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An analysis of the stress distribution and evolution in backfilled stopes and on barricades

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ABSTRACT

In mining industry, cemented paste backfill (CPB) is a popular technique of mine voids (called "stopes") backfilling. This backfill is characterised by high content of fine particles and low hydraulic conductivity. During the deposition of CPB, self-weight consolidation takes place with generation of excess pore-water pressure in the backfill. When the pressure is excessively high, the barricade constructed at the base of the stope to retain the CPB in place may become instable. In fact, several cases of barricade failure have been reported in the literature. Therefore, it is a key issue to have a good assessment of the pore-water pressure and stresses in the backfilled stope and on the barricade to ensure a successful and economical application of the CPB. This is however complex because of the drainage and consolidation as well as the hydration of the CPB. The pressures in the backfilled stopes and on barricades can thus be influenced by several factors such as the hydro-geotechnical properties of the backfill, backfilling rate, stope geometry, and efficiency of the drainage system through the barricade. In this paper, the influence of these influencing factors on the stress distribution and evolution in backfilled stopes and on barricade investigated through numerical modeling will be presented and discussed.

1. INTRODUCTION

Every year, the mining industry produces a large amount of tailings that requires proper management. Among the numerous methods available, the use of part of the

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tailings as fill material to fill underground voids has become a common practice in underground mines worldwide. This practice reduces the amount of mine wastes disposed on ground surface. It can be considered as environment friendly solution of mine waste management (Aubertin et al. 2002; Benzaazoua et al. 2008). Other benefits from the mine backfill include an improved ground stability, a reduced ground subsidence associated with the underground mining activities, an increased ore recovery rate, a reduced ore dilution, and an improved energy efficiency of ventilation system (e.g., Darling 2011).

Over the years, a large number of works have been published on stress estimation in backfilled stopes through analytical (Askew et al. 1978; Aubertin et al. 2003; Li et al. 2005; Pirapakaran and Sivakugan 2007a; Li and Aubertin 2008, 2009a, 2009b, 2010; Ting et al. 2011, 2012), experimental (Knutsson 1981; Belem et al. 2004; Pirapakaran and Sivakugan 2007a; Ting et al. 2012; Thompson et al. 2012; Doherty et al. 2015) and numerical (Aubertin et al. 2003; Li et al. 2003, 2007, 2010; Li and Aubertin 2009b; Falaknaz et al. 2015a, 2015b, 2015c) investigations. The stress distribution on barricades in drift has also be analysed by Li and Aubertin (2009d, 2009e).

It is noted that all these works focused on the stress distribution within backfilled stopes associated with the occurrence of arching effect. The drainage and consolidation of the backfill were not considered. Recently, the influence of drainage and consolidation of backfill on the pressure in backfilled stopes has been investigated by El Mkadmi et al. (2014). This work projected an insight on the significant influence of the filling rate on the maximum stresses within the stopes. However, it is noted that the models of El Mkadmi et al. (2014) remain relatively simple. For instance, their models considered only one draining point at the base of the draw-point or a draining line along the base of the stope. The height and the reduced cross section of the drifts as well as the position of the barricade were not taken into account.

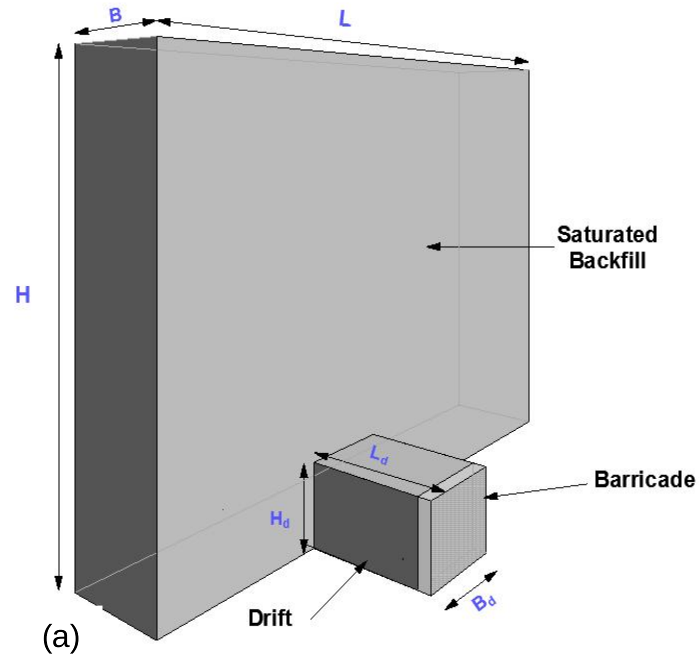
In this paper, the stresses and pore water pressures in backfilled stope and on barricades will be analyzed by numerical modeling after taking into account more realistic stope and drift geometries, backfill properties, filling rate and hydraulic boundary conditions.

2. NUMERICAL MODELS

The SIGMA/W 2D (plane strain) finite element program (Geo-Slope 2007) has been used to analyze the hydro-geotechnical response of cemented paste backfill progressively deposited in the stope.

Figure 1a schematically shows a backfilled stope with a barricade in the drift. The stope has a width of B, a length of L. It is backfilled to a height of H by the progressive deposition of the cemented paste backfill. The drift has a width of B_d and a height of H_d.

The barricade having the same width and height as the drift is positioned at a distance of L_d from the draw-point (stope entrance).



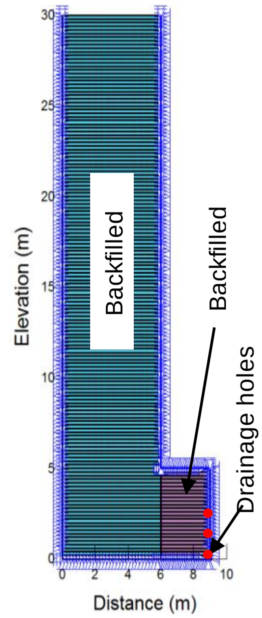


Fig. 1 A typical vertical backfilled stope with a barricade in the drift (adapted from Li and Aubertin 2009b): (a) physical model; (b) numerical model built with SIGMA/W.

Table 1 presents the programme of numerical simulations performed for analyzing the influence of the several parameters on the stress and pressure evolution in the stope and on barricade. Along the height of the barricade, three draining holes were considered.

Table 1 Program of numerical simulations and the various parameters used in the numerical simulations (with B = 6 m, L = 20 m, H = 30 m, B_d = 5 m, H_d = 5 m, L_d = 3 m, γ_{sat} = 20 kN/m^3, ϕ' = 30, μ = 0.333, E = 10 MPa)

Cases	k_{sat} (m/s)		Filling rate (m/h)
	stope	Drift	
1	variable	variable	0.3
2	10^{-7}	2.5×10^{-8}	Variable

3. NUMERICAL RESULTS

The evolution of the pore water pressure and total stresses in the stope and drift has been presented previously for the reference case. Below, the influence of influencing factors on the stresses and pressure on the barricade is presented. These include the position of the barricade (L_d), stope width (B), filling rate (v), the hydraulic conductivity k_{sat}, internal friction angle ϕ' and Young's modulus E of the backfill, and the number of draining holes (n_d). The details of these case studies are given in Table 1.

Figure 2 shows the variation of the pore water pressure (Fig. 2a) and horizontal total stress (Fig. 2b) on the barricade at mid-height elevation, starting from the beginning of the stope filling operation when the hydraulic conductivity of the backfill increases from 10^{-8} to 10^{-5} m/s. One sees that the hydraulic conductivity of the backfill plays a key role in the pore water pressure and total stresses. With cemented paste fill having a hydraulic conductivity typically between 10^{-8} and 10^{-7} m/s, the peak pore water pressure can vary between 357 and 510 kPa, while the peak values of the horizontal stress change between 480 and 544 kPa. With a backfill similar to hydraulic backfill that has a hydraulic conductivity typically between 10^{-5} m/s and 10^{-6} m/s, the peak pore water pressure drops dramatically to some values between 21 and 156 kPa, while the peak values of the horizontal stress change between 102 and 290 kPa.. These results demonstrate that the hydraulic fill is less dangerous than the paste fill in terms of pressure on barricade at the same height.

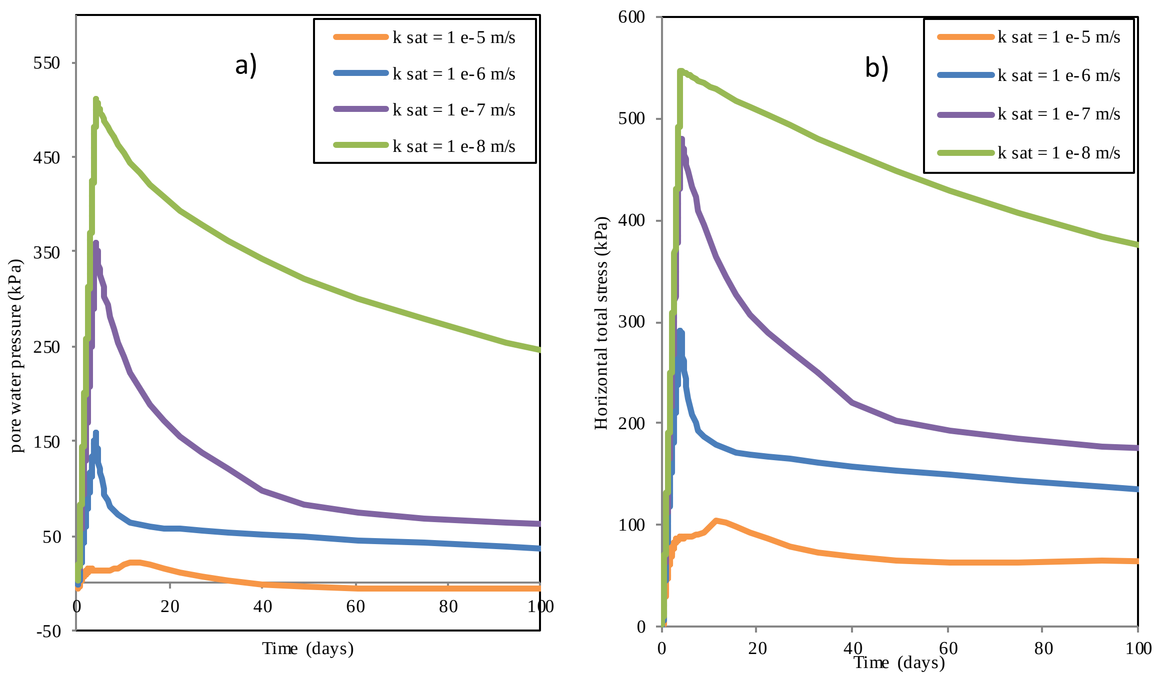


Fig. 2 Evolution of the pore water pressure (a) and horizontal total stress (b) on the barricade at the mid-height elevation with different hydraulic conductivity of backfill (details given in Table 1, case 1).

Figure 3 shows the variation of the pore water pressure (Fig. 3a) and horizontal total stress (Fig. 3b) on the barricade at mid-height elevation, with time starting from the beginning of the stope filling operation when the filling rate changes from 0.1 to 1 m/h. These results indicate that higher peak stress and pore water pressure should be expected with fast filling. The peak stress and pore water pressure can be reduced by slow downing the stope filling. These results confirm the results presented by El Mkadmi et al. (2014).

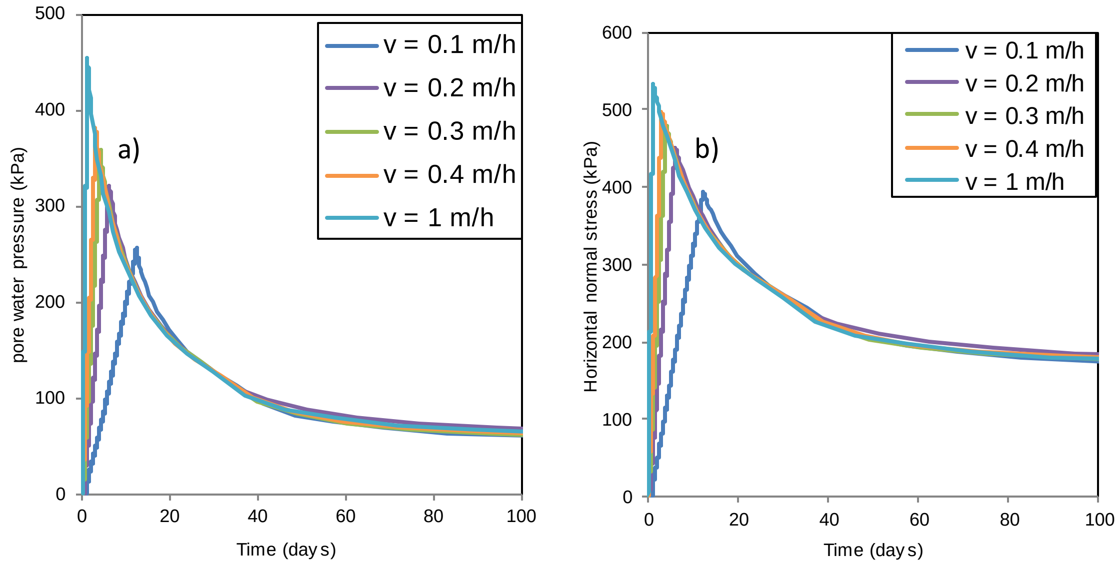


Fig. 3 Evolution of the pore water pressure (a) and horizontal total stress (b) on the barricade at the mid-height elevation with different filling rates (details given in Table 1, case 2).

4. DISCUSSION

The numerical results shown above indicate that the numerical modeling is an effective mean to analyse the hydro-geotechnical behavior of the backfill. However, one should keep in mind that the models used are 2D (plane strain). The effect of the third dimension has been neglected. The hydraulic conductivity of the drift backfill has been reduced by considering its value being proportional to the ratio between the stope length and drift width. In the future, these three dimensional problems should be treated by 3D numerical models with 3D numerical codes.

Another limitation of the numerical models is associated with the neglecting of the backfill properties evolution related to the cement hydration. The investigation of the stresses and pore water pressure in backfilled stopes and on barricade by considering the properties evolution with time is ongoing and can be part of future publications.

5. CONCLUSION

A number of numerical simulations have been performed. A part of the results has been presented here. The results indicate that higher peak stress and pore water pressure should be expected with fast backfill filling operation. In addition, the hydraulic conductivity of the backfill influences significantly the total stresses and pore water pressures on the barricade. In general, the peak total stress and pore water pressure increase as the hydraulic conductivity of the backfill decreases. The application of cemented paste fill can result in significantly higher peak pore water pressure and total stress than hydraulic backfill. This conclusion does not correspond to the common point view of many practitioners who usually estimate higher pressure based on the observation of abundant free water drainage with hydraulic fill.

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References

Askew J., McCarthy P.L., Fitzgerald D.J. (1978), “Backfill research for pillar extraction at ZC/NBHC,“ In: Mining with back- fill: *12 canadian rock mechanics symposium*, 23–25 May 1978, Sudbury. CIM pp 100–110

Aubertin, M., Bussière, B., and Bernier, L., (2002), “Environnement et gestion des rejets miniers,“ *Les Presses Internationales de Polytechnique*, Montreal, Que.

Aubertin, M., Li, L., Arnoldi, S., Belem, T., Bussière, B., Benzaazoua, M., and Simon, R. (2003), “Interaction between backfill and rock mass in narrow stopes,“ In Soil and Rock America, **1**, 1157–1164.

Belem, T., Harvey, A., Simon, R., Aubertin, M., (2004), “Measurement of internal pressures of a gold mine pastefill during and after the stope backfilling, “. *Proc. 5th International Symp. On Ground support in mining and underground construction*, 28-30 September 2004, Perth, Western Australia Benzaazoua, M., Bussière, B., Demers, I., Aubertin, M., Fried, E., Blier, A., (2008), “ Integrated mine tailings management by combining environmental desulphurization and cemented paste backfill: application to mine Doyon, Quebec, “ *Canada. Miner. Eng.* **21** (4), 330e340.

Darling, P., (2011). “SME Mining Engineering Handbook,“ *Third Edition*. SME.

Doherty, J.P., Hasan, A., Suazo, G.H., Fourie, A., (2015), "Investigation of some controllable factors that impact the stress state in cemented paste backfill," *Canadian Geotechnical Journal,* **52**(12): 1901-1912.

El Mkadmi N, Aubertin M, Li L., (2014), "Effect of drainage and sequential filling on the behavior of backfill in mine stopes," *Can. Geotech. J*. **51**(1):1–15

Falaknaz, N., Aubertin, M., Li, L., (2015a), "Evaluation of the stress state in two adjacent backfilled stopes within an elasto-plastic rock mass, " *Geotechnical and Geological Engineering*, 24 pages. DOI : 10.1007/s10706-015-9868-6

Falaknaz, N., Aubertin, M., Li, L., (2015b), "Numerical analyses of the stress state in two neighboring stopes excavated and backfilled in sequence," *International Journal of Geomechanics*, **15**(6), 17 pages. DOI : 10.1061/(ASCE)GM.1943-5622.0000466

Falaknaz, N., Aubertin, M., Li, L., (2015c), "Numerical investigation of the geomechanical response of adjacent backfilled stopes, "*Canadian Geotechnical Journal*, **52**(10), p. 1507-1525. DOI : 10.1139/cgj-2014-0056

Geo-Slope, (2008), "Stress-deformation modeling with SIGMA/W 2007," *3rd ed. GEO-SLOPE International Ltd.*

Li L, Aubertin M., (2008), "An improved analytical solution to estimate the stress state in sub-vertical backfilled stopes, " *Can. Geotech. J.* **45**(10):1487–1496. doi:10.1139/T08-060Li, L., and Aubertin, M., (2009a), "A three-dimensional analysis of the total and effective stresses in submerged backfilled stopes,"*Geotechnical and Geological Engineering*, **27**: 559–569. doi:10.1007/s10706-009-9257-0.

Li, L., and Aubertin, M., (2009*b)*, "Numerical investigation of the stress state in inclined backfilled stopes," *International Journal of Geomechanics,* **9**(2): 52– 62. doi:10.1061/(ASCE)1532-3641(2009)9:2(52).

Li, L., Aubertin, M., (2009c), "Horizontal pressure on barricades for backfilled stopes," Part I: Fully drained conditions. *Canadian Geotechnical Journal* **46**(1): 37-46.

Li, L., Aubertin, M., (2009d) "Horizontal pressure on barricades for backfilled stopes," Part II: Submerged conditions. *Canadian Geotechnical Journal* **46**(1): 47-56.

Li, L., and Aubertin, M., (2010), "An analytical solution for the nonlinear distribution of effective and total stresses in vertical backfilled stopes," *Geomechanics and Geoengineering*, **5**(4): 237–245.

Li L, Aubertin M., Shirazi A., Belem T., Simon, R. (2007), "Stress distribution in inclined backfilled stopes, " In: *Proceedings of the 9th international symposium in mining with backfill* (on CD-ROM), 29 April–2 May 2007, Montreal. *CIM*

Li, L., Aubertin, M., Simon, R., Bussière, B., and Belem, T., (2003), "Modeling arching effects in narrow backfilled stopes with FLAC," *In FLAC and numerical modeling in geomechanics*. A.A. Balkema, Rotterdam, the Netherlands. pp. 211–219.

Li, L., Aubertin, M., and Belem, T., (2005), "Formulation of a three dimensional analytical solution to evaluate stresses in backfilled vertical narrow openings," *Canadian Geotechnical Journal*, **42**(6): 1705–1717. doi:10.1139/t05-084.

Li, L., Aubertin, M., and Shirazi, A., (2010), "Implementation and application of a new elastoplastic model based on a multiaxial criterion to assess the stress state near underground openings,“ *International Journal of Geomechanics*, **10**(1): 13–21. doi:10.1061/(ASCE)1532-3641(2010)10:1(13).

Pirapakaran, K., and Sivakugan, N., (2007a), “*A laboratory model to study arching within a hydraulic fill stope,* “ *Geotechnical Testing Journal*, **30** (6). pp. 496-503.

Pirapakaran, K., and Sivakugan, N., (2007b), “Arching within hydraulic fill stopes, “ *Geotechnical and Geological Engineering*, **25** (1). pp. 25-35

Thompson, B.D., Bawden, W.F., and Grabinsky, M.W., (2012), “In situ measurements of cemented paste backfill at the Cayeli Mine,“ *Canadian Geotechnical Journal*, **49**(7): 755–772. doi:10.1139/t2012-040

Ting, C.H., Shukla, S.K. and Sivakugan, N.. (2011), “Arching in soils applied to inclined mine stopes, “ *Int. J. Geomech.* **11**(1): 29-35.

Ting, C.H., Shukla, S.K. and Sivakugan, N.. (2012),. “Laboratory simulation of the stresses within inclined stopes, “ *Geotechnical Testing Journal*, **35** (2) (2012), pp. 280–294