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# Development of roadway through backfilled stope for underhand mining: a case study

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## Abstract

In underground mines, roadways are developed through rock mass for approaching to the ore body. In conventional metal mining methods, crown and sill pillars are left for support of upper and lower levels. These pillars contain valuable high-grade minerals which may be permanently lost, if not extracted. In underhand mining, there is no need to leave crown and sill pillars since the stoping is done using top-down sequence by paste backfilling of extracted stopes. The underhand mining method is performed at Sindesar Khurd Mine, India. In this method, roadways need to be developed through cemented paste fill (CPF) for the extraction of underlying stopes. Backfilling process is done in two stages, initially a plug pour (10% Cement) of 9 m height followed by bulk fill (4% Cement). In this study, physio-mechanical properties of Plug fill and Bulk fill are determined in laboratory. Further, numerical modelling was carried out using FLAC 3D software to simulate the development of 4.8 m x 4.8 m roadway through the plug fill for to analyse the stability of the roadway. The stope dimensions of 20 m width, 25 m length, 25 m height, and 800 m depth are numerically modelled. Mohr coulomb failure criterion is used for elasto-plastic analysis. The results show that roadway is safe to use if, CPF has internal angle of friction of 30 deg and cohesion of 150 kPa and 50 kPa for plug fill and bulk fill, respectively. These properties provide the minimum yielding height of 0.25 m in the roof. Further, shotcrete lining of 100 mm thickness and M35 grade provides yielding height to negligible value. In essence, this study provides the minimum required cohesion and internal angle of friction for CPF, if roadway it to be development in underhand mining method.

## Keywords

CPF (Cemented paste fill), Plug fill, Bulk fill, underhand mining

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# 1 Introduction

In deep metal mines the mining sequence carried out is underhand top-down sequence where it makes the mining more economical and stable due to the more ore recovery and provision of supports using paste filling of void stopes. While working at greater depth using overhand (down to top) mining sequence which requires leaving significant quantity of ore in crown and sill pillars. During stope extraction at failure along hanging wall and crown is the most common problem. To mitigate such problems adopting underhand mining below cemented paste filling (CPF) is one of the suitable methods. The paste fill mining is mainly adopted for the recovering ore from the stopes left for the supporting (Li et al., 2011; Sobhi & Li, 2017). In this process paste backfill is placed into voids of previously extracted stopes which provides supporting for the extraction of secondary stopes and the walls of the stopes subjected to confinement due to the backfill, which does not allow the collapsing of walls and roof thereby providing the overall stability and subsidence control (Brady & Brown, 2006; Dirige et al., 2009). It provides ground support to pillars and walls, additionally It also helps in preventing caving and roof falls and enhances pillar recovery thereby improving productivity (Coates, 1981; Mitchell, 1989). Strength of the CPF is dependent on curing time, cement content and material properties (Yang et al., 2017). However, paste backfilling is not economical for the small-scale mining industries in such scenario adopting the cemented paste fill (CPF) should be considered accordingly with respect to the mine. while performing this process there are instances that requires redevelopment of cured paste fill (Andrieux et al., 2003; Soni & Ripepi, 2019) for accessing the ore body. It is necessary to understand the stability of roadway for the safety of men and machinery working under the paste fill (Belem & Benzaazoua, 2008; Sivakugan et al., 2015).

As per literature, limited research has been done for development in paste mass. Most of studies have been done in narrow vein and small level interval stopes (cut and fill) using conventional support methods like Sill mate support. Owing to the above limitations, in this paper numerical study is done to determine the strength parameters of paste mass which is required for development in cemented paste fill. Further, numerical models with shotcrete lining are also analysed to assess safe development condition on CPF.

## 1.1 Underhand mining using CPF

Underhand mining is used to extract ore in deep high stress mines, allowing mines to manage the stress and minimise development in weak damaged rock masses. In underhand mining, there is no need to leave crown and sill pillar since the stoping is done using top-down sequence by paste backfilling of extracted stopes. Currently, the underhand mining method is performed at one of the metal mines in northern part of Rajasthan. Sindesar Khurd Mine, India. In this method, roadways need to be developed through cemented paste fill (CPF) for the extraction of underlying stopes. The Backfilling process is done in two stages, initially a plug pours of 9 m height with 10 % OPC followed by bulk fill of less binder content 4 % OPC. Fig. 1a shows involves the redevelopment of a drill level inside the plug of the overlying stope which has been previously extracted and backfilled. The redevelopment of roadways through the paste fill is done for ore recovery from the stopes below the paste fill so that the roadway can be utilised for drilling and blasting the underlaying stope Tell-tale is installed to measured paste mass roof deformation in the drill level. This drill level is used for production drilling and charging in the ore body (Fig. 1b) while extraction level is used for ore mucking (Fig. 1c). Finally, stope is backfilled with cemented paste fill (Fig. 1d).

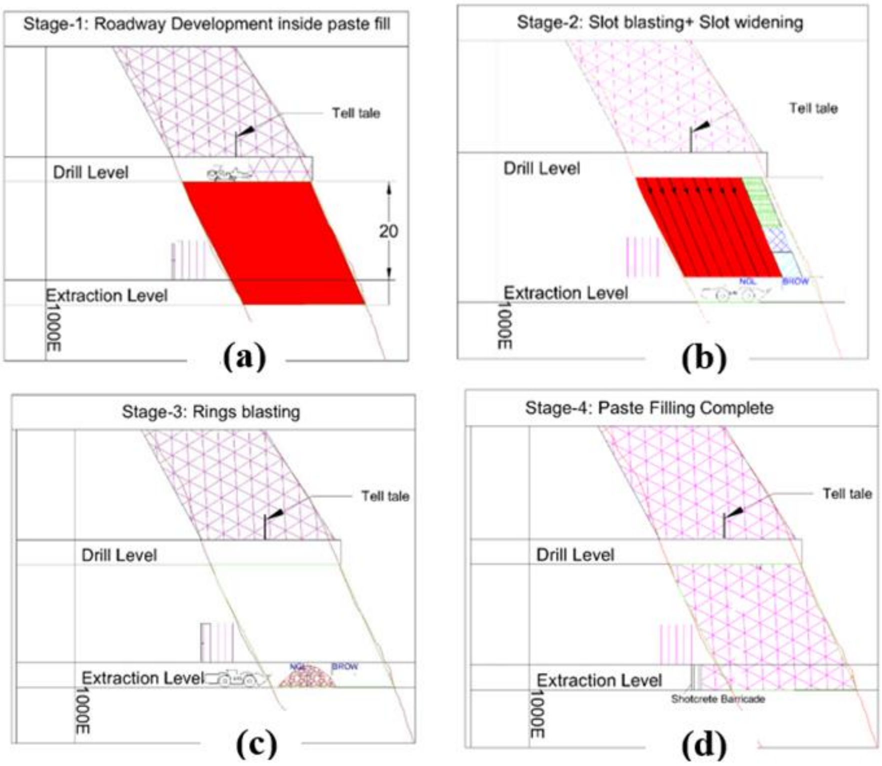


Fig. 1 Underhand mining using paste back fill (a) redevelopment of a drill level in paste mass (b) drill level used for production drilling and charging (c) extraction level used for ore mucking (d) stope is backfilled with cemented paste fill

## 1.2 Properties of Cemented Paste Fill and rock

The mechanical properties of CPF casted samples (plug fill and bulk fill) are determined at different curing durations like 24 hours, 72 hours, 7 days, 14 days, 28 days, and 35 days. The tests are performed as per ISRM suggested methods and properties are shown in Table 1. These results are used for performing elasto-plastic analysis in numerical modelling using FLAC 3D. The mechanical properties of host rock and surrounding rock also determined, and its values shown in

Table 2.

Table 1 Properties of Plug fill and bulk fill

| **Material Property** | **CPF type** | **Curing time** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **24 hrs** | **48 hrs** | **7 days** | **14 days** | **28 days** | **35 days** |
| Density ($Kg/m^3$) | Plug fill 10% OPC<br>Bulk fill 4 % OPC | 2010 to 2070 | | | | | |
| Cohesion (kPa) | Plug fill 10% OPC | 74.38 | 98.54 | 151.72 | 289.62 | 349.44 | 492.67 |
| | Bulk fill 4 % OPC | 25.04 | 35.19 | 51.26 | 81.36 | 124.73 | 160.56 |
| Friction Angle (Deg.) | Plug fill 10% OPC<br>Bulk fill 4 % OPC | 29 to 31 | | | | | |
| Tensile strength (kPa) | Plug fill (Kpa) 10% OPC | 37.51 | 50.03 | 74.83 | 144.46 | 176.38 | 245.47 |
| | Bulk fill (Kpa) 4% OPC | 12.57 | 17.56 | 25.04 | 40.94 | 62.52 | 80.61 |

Table 2 Properties of rock mass

| Rock Type | Density (Dry) (kg/m3) | Uniaxial Compressive Strength (MPa) | Tensile Strength (MPa) | Young's Modulus (Average) (GPa) | Cohesion (MPa) | Friction Angle (Degree) | Poisson's Ratio |
|---|---|---|---|---|---|---|---|
| Ore (Dolomite) | 2877 | 89 | 7.72 | 14.41 | 4.17 | 33.23 | 0.214 |
| Hanging wall (Quartz mica schist) | 1854 | 95 | 8.86 | 17.81 | 5.27 | 36 | 0.223 |
| Foot wall (Biotite schist) | 1870 | 79 | 5.22 | 11.89 | 3.4 | 35.65 | 0.227 |

## 2 Numerical modelling

Numerical modelling was carried out using FLAC 3D software to simulate development of roadway (4.8 m x 4.8 m) inside the paste mass. In modelling, the stope dimensions of 20 m width, 25 m length, 25 m height, and 800 m depth are used. The Mohr coulomb failure criterion is used for elasto-plastic analysis.

The modelling procedure was done in 5 stages in which the initial stage involves the generation of grid based on the stope dimensions and mining boundaries as shown in Fig. 2. In 2nd stage, boundary conditions are fixed and in-situ stresses has been applied. The model is solved in the elastic condition. In 3rd stage, the rock mass was solved by excavating the respective stope for elasto-plastic analysis. After that, the excavated rock mass was backfilled with plug fill to 9 m and rest with bulk fill assigning physico-mechanical properties are given in Table 1. After the backfilling of stope, the development of roadway through the plug fill is simulated and analysed for the stable condition at which the roadway can be utilised safely for the mining of below stopes. Further, numerical analysis was done for the roadway with M35 grade fibre reinforced shotcrete lining of 100 mm thickness.

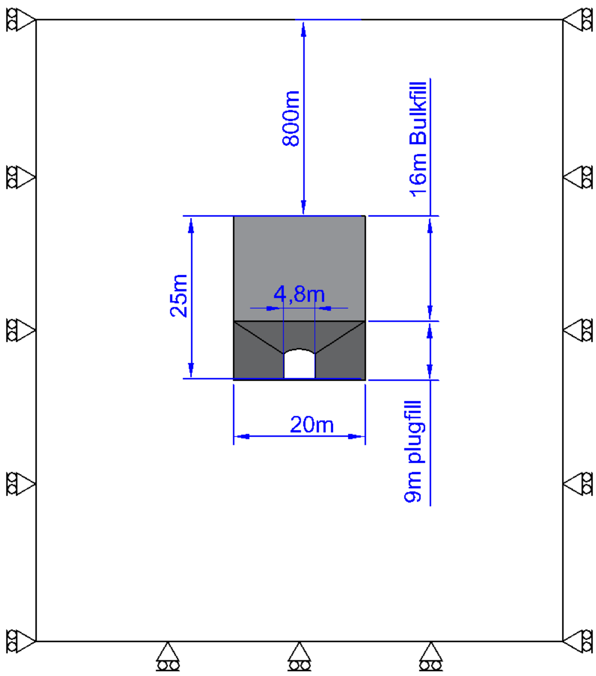

Fig. 2 Model dimensions and boundary conditions

## 3 Results and discussion

The numerical simulations results are analysed for two cases, Case 1: Stability of roadway within CPF without shotcrete lining and Case 2: Stability of roadway within CPF with shotcrete lining.

### 3.1 Case 1: Stability of roadway within CPF without shotcrete lining

The yielding of CPF roof is analysed at different combinations of cohesion for plug and bulk fill (Fig. 3). It is observed that some portion of zones in the backfill are under yielding comprising of both shearing and tension. The stable roadway condition is obtained for plug fill cohesion of 150 kPa and bulk fill cohesion of 50 kPa. A line A-A' is drawn just above the drive roof and B-B' at centre of drive as shown in Fig. 3. Profile of maximum and minimum principal stress along with line A-A' and B-B' are shown in Fig. 4 and Fig. 5, respectively.

In Fig. 4, it is observed that at 0 m there is paste to rock interface so the value of maximum principal stress increases due to stope wall confinement. At 5-6 m stress are decreasing since paste-to-paste interactions and further increases near the excavation due to stress concentration on side wall. The principal stress approaches to maximum at mid of the drive representing the tensile stresses in roof. Same phenomena observed along line B-B' but, at the centre principal stresses are zero due to there is no paste mass. It is also observed that minimum principal stresses along line A-A' and B-B' following the same trends as of maximum principal stresses.

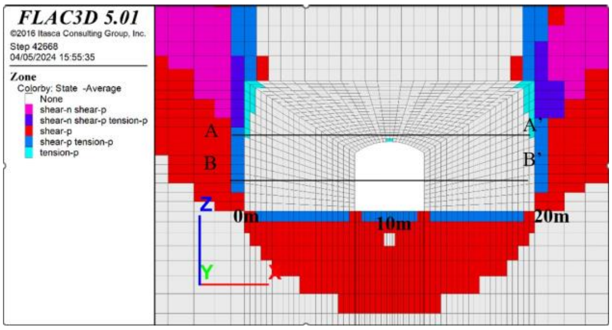


Fig. 3 Yielding in roadway roof with 150 kPa plug fill cohesion and 50 kPa bulk fill cohesion

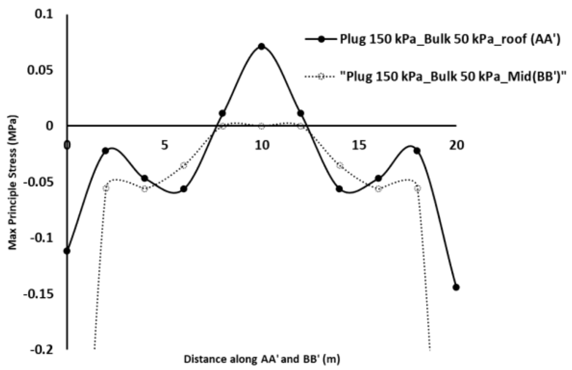


Fig. 4 Profile of maximum principal stress along line A-A' and B-B'

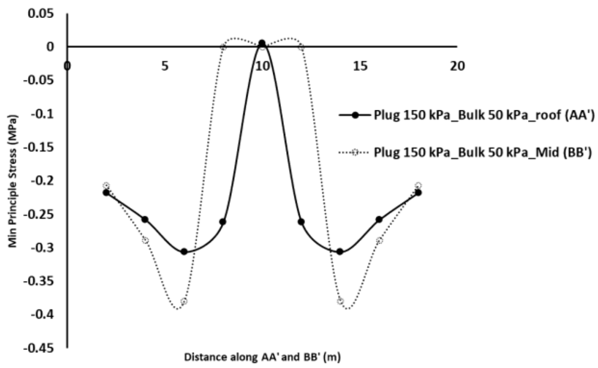


Fig. 5 Profile of minimum principal stress along line A-A' and B-B'

### 3.2 Case 2: Stability of roadway within CPF with shotcrete lining

After the development of the roadway inside paste, shotcrete lining of 50 mm thickness with wire mesh and followed by another 50 mm coat of shotcrete lining is done. Sprayed shotcrete in the roof must support its own weight within minutes of being applied to the roof. The minimum UCS required for shotcrete to support its own weight is typically 0.4MPa. As manpower and machinery safety is involved, 1 MPa considered safe for re-entry of manpower and machinery in the stope. It is observed that M35 grade fibre reinforced shotcrete reaches 1 MPa strength in one hour. Therefore, followings properties of M35 shotcrete grout taken in modelling as shown in Table 3.

Table 3 M35 Shotcrete grout properties for one hour curing time

| **Property of M35 Shotcrete** | **Friction Angle (Deg.)** | **Cohesion (MPa)** | **Density ($Kg/m^3$)** | **Tensile strength (MPa)** |
|---|---|---|---|---|
| | 25 | 0.35 | 2539 | 0.35 |

The shotcrete lining develops the internal pressure over the CPF roadway which prevents the deformation of roof and reduction in percentage yielding. With increased cohesion of plug fill and bulk fill, the yielding height in roof is observed for case 1 and case 2 and the results are shown in Table 4. It is observed that at higher cohesion values (150 kPa plug fill cohesion and 50 kPa bulk fill cohesion) with shotcrete lining the yielding height significantly reduces to zero (Fig. 6). The percentage yielding in CPF is calculated using the ratio of no of zones under plasticity and total volume of CPF. The percentage yielding of CPF for with and without shotcrete condition are shown in Fig. 7 which shows that the use of shotcrete reduces the yielding percent across all values of plug fill cohesion and the reduction is more significant at lower cohesion values (75 – 150 KPa).

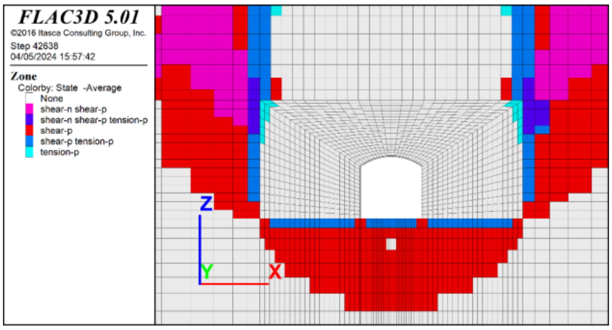


Fig. 6 Yielding in roadway roof with 150 kPa plug fill cohesion and 50 kPa bulk fill cohesion after shotcrete

Table 4 Height of yielding zone in roof

| **Cohesion (MPa)** | | **Height of yielding zone in Roof (m)** | |
|---|---|---|---|
| **Plug fill** | **Bulk fill** | **Without Shotcrete** | **With Shotcrete** |
| 75 | 25 | 2.5 | 2 |
| 100 | 35 | 2 | 1.2 |
| 150 | 50 | 0.2 | 0 |
| 290 | 80 | 0 | 0 |

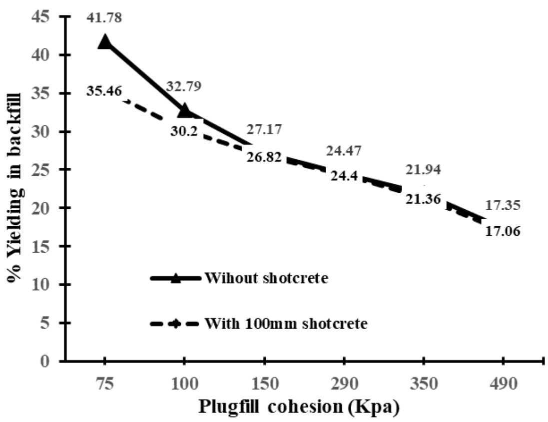


Fig. 7 Percentage yielding of CPF after roadway development

# 4 Conclusion

This study focused on the development of roadway through the paste backfilled stopes in underhand mining. The mechanical properties of CPF casted samples (plug fill and bulk fill) are determine in laboratory and development of roadway (4.8 m x 4.8 m) inside the paste mass is numerical simulated in FLAC 3D. The numerical simulation results show that roadway is safe to use if, CPF has internal angle of friction of 30 deg and cohesion of 150 kPa and 50 kPa for plug fill and bulk fill, respectively. Further, in numerical models, shotcrete lining of 100 mm thickness and M35 grade is used which shows that yielding zone become negligible. This situation provides stable and safe working conditions for development through the CPF. In essence, this study also offers minimum requirement of cohesion and internal angle of friction when development is done through the cemented paste fill.

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