Back Analysis of Narrow Vein Open Stope Stability and Verification Using Kinematic and Empirical Methods

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Abstract. High walls of open stopes in underground stoping mines can be considered to behave in a similar manner to open pit slopes if stability is largely controlled by geological structures. With this assumption the kinematic method of analyses can be used to assess the stability of the footwall, hangingwall, the roof and floor of an open stope. This paper demonstrates the application of kinematic analyses tools such as Rocscience's DIPS® and UNWEDGE® to assess the stability of underground stopes in a narrow vein mine. A back analysis was conducted, using both kinematic methods and the empirical stability graph method, after field investigation of stope failures and review of stope closure reports. The stability graph method showed that the designed stopes were stable with support. However, majority of the stopes audited have apparently failed or were in state of failure, i.e., unstable. Kinematic analyses showed that these stopes were certainly at risk of failure which confirmed the observations. The stability chart used by the mine was eventually adjusted based on the kinematic analyses and observations made, resulting in the stability graph having only three regions: stable, unstable and fail.

Keywords: narrow vein orebody · stope stability · back analyses · empirical stability graph analysis · kinematic analysis

1 Introduction

The underground mine presented in this paper practices narrow vein long-hole stoping method to mine the steeply dipping (70–85°) narrow ore veins. The average vein widths ranging between 0.7 to 1.5 m. The down dip extent of the veining varies from 100 to 200 m and there are over 300 of these veins which are extracted individually. The footwall and hangingwall of the veins are structurally defined. Majority of the structures (joints and foliations) are moderate to steeply dipping and are both parallel and oblique to the ore veins.

Figure 1 shows the salient features of one of the design passports utilized at the mine. A single vein drive (3 m wide and 3 m high) is developed for drilling, support installation and mucking from the base of the stope. Stopes are excavated in sequences from top to bottom to maximise extraction while eliminating sill pillars to create bigger

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stopes. One stope is about 50 m high and divided into sub-level intervals of 12–15 m. The mucked-out stopes are left open without backfilling. Along the strike nominal 10 m rib pillars are left every 50 to 60 m. This results in a narrow open stope of 50 to 60 m in strike length, 0.7 to 1.5 m wide and 50 m high is left open in between the nominal rib pillars.

Cable bolts are installed on the hangingwall side to prevent overbreak dilution, that is breakage and fallout rock material beyond ore boundary. However, significant rockfalls were experienced in majority of the stopes both in the hangingwall and footwall which is not cable bolted. Blast damage and unfavourable structural orientations contributed significantly to these overbreaks and rockfalls. It was suspected that the cable bolts were not effective to prevent the fallouts. Hence, pull-tests were performed on the cable bolts, but found to be sufficiently strong. At this mine the cable bolts are cement grouted, but no face plates are utilized to prevent broken ore hangups. The face plates are not used because the drilling and installation of the cable bolts are very often done from the ore veins in the vein drive (see Fig. 1).

The ineffectiveness of the cable bolts could be attributed to three main reasons; (i) they are in most cases installed parallel to the dominant structures, (ii) the bolt offsets up the stope walls are too large (see Fig. 1), and (iii) cable bolts may not be required at all for this narrow vein deposit as shown this paper.

A review of the mine design parameters indicated that the open stope dimensions were determined on the basis of modified stability graph by [1] and cable bolt parameters on the basis of the stability graph presented by [2]. However, several authors including [3] and [4] have cautioned the use of generic stability graph for dimensioning of narrow vein open stopes. The definition of narrows veins is varied, however, [5] defines it is having thickness less than 5 m.

A back analysis was conducted to assess the stability of the stopes. To facilitate this a series of observations were made utilizing the cavity monitoring system (CMS) to scan the stope voids, visual inspection and assessment of recently blasted stopes and assessment of ROM (run-off-mine) arriving at the crusher to get an estimate of the block sizes. This was compiled into a stope closure report. Kinematic analyses were first performed using Rocscience's DIPS® [6] and UNWEDGE® [7] to observe the stability conditions of the stopes, assuming that the narrow open stopes can be treated as classical slope (similar to open pit slopes). The DIPS and UNWEDGE analysed results were then compared to the back analysis from the stability graph method. The open stope stability prediction made from DIPS kinematic analysis accurately coincided with the stability graph back analysed results.

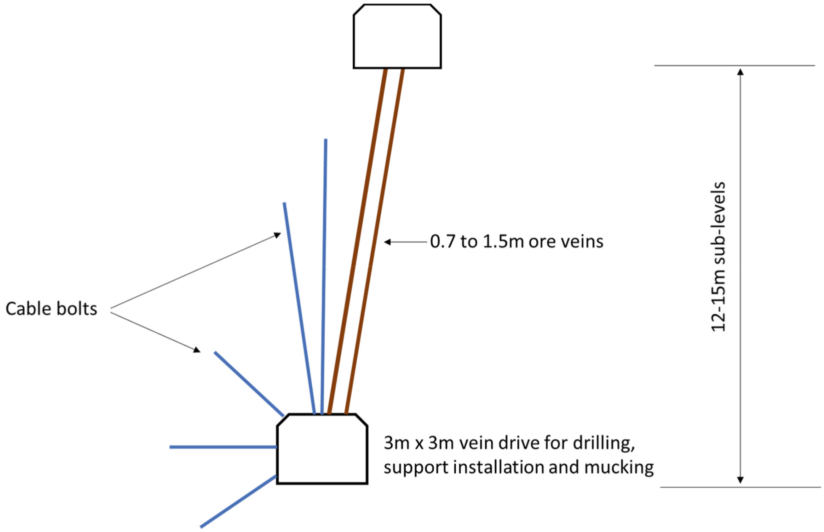

Fig. 1. Schematic of the salient features of one of the design passports.

2 Assessment and Analyses

2.1 Stope Assessment

The stope stability assessment included a package of tasks. These included (i) systematic structural mapping, (ii) stope reconciliation, (iii) back analyses and (iv) kinematic analyses. A detailed scan line mapping was conducted to obtain structural data within the active mining areas. This data was required both for back analyses and kinematic analyses. For stope reconciliation the stopes were surveyed using cavity monitoring system (CMS) and visual stope inspection before and after mucking as part of stope closure reporting. Stopes deemed to have failed or in the state of failure were photographed and catalogued, with clear descriptions of the failure modes, including block size estimation.

Figure 2 shows an example of observations in two of the stopes. On the left image are structurally controlled failures from the hangingwall involving structures parallel to the ore vein. The cable bolts hang like strings unable to prevent the blocks from falling out, despite being closely spaced (1 m by 1 m). The image on the left, although not distinctly clear, shows blocky waste rock ejected from both the hangingwall and footwall mixed with the ore. Mucking was completed remotely with some difficulty. The stope shown in the left image was deemed unstable but not fail, while the stope on right image was considered to have failed. Dilution increased by nearly 50% in the stopes where significant fallouts were observed. CMS data also revealed that in these stopes overbreak often double the width of the blasted stope, up to 2.0 to 2.5 m from the original width of 0.75 to 1.5 m.

Table 1 shows the stability summary of the problematic stopes assessed. Results from kinematic analysis from DIPS are also shown in the table, but the method of analysis is presented in the proceeding subsections.

Fig. 2. Examples of the narrow stopes inspected. Stope L670-V20w is deemed to be in the state of failure, while stope L740-V13w is deemed to have failed.

Table 1. Stability condition of 15 selected problematic stopes assessed

Stope ID	Level	Vein	Stability	DIPS predicted failure mode
540V20N1	540	V20	Unstable	Planar and wedge sliding
600V10N	600	V10	Failed	Planar sliding
620V22N1	620	V22	Unstable	Planar and wedge sliding
650V17N3	650	V17	Failed	Planar sliding
735V34N1	735	V34	Failed	Planar and wedge sliding
735V34N2	735	V34	Unstable	Planar and wedge sliding
735V34N8	735	V34	Failed	Planar and wedge sliding
740V5N1	740	V5	Unstable	Planar sliding
762V5N2	762	V5	Unstable	Planar and wedge sliding
762V5N3	762	V5	Unstable	Planar and wedge sliding
775V34N2	775	V34	Unstable	Planar sliding
775V62N1	775	V62	Unstable	Planer sliding
790V44N1	790	V44	Unstable	Planar and wedge sliding
810V17N3	810	V17	Failed	Planar and wedge sliding
860V33N1	860	V33	Unstable	Planar and wedge sliding

2.2 Back Analysis

For the sake of consistency, the same generic stability graph initially used by the mine, that is [1], was used for the back analysis. The 15 cases shown in Table 1 were analysed. Figure 3 shows the result of the back analysis. The stopes were designed on the basis of 'stable with support'. However, as Fig. 3 shows there are only three possibilities for these stopes; (i) stable, (ii) unstable or (iii) fail. The stability numbers (N') for the stopes analyzed lie at the very tip or almost outside the "stable with support" region, see Fig. 3. This indicates that the stopes will be unstable regardless of being supported.

As noted earlier, majority of the stopes remained open until mucking was completed despite experiencing significant overbreak (1.5 to 3.0 m overbreak). Based on this back analysis and observations a simple criterion was established on the basis of overbreak and dilution to assess the stability condition of the stopes. These are as follows:

Overbreak:

- Less than 1.5 m – stable
- 1.5 to 3.0 m – unstable
- Greater than 3.0 m – fail

Dilution:

- Less than 15% – stable
- 15 to 30% – unstable
- Greater than 30% – fail

'Fail' in this case means significant rock fall with overbreak greater than 3.0 m, inducing dilution exceeding 30%. Caving and total collapse did not occur at this mine.

An ELOS (Equivalent Linear Overbreak Slough) based stability graph such as presented by [8] and [9] would also yield only three regions. [9] defines the three regions as, (i) stable, (ii) transition and (iii) cave.

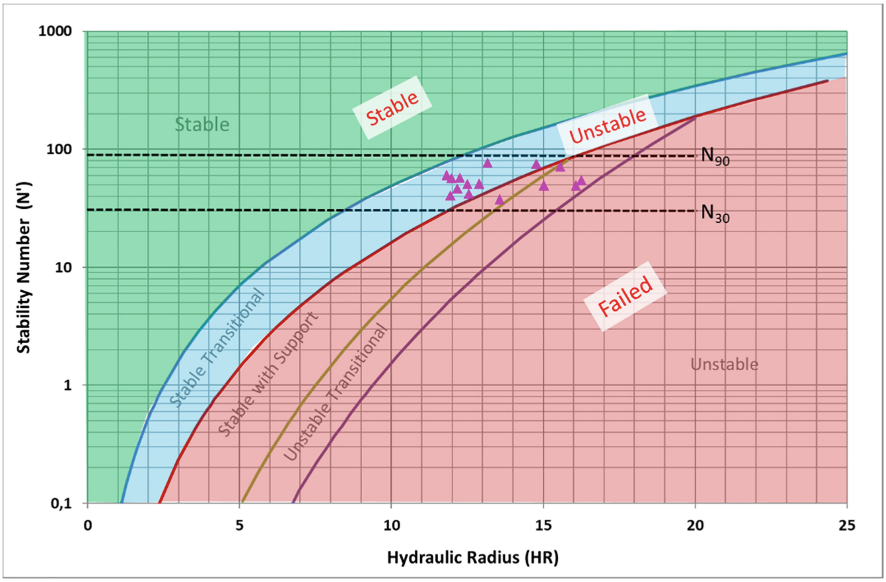

Fig. 3. Back analyses of the selected 15 narrow vein open stopes. The stability stopes fell within the 'stable transitional' and 'unstable transitional' including 'stable with support'.

2.3 Kinematic Analyses

DIPS analysis

DIPS analysis was performed to assess the stability conditions of the tall narrow open stope walls. Options for kinematic analysis of wedge and planar sliding in DIPS were utilized. Figure 4 shows planar sliding as potential risk in open stope walls of Vein 20, which was evident and shown in Fig. 2. In Fig. 5 the DIPS analysis also shows formations of wedges resulting from structures oblique to the stope wall cross-cutting the those parallel to the stope wall. Throughout the mine both planar and wedge instabilities were observed. The fallen-out blocks are typically slender.

The kinematic stability analysis performed in DIPS were summarized as shown by the sample in Table 2. Only 6 cases are shown for the purpose of this publication. The results are then used to complete to Table 1 as part of back analyses and validation.

UNWEDGE analysis

For the UDWEDGE analysis the actual stopes shapes in two-dimensions were imported from CAD wireframes into UNWEDGE software into order to maintain the geometrical integrity. The wedges formed in the hangingwall and footwall were scaled based on the visual assessments of the blocks that fell into the stope and also from observations at the crusher dumping point (Fig. 6). Block sizes of anywhere between 0.5 to 1.5 m^3, weighing 1.0 to 4.0 tonnes, were observed. Wedges are also formed in the roof and floor of the drives, but they are subject to fall out during production blasts (Fig. 7). The wedges formed on the stope walls are slender, consistent with the oblique cross cutting structures. The UNWEDGE program also allows for the estimation of potential fallout volume, which can be used for overbreak and dilution estimation.

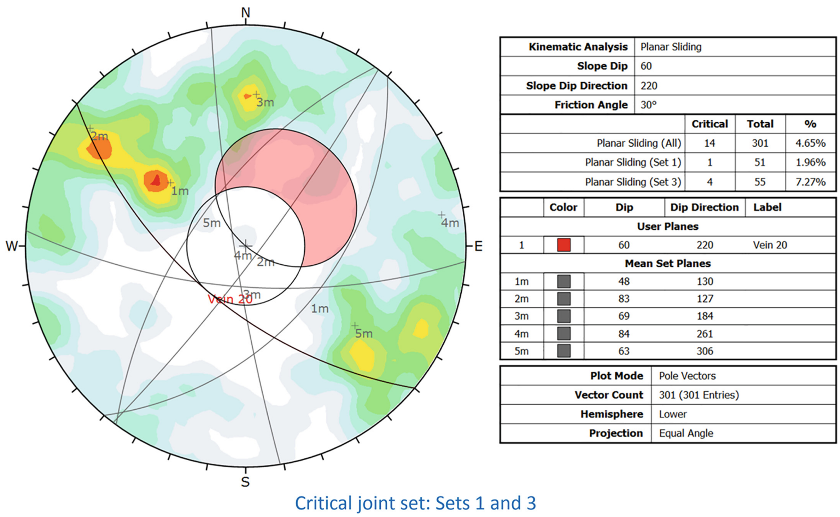

Fig. 4. Planar sliding is clearly indicated by DIPS analysis for the Vein 20, which confirms the observation in L670-V20 (see Fig. 2).

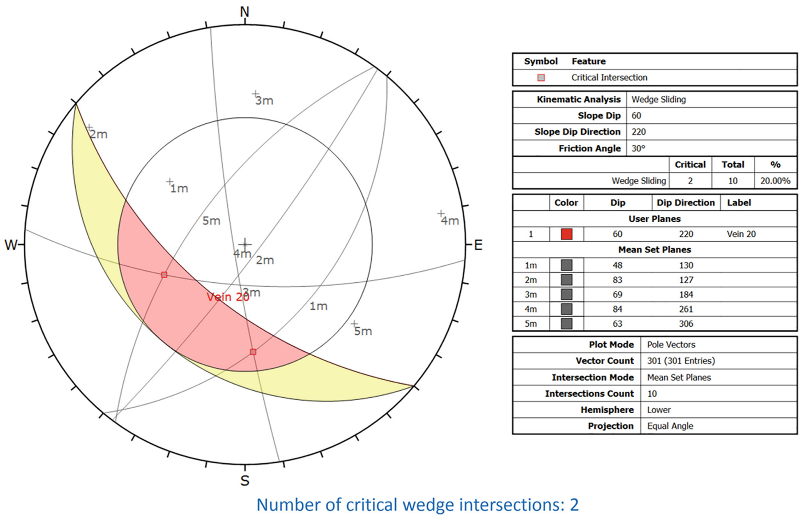

Fig. 5. Wedge formations and risk of wedge sliding in Vein 20.

Table 2. An example of DIPS kinematic analysis used to validate observations in Table 1.

Vein	Number of joint sets	Dip/Dip-direction	Sliding potential
11-west	3	J1: 84/233, J2: 88/276 J3: 73/313	Less likely
17-east + west	2	J1: 56/181, J2: 67/126	Planar
20-east + west	5	J1: 48/130, J2: 83/127 J3: 69/184, J4: 84/261 J5: 63/306	Planar + Wedge
33-west	5	J1: 77/008, J2: 69/120 J3: 84/067, J4: 65/302 J5: 61/226	Planar + wedge
34-east + west	5	J1: 79/247, J2: 58/148 J3: 76/345, J4: 78/104 J5: 70/197	Planar + wedge
35-east	3	J1: 60/069, J2: 55/217 J3: 58/277	Wedge

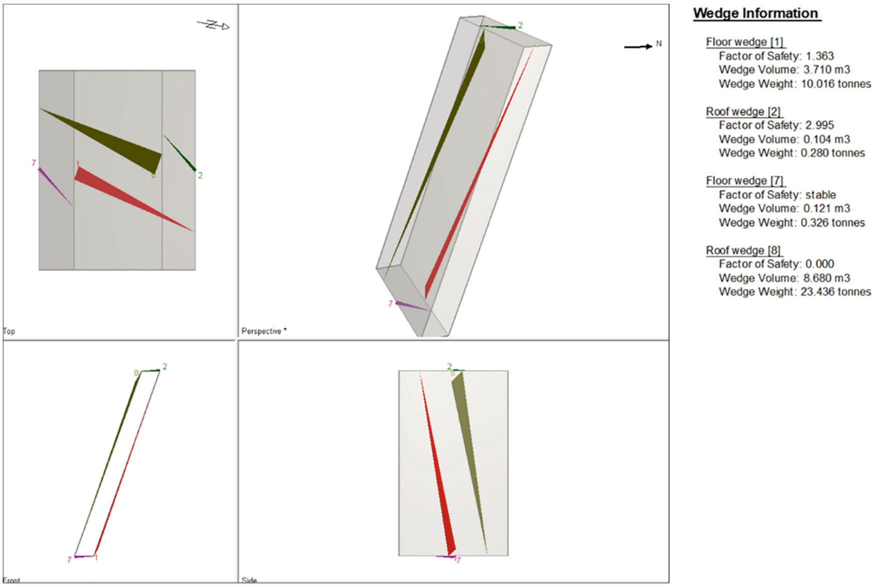

Fig. 6. Wedge formations in the open stope wall of Vein 20, scaled to match block sizes observed.

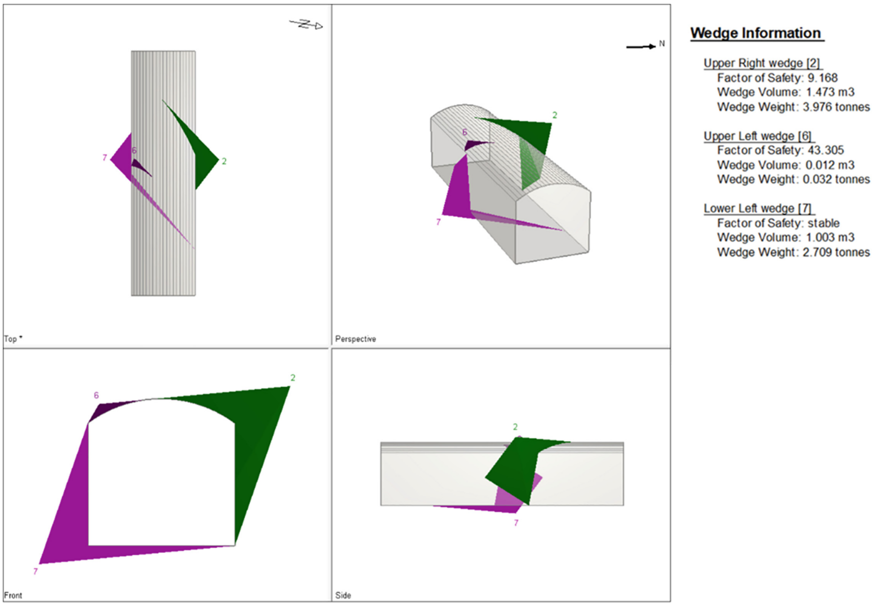

Fig. 7. Wedge formations in the vein drive of Vein 20, scaled to match block sizes observed.

3 Conclusion

The DIPS program with its kinematic options can enable the identification of potentially unstable open stopes and the mode of failure. This was clearly demonstrated in this paper for the narrow open stopes which were validated by back analysis using the stability graph method. The wedge analysis using the software UNWEDGE, with blocks scaled to match observations, could be used to estimate overbreak and dilution as the software can report rock volume that can potentially fallout from the stopes. This evaluation could have been improved if the wedge volume had been matched to the CMS data. Since the narrow vein open stopes were relatively tall (50 m in tall) the assumptions that stope walls could be treated as an open pit slope is considered valid.

On the notion of stability graph, the generic stability graph over-estimated the stability of the long-hole narrow open stopes. Majority of the stopes analyzed were either failed or deemed unstable. The stability numbers (N) of the stopes analyzed in this paper occur at the very tip or outside of the “stable with support” region in a generic stability graph, indicating that the stopes would be unstable regardless of being supported. Thus, for this case mine only three possibilities are observed; stable, unstable or fail. The stope stability is best defined by overbreak and dilution factors, following the ELOS stability graph presented by for example [8].

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