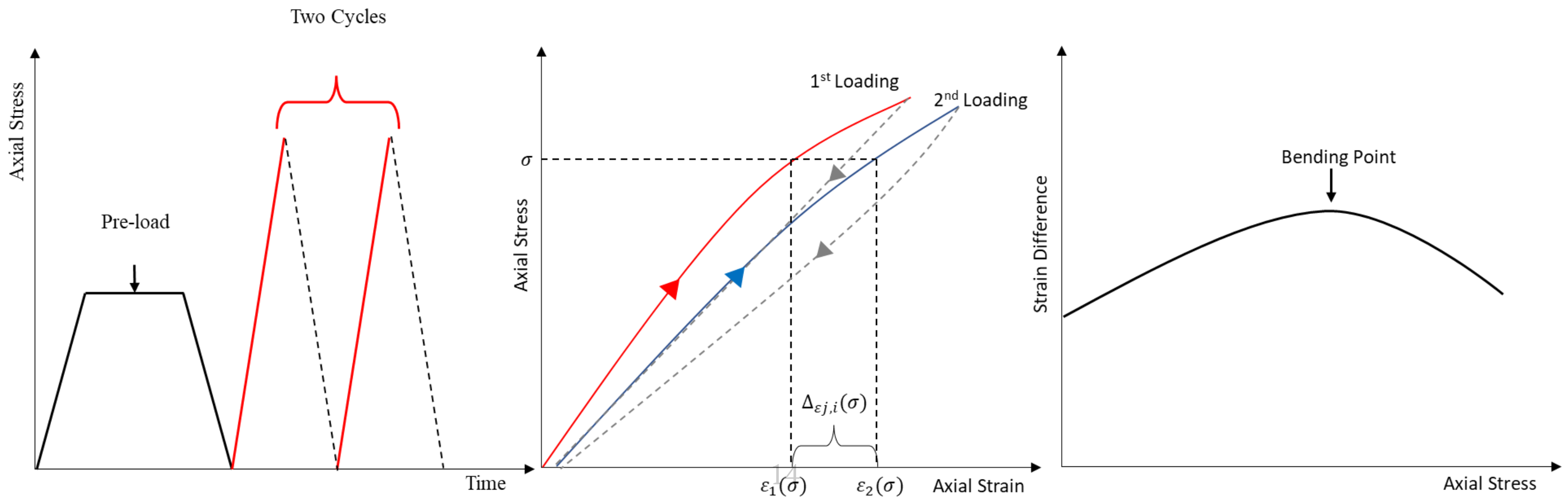
- First observed by Joseph Kaiser in 1950's (Kaiser 1953) therefore known as the Kaiser effect.
- In this method the rock specimen is preloaded to simulate in-situ stresses.
- Two cycles of uniaxial compression is then applied to a higher stress level.
- Applied stresses are measured by plotting the cumulative AE hits against the stress which shows a clear point of inflection at applied stress levels.



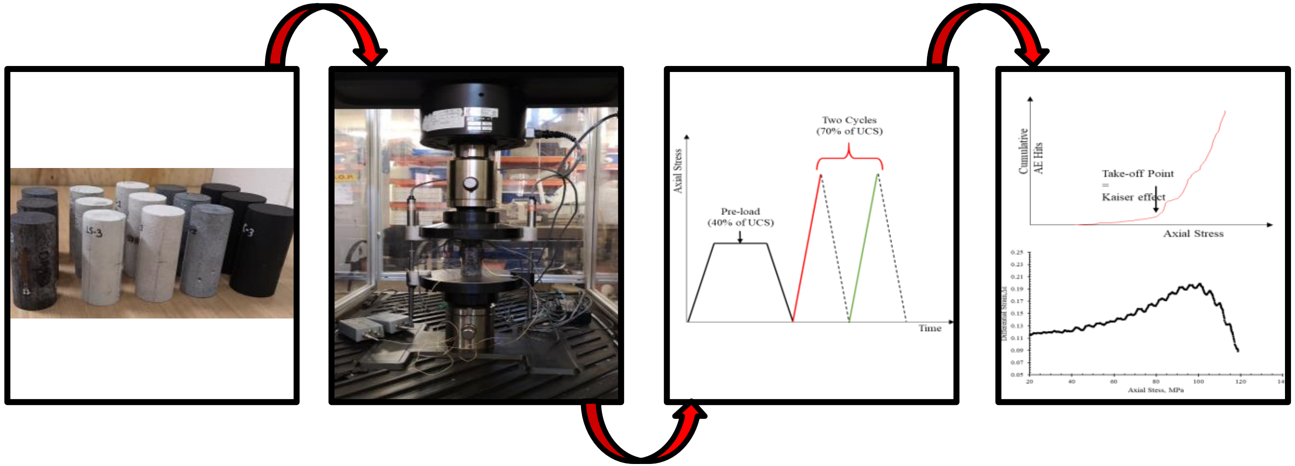
Deformation Rate Analysis (DRA)

- Introduced by Yamamoto et al. (1990)
- The strain difference values between the two loading cycles is given by a strain difference function $\Delta_{\varepsilon j,i}(\sigma)$

$$\Delta_{\varepsilon j,i}(\sigma) = \varepsilon_j(\sigma) - \varepsilon_i(\sigma); \quad j > i \qquad (1)$$

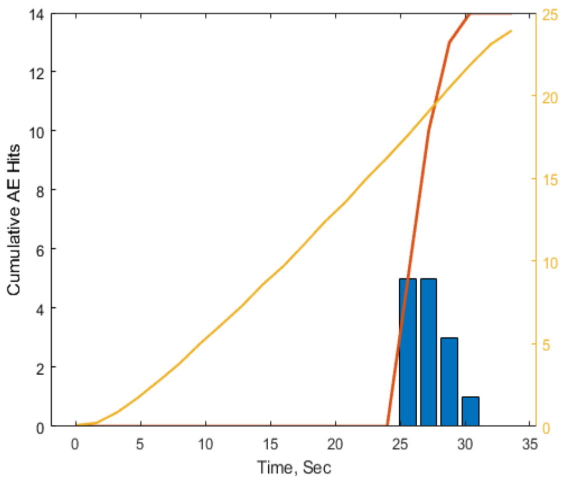


Methodology

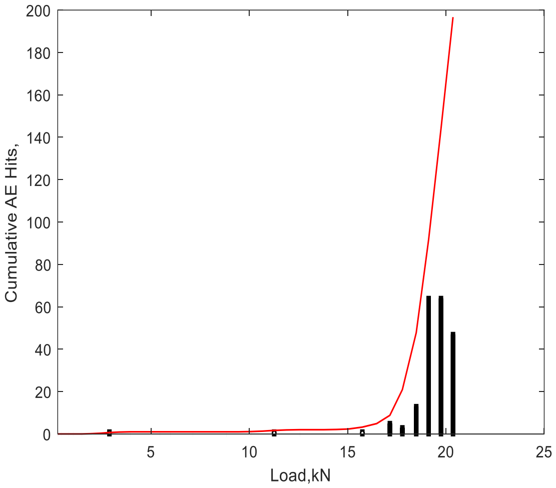


Felicity Ratio (FR) = Measured Stress/ Applied Stress

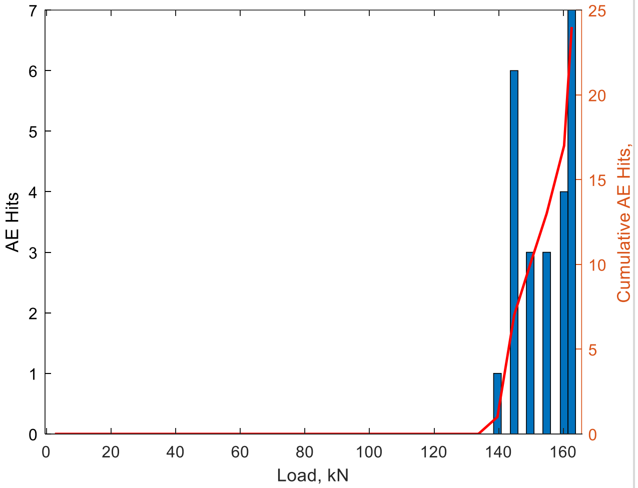
Results



Cumulative AE Hits
Stress, MPa
Time, Sec
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
14
0
5
10
15
20
25

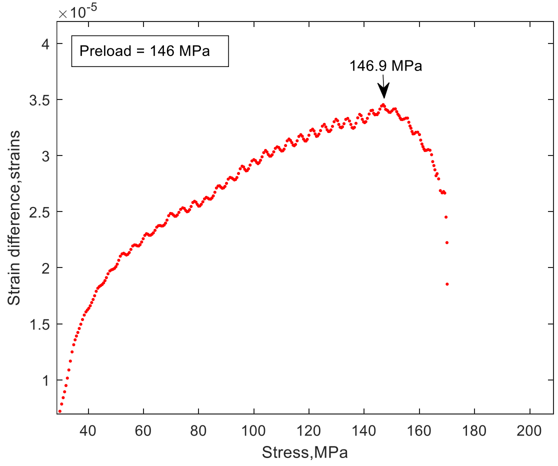


Cumulative AE Hits,
Load,kN
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
200

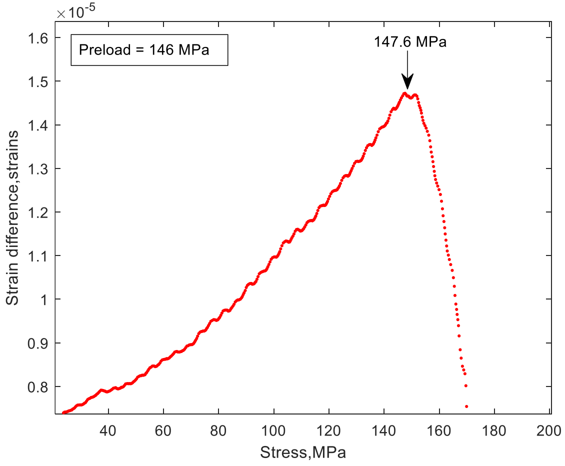


AE Hits
Cumulative AE Hits,
Load, kN
0
20
40
60
80
100
120
140
160
0
1
2
3
4
5
6
7
0
5
10
15
20
25

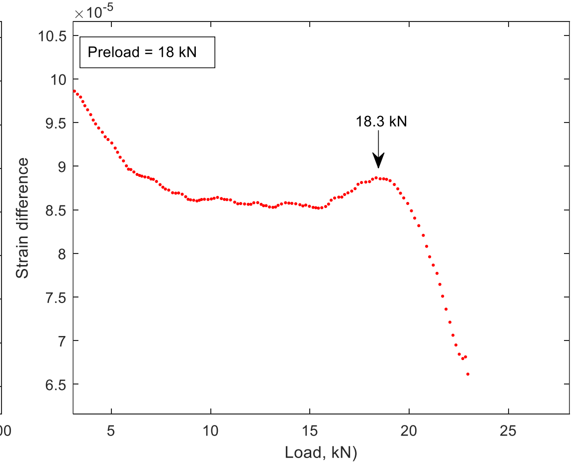
Results



Preload = 146 MPa
146.9 MPa
Strain difference,strains
Stress,MPa

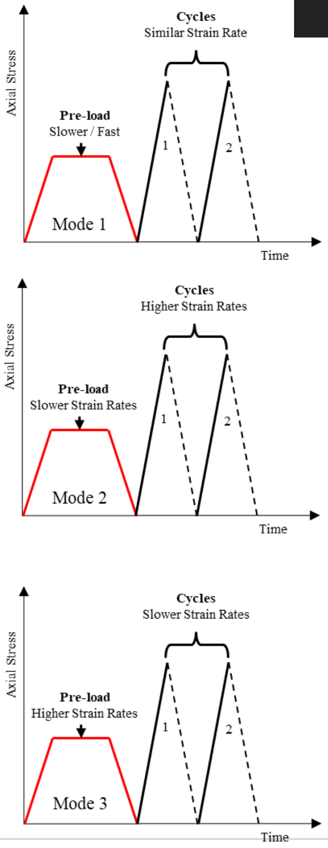


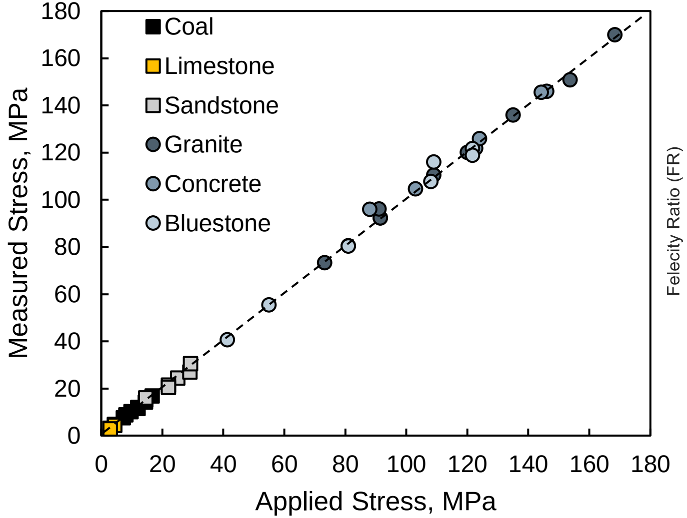
Preload = 146 MPa
147.6 MPa
Strain difference,strains
Stress,MPa

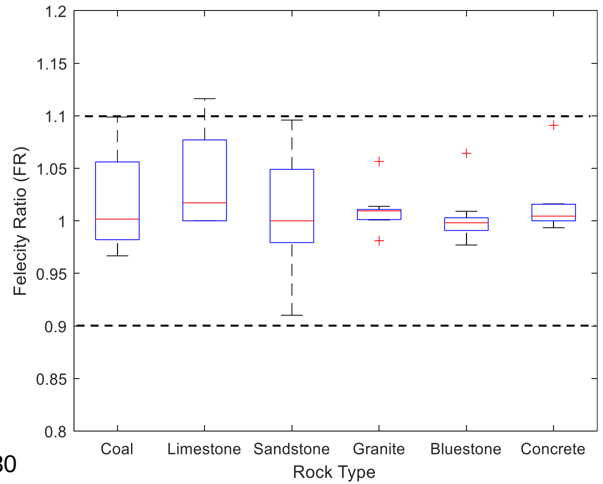


Preload = 18 kN
18.3 kN
Strain difference
Load, kN)

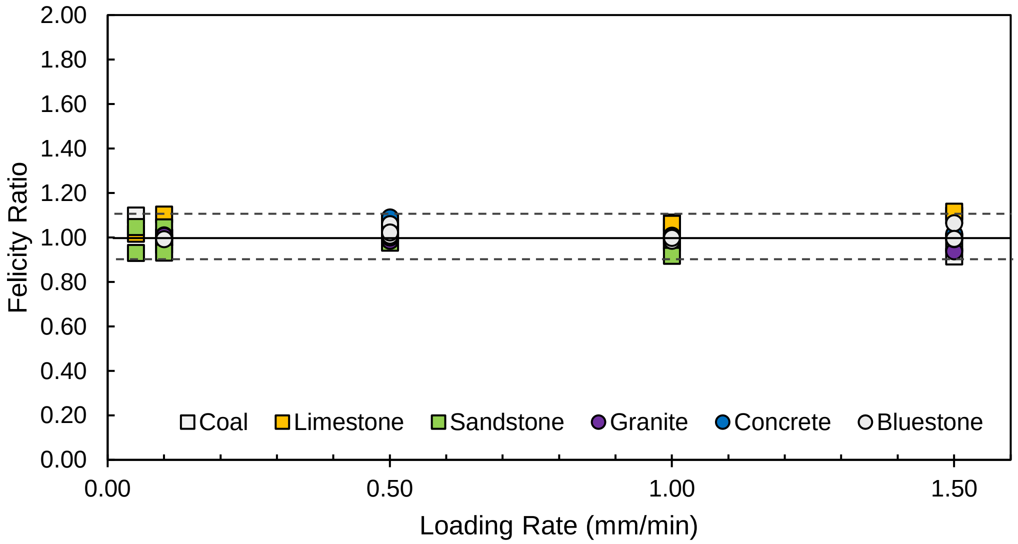
Effect of Loading Modes

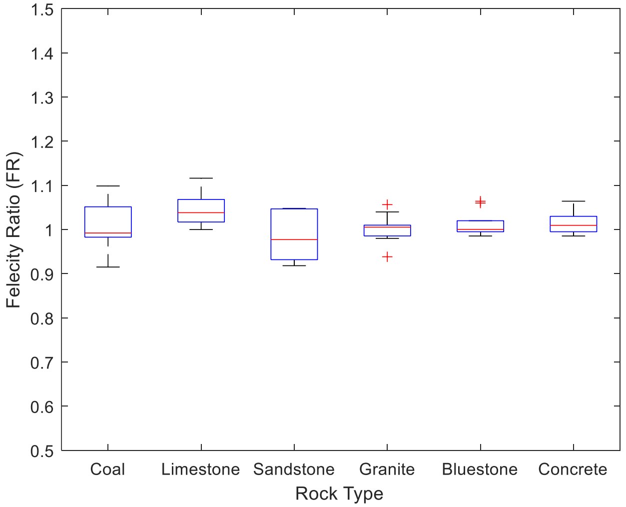




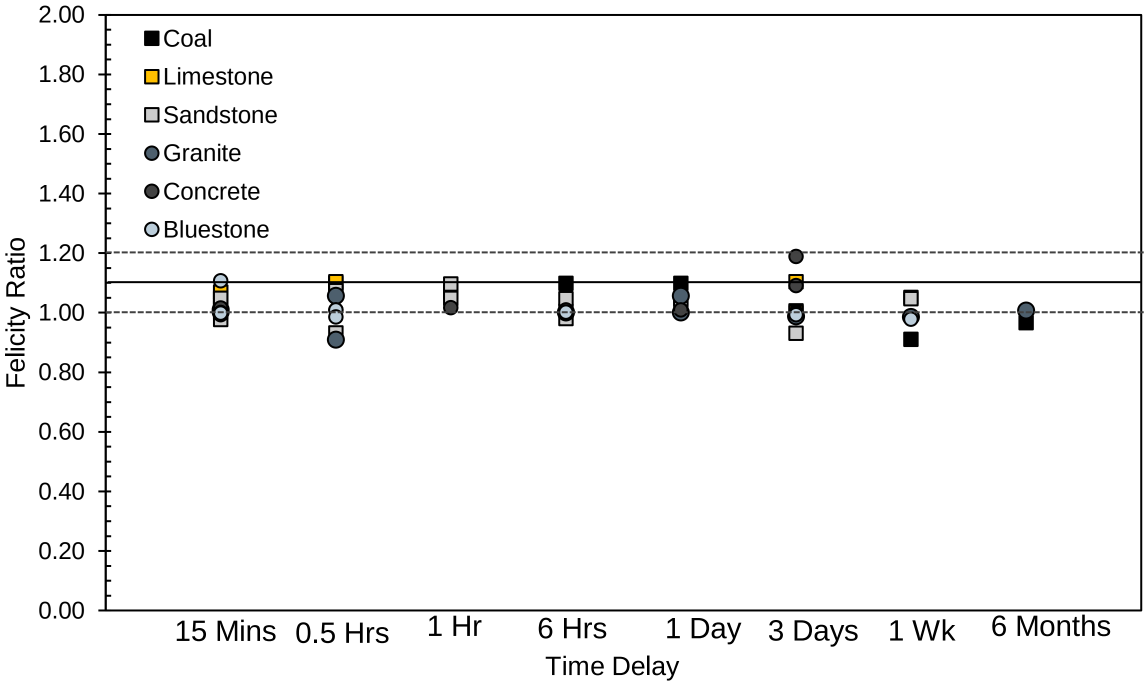


Effect of Loading Rate





Effect of Time Delay



Conclusion

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Inflection Point

A clear point of inflection was observed in both DRA and AE analysis precisely at the prestress levels when the specimens were loaded in the range of 40% to 80% of the rock UCS, below and above which the FR drops significantly.

Effect of Loading Rate

The Keff is not affected by the loading conditions, modes of loading, and the loading rates. However, at faster loading rates the bending point is more pronounced, and the FR is close to one.

Effect of Time Delay

Likewise, no time dependency of the Keff was observed for the time delays between 0.5 hr to 1 month.

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This presentation participates in OSPP

EGU

Outstanding Student Poster & PICO Contest

Thank You!

Any questions?

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References

1. Kang H, Zhang X, Si L, Wu Y, Gao F, (2010). In-situ stress measurements and stress distribution characteristics in underground coal mines in China. Engineering Geology, 116(3–4),333-345.
2. Brady B H G, Brown E T (1994). Rock Mechanics: For underground mining (Second edition. ed.). Dordrecht: Dordrecht: Springer Netherlands.
3. Fairhusrt, C. (2003). Stress estimation in rock: a brief history and review International Journal of Rock Mechanics & Mining Sciences, 40, 957–973 Gadde, M. (2003). Effect of in-situ stresses on the stability of coal mine development workings. In S. S. Peng (Ed.): ProQuest Dissertations Publishing.
4. Haimson B C, and Fairhurst C (1970). In situ stress determination at great depth by means of hydraulic fracturing. In Proc. 11th U.S. Nat Symp. on Rock Mechanics - Theory and Practice. 559-589. New York: Soc. Min. Eng of AIME.
5. Kaiser, E. J. (1953). A Study of Acoustic Phenomena in Tensile Test Technische Hochschule, München, Munich, 43.
6. Karakus, M., Perez, S., & D, G. (2015, April 14-17, 2015). In-situ Stress Measurement from Oriented Sub-cores Using Kaiser Effect. Paper presented at the 24th International Mining Congress and Exhibition of Turkey, Antalya, Turkey.
7. Lavrov, A. (2003). The Kaiser effect in rocks: principles and stress estimation techniques. International Journal of Rock Mechanics & Mining Sciences., 40, 151–171.
8. Rocscience (2022), 3D Modelling of underground excavation with EX3 and RS3. accessed 20 May 2022, https://www.rocscience.com/learning/3d-modelling-of-undergroud-excavations-with-ex3-and-rs3.
9. Seto, Utagawa, M., Katsuyama, K., & Kiyama, T. (1998). In Situ Stress determination using AE and DRA techniques. . International Journal of Rock Mechanics and Mining Sciences., 35(4-5), 458-459.
10. Villaescusa, E., Seto, M., Baird, G. (2002). Stress measurement from oriented core. Int J Rock Mech Min Sci; 39:603–15.
11. Windsor, C.R., Villaescusa, E., & Machuca, L.A. (2010). A Comparison of Rock Stresses Measured by WASM AE With Results from Other Techniques That Measure the Complete Rock Stress Tensor. International Symposium on In-Situ Rock Stress, International Society for Rock Mechanics and Rock Engineering,
12. Worotnicki G, and Walton R J (1976). Triaxial "Hollow Inclusion" gauges for determination of rock stresses in-situ. Proc. ISRM Symposium on Investigation of Stresses in Rock - Advances in Stress Measurement: 1-8. I.E. Aust., Nat. Conf. Pub. No.76/4.
13. Yamamoto, K., Kuwahara, Y., Kato, N., & Hirasawa, T. (1990). Deformation rate analysis: A new method for in situ stress estimation from inelastic deformation of rock samples under uniaxial compressions. Tohoku Geophys. J. (Sci. Rep. Tohoku Univ), 33(5), 127–147