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Effect of horizontal stress on shallow coalmine slopes

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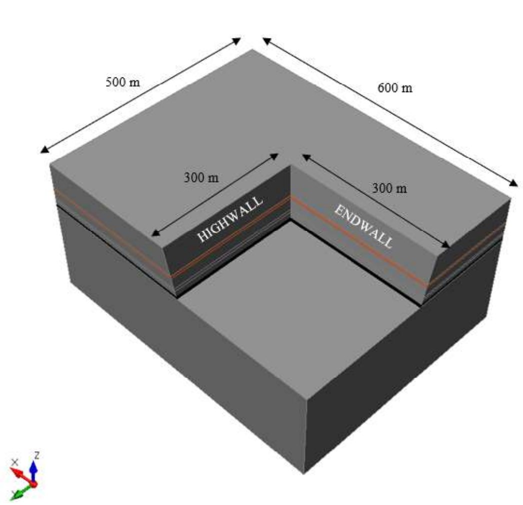
INTRODUCTION

This paper presents a parametric analysis showing the impact of virgin in situ stresses on a shallow (less than 100 to 150 m) high slope in a jointed sedimentary rock environment. Slope stability is assessed at varying ratios of slope orientation and horizontal stresses. The results of this study indicate stress conditions should be included in stability assessments of excavated slopes, particularly where structure is orientated perpendicular to the direction of horizontal stress.

Some consideration of stress state is applied in deep open cut pits (eg those with planned excavations of 400–1200 m) (Myrvang *et al,* 1993; Stacey *et al,* 2003; de Bruyn *et al,* 2014; Kozyrev *et al,* 2015). Dodd and Anderson (1972), Kalkani and Piteau (1976), Lee (1978), Coulthard *et al* (1992), Noorani *et al* (2011) have studied the effect or horizontal stress and its impact on slope stability, showing that tensile stresses tend to develop at the crest of the slope, with larger tensile zones for higher horizonal stresses and steeper slope angles (Stacey, 1970, 1973; Sjoberg, 2013). However, the consideration of virgin stresses on shallow slope stability is less frequent (Lynch *et al,* 2005; Dight, 2006; Lucas, 2006; Sjoberg, 2013). This has led many geotechnical engineers to believe the impact of virgin in situ stresses on open cut slope stability is minimal and not worth time or consideration in modelling, or their effects on slope stability are still poorly understood (Stacey *et al*, 2003; Sjoberg, 2013).

PARAMETRIC STUDY

The effect of horizontal stress on a shallow jointed coalmine slope was assessed using 3D finite element modelling (FEM), using RS3 code (Rocscience, Inc., 2021). Elastic analyses were run to determine the distribution of stresses at varying horizontal stresses. Jointed rock mass was simulated by applying anisotropy through ubiquitous joints. A consistent slope configuration of 75° slope batter and 100 m slope height was modelled, in a 90° highwall-endwall configuration, to show the stress distribution around the corners of typical open pit design configurations, Figure 1. A parametric study was then completed varying horizontal stress (K1) orientations, relative to the highwall orientation, to show the variance in tensile stress behind the excavated face. Horizontal stresses of K1 = 2 and K2 = 0.8 were applied to the models (after Mark and Gadde, 2010). Modelled scenarios are summarised in Table 1. A graded mesh (minimum mesh size of 5 m, maximum mesh size of 50 m) was applied to the model.



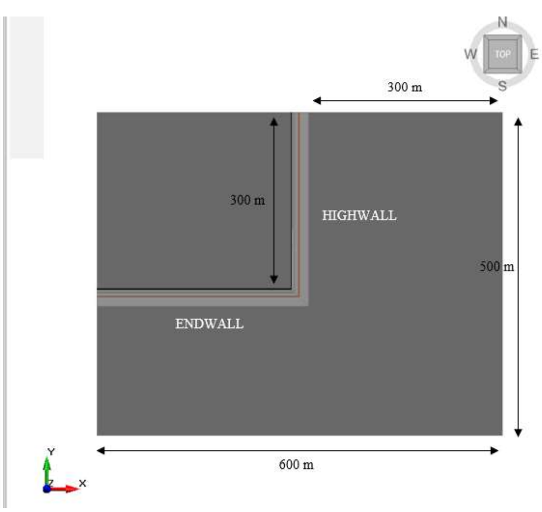


FIG 1 – Model dimensions. Oblique view (left); Plan view (right).

TABLE 1

Modelled scenarios.

Scenario	HW orientation (DDNº)	Joint condition	K1	K2	K1 Trend (°)
1	270º	Ubiquitous	2	0.8	90
2	270º	Ubiquitous	2	0.8	75
3	270º	Ubiquitous	2	0.8	60
4	270º	Ubiquitous	2	0.8	45
5	270º	Ubiquitous	2	0.8	30
6	270º	Ubiquitous	2	0.8	15

Material parameters applied to 3D models are summarised in Table 2. Ubiquitous joints were modelled with a trend of 0° and plunge of 90°. Applied Joint normal stiffness = 100 000 kPa, shear stiffness = 10 000 kPa.

TABLE 2

Material parameters.

Material	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (º)	Peak Tensile Strength (kPa)	Poisson's ratio	Young's modulus (MPa)
Jointed Fresh coal measure rock	24	200	35	0	0.4	4 000 000
Joints	24	2	12	0	-	-
Coal	15	35	30	1	0.25	3 500 000
Competent Sandstone	26	300	38	1	0.4	4 500 000

RESULTS

The parametric study shows that tensile stress is highest behind the highwall face when horizontal stress is perpendicular to joint orientation and highwall orientation; and tensile stresses are lowest when horizontal stress is nearing parallel to joint orientation, Figure 2.

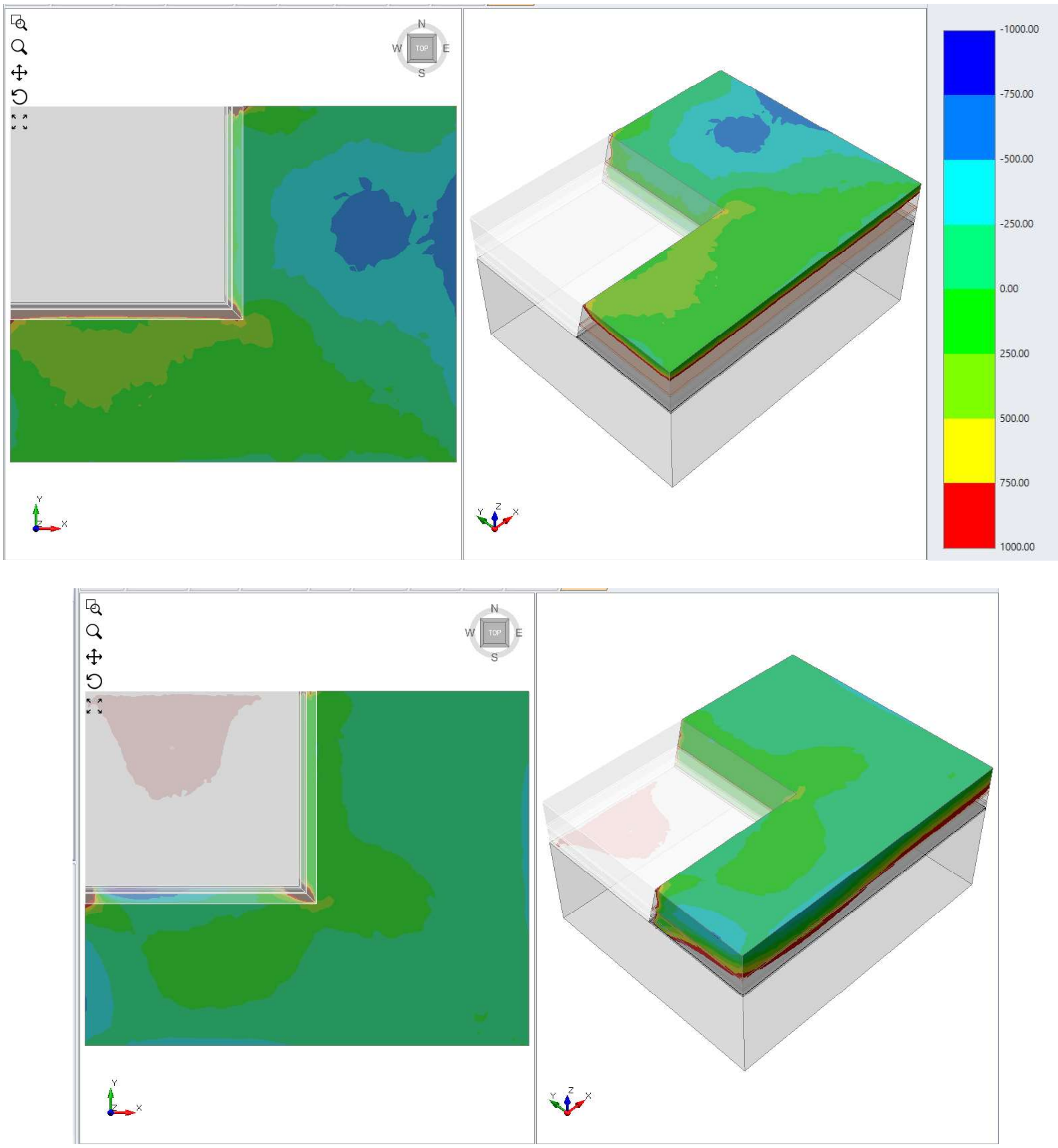


FIG 2 – Contours of SigmaXX Effective, showing modelled tensile stress. Top: K1 = 90° (ie horizontal stress is perpendicular to slope orientation). Plan view (top left), Oblique view (top right). Bottom: K1 = 15° (ie horizontal stress is near parallel to slope orientation). Plan view (bottom left), Oblique view (bottom right).

In all modelled K1 orientations, compressive stresses are higher at the toe of the slope compared to at the crest in both the highwall and endwall.

Results also indicate a compression zone in all scenarios at the intersection of the highwall and endwall. This stretch notch is observed to decrease as horizontal stress orientation nears parallel to joint orientation.

DISCUSSION

The results of this parametric study are in agreeance with other publications that analysed the effect of horizontal stresses on pit wall stability.

Kozyrev *et al* (2015) found that induced fracturing and dynamic rock pressure events in-pit slopes were governed by the slope orientation relative to the maximum compression orientation and that high compressive stresses heightened rock burst hazards.

Stacey *et al* (2003) reported that stresses at the toe of slopes were found to be concentrated and compressive. And for higher K ratios tensile stress zones develop in the crest of the slope. Stacey *et al* (2003) remarked that this tensile stress zone can be significant, and often tension cracks will develop behind the slope crest.

Resultant tension cracks forming in the extension zone may not only lead to an increase in susceptibility for toppling failure depending on joint orientations, but will also likely create zones of preferential groundwater pooling and surface water drainage that will be detrimental to slope stability.

CONCLUSIONS

This paper has provided several case studies to show that horizontal stresses can affect the stability of shallow (less than 100 to 150 m) coalmine slopes.

Cases show that tensile stress is highest behind the highwall face when horizontal stress is perpendicular to joint orientation and highwall orientation. High tensile stresses behind an excavated slope crest can accentuate the likelihood of slope failure along joints near parallel to the slope face.

Cases also show that compressive stresses are higher at the toe of the slope at varying K1 orientations. High compressive stresses may lead to floor heaving which may then trigger instability in the surrounding slopes.

Although difficult to modify slope designs once mining commences (eg due to economics of mining down dip), this study shows the importance of considering horizontal stresses on slope stability for shallow pit configurations traditionally not considered susceptible to failure by *in situ* stresses.

To adequately assess the impact of horizontal stresses 3D numerical analysis methods should be utilised in slope stability assessments.

REFERENCES

Coulthard, M, Journet, N and Swindells, C, 1992. Integration of stress analysis into mine excavation design, rock mechanics, In *Proceedings: 33rd US Symposium on Rock Mechanics*, New Mexico, pp. 451–460.

de Bruyn, I, Baczynski, N, Lee, M, Mills, K, Mylvaganam, J and Prado, D, 2014. The Application of Rock Stress Inputs to Stability Assessments at Ok Tedi Mine, Papua New Guinea, In *Proceedings: AusRock 2014: Third Australasian Ground Control in Mining Conference*, Melbourne.

Dight, P, 2006. Pit wall failures on 'unknown structures, *J Sth Afr Inst Min Metall*, 106:451–458.

Dodd, J and Anderson, H, 1972. Tectonic stresses and rock slope stability, In *Proceedings: Thirteenth Symposium on Rock Mechanics*, New York, pp. 171–182.

Kalkani, E and Piteau, D, 1976. Finite element analysis of topping failure at Hell's Gate Bluffs, British Columbia, *Bull Ass Engineering Geology*, 13(4):315–327.

Kozyrev, A, Semenova, I, Rybin, V and Avetisyan, M, 2015. Stress redistribution in deep open pit mine Zhelezny at Kovdor iron ore deposit, *Journal of Mining Science*, 51(4):659–665.

Lee, C, 1978. Stress relief and cliff stability at a power station near Niagara Falls, *Engineering Geology*, 12:193–204.

Lucas, D, 2006. Stress failure of a shallow open cut mine, Australian Centre for Geomechanics, December Newsletter, pp. 4–6.

Lynch, R, Wuite, R, Smith, B and Cichowicz, A, 2005. Microseismic Monitoring of Open Pit Slopes, In: *Proceedings of the Sixth International Symposium on Rockburst and Seismicity in Mines*, Australian Centre for Geomechanics, Perth, pp. 581–592.

Mark, C and Gadde, M, 2010. Global trends in coal mine horizontal stress measurements, In *Proceedings: Coal Operators' Conference*, Wollongong, pp. 21–39.

Myrvang, A, Handsen, S and Sörensen, T, 1993. Rock stress redistribution around an open pit mine in hardrock, *Int J Rock Mech Min Sci & Geomech Abstr*, 30(7):1001–1004.

Noorani, R, Ahangari, K and Aloodari, S, 2011. The influence of horizontal stress on the failure mechanism and slope stability in Chador-Malu Iron Open Pit Mine, In *Proceedings: International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering (Slope Stability 2011)*, Vancouver.

Rocscience, Inc., 2021. https://www.rocscience.com/support/rs3/release-notes

Sjoberg, J, 2013. Numerical analysis, slope design and in situ stress, In *Proceedings: Slope Stability 2013*, Perth, pp. 29–42.

Stacey, T, 1970. The stresses surrounding open pit mine slopes, In *Planning Open Pit Mines*, P W J van Rensburg (ed), A.A. Balkema, pp. 199–207.

Stacey, T, 1973. A three-dimensional consideration of the stresses surrounding open pit mine slopes, *International Journal of Rock Mechanics and Mining Sciences*, 10:523–533.

Stacey, T, Xianbin, Y, Armstrong, R and Keyter, G, 2003. New slope stability considerations for deep open pit mines*, The Journal of The South African Institute of Mining and Metallurgy*, 103(6):373–390.