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Stability Evaluation of Two Parallel Declines Joining Multi-Workings with Low Interburden Thickness

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ABSTRACT: This paper outlines the analysis methods and results used in a geotechnical evaluation performed on the stability of two declines at the Skyline Mine. The Lower O'Connor-A (LOA) seam has been displaced by a fault within the study area at the mine. The declines have been driven in relatively thin interburden and connect the existing mains in the LOA seam to the mains in the same coal seam in the proposed underlying mine level. The primary objective of the study was assess the roof and rib stability of both the declines and the connecting crosscut, while establishing a viable brow thickness above the decline entrance. The impact of driving the declines on the stability of the mains pillars in the proximity of the decline in the upper and lower levels were analyzed, while concurrently evaluating the effect of multi-seam mining in the lower level mains pillars. The study was performed using a combination of numerical modeling tools, LAMODEL and FLAC3D. The study results indicated likely rib and roof stability within the declines and crosscut, as well as the pillars in the vicinity of declines in both the mining levels.

1. INTRODUCTION

The Skyline Mine (Skyline) is a deep underground coal in Central Utah located southeast of Salt Lake City. A geotechnical evaluation was performed to assess the stability implications of driving two declines in the relatively thin interburden at the Skyline Mine. This study was performed prior to the work to evaluate the stability of two declines connecting the existing LOA seam mains in Mine-2 (mid-level) at Skyline to the LOA mains in the underlying SWR (Southwest Reserves, bottom level)), as the seam has been displaced by a fault. The proposed mains were developed after ramping down two declines from the existing mains in the up-thrust side of the LOA Seam to the down-thrust side. The newly developed mains are directly overlain by existing mains in the Lower O'Connor-B (LOB) Seam in Mine-2 (Figure 1) and sealed workings in Mine-1 (upper level) in the Upper O'Conner (UO) seam. Information from drill holes near the decline bottom indicated the SWR mains are separated from the Mine-2 mains by an interburden thickness of approximately 26 feet (ft). The SWR mains in the LOA seam will service several proposed longwall panels in the lowermost level. These mains are anticipated to be in service for upwards of 10 years.

Since the completion of the study, the mains have been developed by ramping down two declines from the existing mains in the up-thrust side of the LOA Seam to the down-thrust side. The interburden was excavated utilizing a continuous mining machine for the initial floor. A roadheader was then utilized to establish the brow, and was used for the remainder of the project. The declines were excavated at an angle of approximately 8 degrees from horizontal. The declines are spaced approximately 59-feet apart (rib-to-rib) and have their centerlines coincident with the mains entries in Mine-2 (mid-level) and SWR workings (lower level).

Geotechnical exploration prior to the study established the interburden rock mass to be a single sandstone layer approximately 26-feet thick, with minimal jointing present. During excavation of the declines, an error was discovered in the interpretation of the drilling data. This discovery resulted in the decision to drill an additional drillhole from the upper Mine 2 seam to the location where the declines were designed to intersect the lower LOA seam. The rock interburden was found to be 38 feet thick at this location. It was also determined that the apparent dip of the seams was greater than previously thought. This new information required a minor change to the design of the declines. Fortunately, the increased apparent dip compensated for the increased interburden

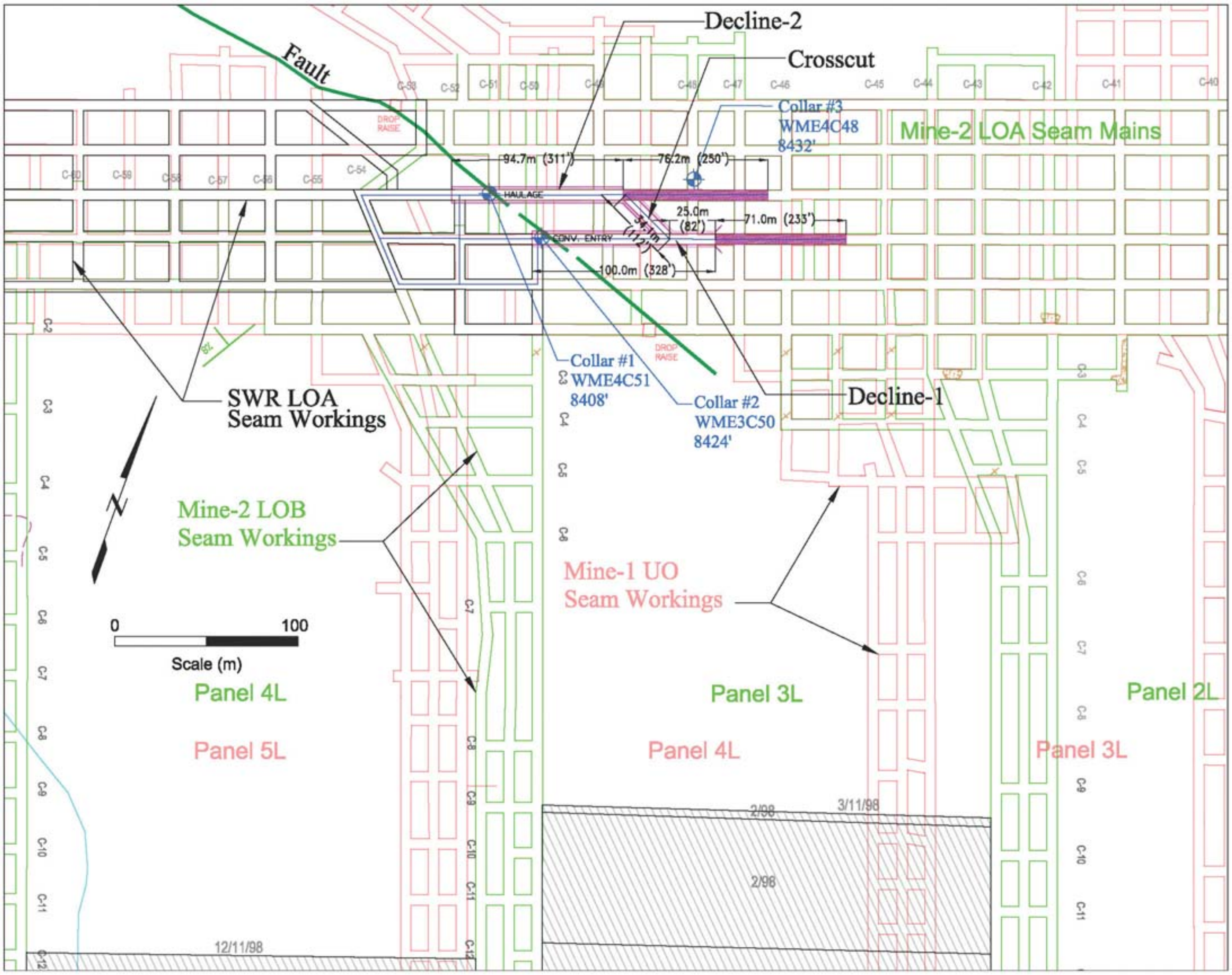


Fig. 1. Study area

Both the declines are connected with a crosscut at approximate mid-length. The width of both the declines and inter-decline crosscut are 20 ft. The declines and crosscut have an arched cross-sectional area. The height is approximately 12.5 ft at the center, tapering to 9 ft at the corners. The declines also intercept the fault zone responsible for parting of the LOA seam close to lower level workings (Figure 1).

During excavation, both the declines were ramped down, from Mine-2, in the interburden up to a depth of approximately 20 ft, until the brow demonstrated adequate stability. Concurrent with this stage, the arched supports were placed from the coinciding Mine-2 entries leading to within approximately 20 ft of the respective brows of the declines. Once the arched supports had been installed, the declines were promptly advanced inby the brows and the excavated interburden above the supports was replaced with low-strength backfill to prevent loose rocks from exposed roof above the declines impacting the supports and also, to provide confinement to adjacent pillar ribs. A schematic vertical section diagram of the declines is presented in Figure 2.

Primary support consisting of fully grouted rebar on 4 foot centers was installed on cycle, with steel supports installed as supplemental support. Although roof conditions were generally good, the steel supports were advanced as the declines were excavated.

The primary objective of the study was assess the roof and rib stability of both the declines and the connecting crosscut, while establishing a viable brow thickness above the respective decline entrances. The impact of driving the declines on the stability of the mains pillars in the proximity of the decline in the upper and lower levels were analyzed, while concurrently evaluating the effect of multi-seam mining in the lower level mains pillars. The study was performed using a combination of numerical modeling tools, LAMODEL and FLAC3D. In addition to the primary objective of performing stability analyses on the declines and the SWR mains (lower level) pillars, this study also evaluated the

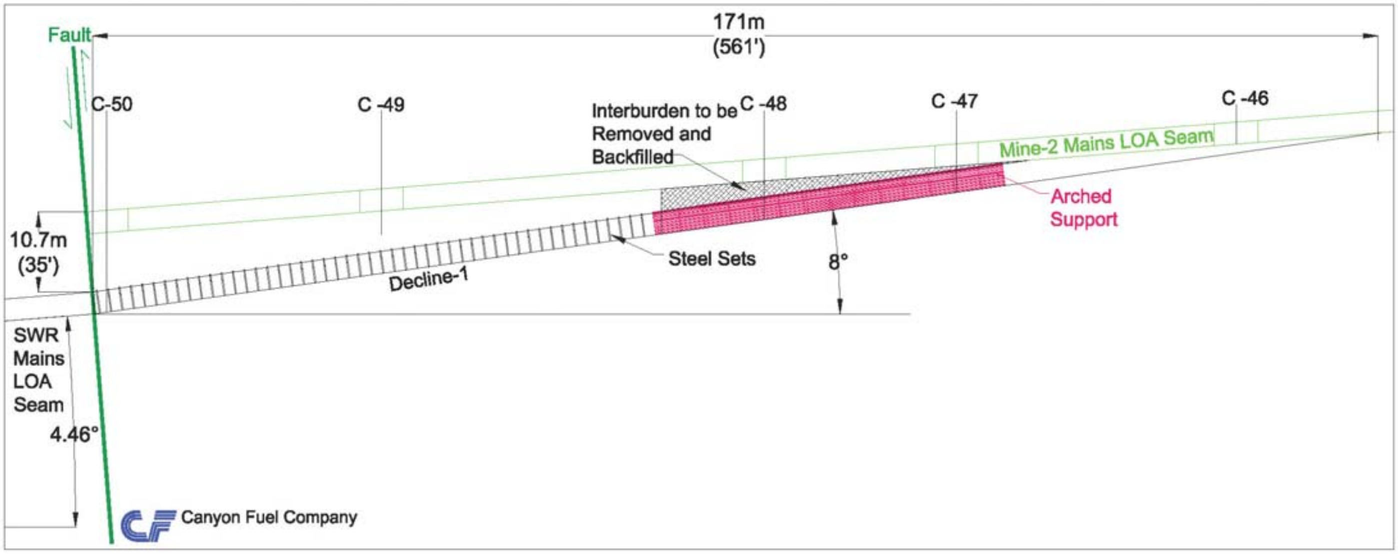


Fig. 2. Schematic diagram of decline with arched-support option

stability of an equipment change-out crosscut joining the two declines. The adequacy of the proposed roof bolting and standing ground support was also studied.

2. INVESTIGATION APPROACH

As the first step towards performing the analysis, maps of existing and proposed workings, geological borehole logs, overburden and interburden thicknesses, and strata characterization data relevant to the study area were reviewed. The next step involved development of a model using LAMODEL (Heasley, 1998) that incorporated the existing UO workings in Mine-1 (upper level) and both LOA and LOB Seam workings in Mine-2 (mid-level). LAMODEL is a non-linear, boundary-element, displacement-discontinuity code for estimating stress, displacement, and yielding in tabular deposits such as coal. The purpose of this step was to assess the state of stress in the Mine-2 (mid-level) mains pillars in vicinity of the proposed declines due to the impact of the multi-seam stresses from the overlying Mine-1 (upper level) workings and from the adjacent mined out panels in Mine-2 (mid-level). Determining this stress distribution in LAMODEL, and applying it to the subsequent three-dimensional (3D) modeling stage, simplified the analysis by eliminating the necessity of including the geometry of the Mine-1 workings and mined out panels in Mine-2 (mid-level) in the ensuing 3D model.

In the second stage of the study, FLAC3D, a 3D numerical analysis code, was used to develop and analyze a numerical model that simulated the impact of decline excavation. In the model, the ground stress state in the Mine-2 (mid-level) mains pillars obtained from the preceding LAMODEL analysis was replicated, for the pre-excavation stage of the two declines. This was followed by simulating excavations of both the declines and the inter-decline crosscut in their proposed geometry. The last step was the excavation of the SWR mains (lower level). The 3D numerical model also incorporated the proposed ground support to assess their adequacy.

3. LAMODEL ANALYSIS AND RESULTS

The two-dimensional numerical model developed to analyze the stress state in the Mine-2 (mid-level) mains pillars prior to excavation of the declines included existing workings from both Mine-1 (upper level) and Mine-2 (mid-level) workings, within a 3,000-ft × 3,000-ft study area (Figure 1). The selected study area included longwall panels from all three seams (UO, LOA and LOB) in addition to the mains pillars in the respective seams. The study area was centered around the location for the two declines. Square elements of 3-ft × 3-ft were used to develop model grids of the above workings. The extraction height was assumed to be a constant 9-ft in both Mine-1 and Mine-2 workings. The interburden thickness between Mine-1 and Mine-2 was assumed to be a constant 80-ft, which was the approximate average separation between the two levels within the study area. The strata parameters for the overburden, interburden, and coal were kept the same as those calibrated during a previous geotechnical study of the same workings (AAI 2014). A summary of the LAMODEL input parameters obtained through calibration, which were also used in the current study, are presented in Table 1.

The numerical model, in this phase of study, included two steps. In the first step, the Mine-2 (mid-level) mains area of the LOA and LOB Seams was simulated as unmined coal, with mined out Panels 3L/4L in Mine-2 as the only workings on that level. The purpose of this step was to assess the impact of Panel 3L/4L gobs and the overlying Mine-1 workings at the location of Mine-2

Table 1. Summary of LAMODEL Input Parameters

Parameter	Value
Mining height (ft)	9.0
In situ coal strength (psi)	900
Young's Modulus (*E*) (coal) (psi)	300,000
Poisson's ratio (ν) (coal)	0.25
Elastic Modulus (*E*) (rock mass) (psi)	1,250,000
Poisson's ratio (ν) (rock mass)	0.15
Gob stiffness (initial/final) (psi)	50,000/500,000
psi = pounds per square inch	

mains. In the second step, the Mine-2 mains and other accessory workings to Panels 3L/4L were simulated to analyze the state of stress and yielding in the mains pillars in the vicinity of the proposed declines, which also incorporated impacts of the overlying workings and adjacent gobs. The local topography was used in the models to incorporate overburden loads on the workings, based on the supplied topographic maps. The fault zone separating the LOA and LOB Seams within Mine-2 (mid-level) was not simulated at this stage of study.

The predicted vertical stress state plot in Mine-2 (mid-level) due to the presence of Panels 3L/4L gob areas and the overlying Mine-1 (upper level) workings is presented in Figure 3. This stress state was recreated in the 3D numerical model (FLAC3D) in the following stage of the study, prior to excavation of the Mine-2 mains in that model. The extraction of Panels 3L/4L without development of the Mine-2 mains represents a hypothetical situation. However, this step provides critical insight to the state of pre-mining stress at the mains location that had to be duplicated in the 3D model. The 3D model excluded the gob areas and UO Seam workings for computational efficiency, but their effects on the mains located in Mine-2 (mid-level) were accounted for. The stress distribution along the Mine-2 mains indicates increasing vertical stress from east to west, from approximately 850 psi to 1150 psi, consistent with increasing cover depth in that general direction. However, the impact of multi-seam mining and gob abutment stresses were minimal. The yield conditions in the Mine-2 (mid-level) mains predicated in the modeling results, excluded from this paper for brevity, were consistent with field observations.

4. FLAC3D STABILITY ANALYSIS

4.1. 3D Model Development

In addition to the LAMODEL analysis, a detailed numerical modeling analysis was performed to assess the stability of the declines and lowermost SWR workings the 3D analytical tool FLAC3D. The 3D nature of the geotechnical issues in and around the declines necessitated this approach. A 3D numerical model was developed using 3D brick-shaped (rectangular cuboid) elements to simulate the decline

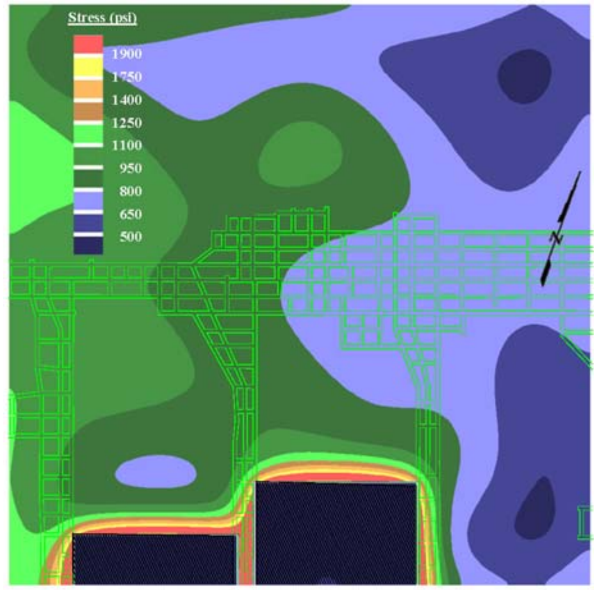


Fig. 3. Stresses in mains pillars location due to panels 3L and 4L, Mine-2.

configuration. The model incorporated the existing Mine-2 (mid-level) mains between crosscuts C-44 and C-59, which encompassed the entrance and bottom of both declines. The proposed decline bottom pillar geometry was also incorporated into the model.

The coal thickness and extraction height was assumed to be 9 ft in both the upper Mine-2 (mid-level) and lowermost SWR workings. The mains entry and crosscut widths in both levels were assumed to be 18 ft in the model. The SWR mains (lower level) entries coincident with the declines were assumed to be 20 ft wide. The height and width of both the declines and inter-decline crosscut were assumed to be 12 ft and 20 ft, respectively. Although the declines and crosscuts were excavated using a roadheader, resulting in curved corners in their cross-sections, a rectangular cross-section was used for efficient model development. This also represented a more conservative scenario from a corner stress concentration viewpoint. Interburden thickness between the Mine-2 and SWR workings was assumed to be a constant 26 ft, for conservatism, even though the interburden thickness increases at a distance to the west from the decline bottoms.

The decline brow thickness was kept constant at 7 ft, based on preliminary results that indicated that this brow thickness above the declines was likely to be self-supporting. The arched supports extended from the coinciding entry in Mine-2 to the brow of the declines in the model. The arched supports were simulated as a combination of steel sets spaced 5 ft apart, wrapped by steel liners (to simulate lagging). Even though the steel liners (lagging) in the proposed arched support design are corrugated, a non-corrugated steel liner of the same gauge was used for conservatism. The model mesh had finer elements within and near the declines, and a coarser mesh away from the declines, for computational efficiency.

Both roof bolting and standing supports proposed in the decline and SWR workings were explicitly modeled. Fully grouted bolts (Grade-75, 1 inch diameter) installed in a 4 ft × 4 ft pattern were simulated in the roofs of Mine-2 (mid-level) and SWR (lower level) working as well as both the declines and the crosscut of the model. The structural members at the decline entrance were simulated with W4x13 beams (Grade-50 steel) on 5-ft spacing, as recommended by one of Skyline's vendors. The steel liner (lagging) elements were simulated as 14-gage flat steel sheets. Steel sets consisting of W6x20 beams (Grade-50 steel) with 5-ft spacing were assumed to support the rock portion of the declines and the inter-decline crosscut in this model.

The rock mass properties assigned to the various strata used in the model came from several sources; historical geotechnical site characterizations performed in vicinity of the study area (Seegmiller, 1977, 1980, 1982 and 1984), a previous calibration study performed on the LOA Seam mains (AAI, 2014), and a preceding limited geotechnical investigation performed at the site in 2014. The 2014 site characterization included three exploratory boreholes in the floor of the Mine-2 (mid-level) mains near the proposed declines; one hole immediately east of the fault zone and two immediately west of the fault zone. This was followed by laboratory characterization of core samples obtained during drilling, which indicated that the declines will be excavated exclusively through a competent and very lightly jointed sandstone rock mass. This observation has been validated during excavation of the declines.

Given that a fault displaces the LOA Seam approximately to the level of the LOB Seam within Mine-2 (mid-level), the fault was modeled as a 2-ft-thick weak zone extending from the roof of Mine 2 to the floor of SWR workings (lower level) through the decline. The overburden material present above the LOB Seam in Mine-2, west of the fault zone, was assigned properties of the LOB Seam roof material, aggregated from historical characterization data. The 26-ft-thick interburden between the LOB and LOA Seams, west of the fault zone, was assigned strength properties using a weighted average material approach based on historical data and laboratory test results from the recently cored interburden samples. The overburden material above the LOA Seam in Mine-2 (mid-level), east of the fault zone, was assigned the same properties as the LOA-LOB interburden. The floor of the LOA Seam in both Mine-2 and SWR mains was assigned weighted average material properties from historical data and recent characterization data. Coal in both Mine-2 (mid-level) and the SWR workings (lower level) was assigned the calibrated material properties used in the LAMODEL analysis. The fault zone separating the LOA and LOB Seams was assigned weakened rock mass properties with low cohesion and tensile strength in the model. The backfill, placed on the decline arch supports, were assigned properties based on engineering judgment and past experience of modeling similar material, assuming a uniaxial compressive strength (UCS) of 2,000 psi. However, the analysis results indicated that the strength of the backfill is not critical to the stability of the decline entrance and a lower strength material (down to in-situ strength of 1,000 psi) may be used. The intact rock and rock mass properties used in both the 3D numerical model are presented in Table 2.

The FLAC3D model was simulated in four stages. In the first stage, a solid-only model representing pre-mining ground conditions in Mine-2 was simulated that replicated the pre-development state of stress in the Mine-2 (mid-level) mains area obtained from the LAMODEL results. Thus, the influence of mining from the overlying UO Seam in Mine-1 (upper level) and Panel 3L/4L gobs in the Mine-2 horizon were accounted for in this stage. In the second stage, all the mains in Mine-2 within the study area were excavated, followed by installation of roof bolts in this level. In the third stage, the excavation of the declines and the inter-decline crosscut was simulated. The third stage also included the concurrent installation of roof bolts and standing support within the declines and the connecting crosscut, followed by placement of backfill above the arched supports. The fourth stage involved excavation of the lowermost SWR workings followed by installation of roof bolts in this level. All excavations in the respective steps of the numerical modeling were done in a single-step and "wish-in-place" manner for computational efficiency. This approach is conservative as well. Both Mine-2 (mid-level) and SWR (lower level) workings were assumed to be horizontal in the developed model, and the gravitational vector was adjusted to account for the respective seam dips. Based on observations during the field visit and site investigations, the declines are unlikely to be affected by groundwater and therefore, dry conditions were assumed in the model. The model states were cycled 100 steps prior to installation of ground support and then cycled to steady-state equilibrium, with the equilibrium criterion being an unbalanced force ratio of 1 × 10-5.

4.2. Decline Model (3D) Analysis Results

The analysis results obtained from the 3D numerical modeling are presented in Figures 4 through 9. Figures 4a and 4b present plan view (at mid-rib-height) yield condition and stability factor (SF, ratio of strength to stress) plots for the Mine-2 mains for the second step of modeling, representing the decline pre-excavation phase. The level of pillar rib yielding increases from east to west, with increasing overburden depth. The yielding

Table 2. Material Properties Used in FLAC3D Analysis

	Intact Rock Properties		Hoek-Brown* Parameters		Rock Mass Properties			
Rock Type	Uniaxial Compressive Strength (psi)	Young's Modulus (×10^6 psi)	GSI	m_i	Cohesion (psi)	Friction Angle (degree)	Tensile Strength (psi)	Young's Modulus (×10^6 psi)
Overburden (west of fault)	6,000	1.25	70	17	475	41	37	0.91
Overburden (east of fault)	5,500	1.22	70	17	433	41	33	0.89
Interburden	5,500	1.22	70	17	433	41	33	0.89
LOA Floor	5,098	1.25	70	17	400	41	31	0.91
Fault Zone	-	-	-	-	100	20	20	0.10
Coal	-	-	-	-	260	30	90	0.30
Backfill	-	-	-	-	25	35	01	0.10

GSI = Geological Strength Index; "-" = not applicable for these four cases
* Hoek, Carranza-Torres, and Corkum (2002)

observed in the Mine-2 mains is limited to the immediate pillar rib only, which is consistent with the field observations. Marginally higher pillar rib yielding is noted along the fault. Overall, the mains pillar cores maintain SF values of at least 2, indicating long-term pillar stability, consistent with field observations. A higher level of yielding (tension-p) is noted in the floor of the two center entries (Figure 4a), which may be attributed to the wider entry width (20 ft) prior to decline excavation and a higher model mesh density in the floor of the two entries. The notation "p" denotes yielding in the past and the notation "n" denotes current occurrence of yielding. Yielding-in-past (-p) represents a scenario, where the state of stress of a zone has met the material failure limit and reverted to a more stable state by transferring stresses to its neighboring zones. On the other hand, yielding-now (-n) indicates a zone experiencing a state of stress on par with the failure limit.

The yield condition and SF plots in the post-decline excavation stage of second model are presented in Figures 5a and 5b, respectively. Marginally higher yielding and lower SF values are noted in the pillar ribs and floor along the fault. Slightly higher rib yielding and lowering of pillar SF values is also observed in the pillars on either side of the decline entrances. This difference can be attributed to the reduced level of confinement provided by the weak backfill material to the pillar ribs in Mine-2 (mid-level).

Figures 6 and 7 present the yield condition and SF plots along both declines from the second model. Figures 6a through 6d present results along a vertical section taken at the outer edge of the respective declines. Figures 7a through 7d present results along an inclined plane parallel to the floor of the respective declines at mid-rib-height. The results show complete yielding of the backfill mass, which is to be expected given its low strength. However, given the presence of adequately designed arched supports underneath, which holds the backfill in place, this is unlikely to pose any stability issues. Rib yielding along the declines is minimal, except for at the entrances and at the crosscut location, which is also the trend the SF plots follow. This may be attributed to the increased rib height and lack of confinement at the entrance and increased span at the crosscut location, respectively. The roof in both declines, beyond the 7-ft thick brow, are free of extensive yielding and exhibit SF values larger than 2. No adverse effect of the fault is observed. Overall, the modeling results indicate that the declines are likely to be stable. Localized rib spalling is indicated, especially in the decline-crosscut intersection with an acute angle of contact and at the decline entrances.

The state of the crosscut and decline-crosscut intersection are shown in Figures 8a and 8b. Yielded zones with low SF (<1), of 1 ft width, are present along the rib of the crosscut, and increase to approximately 5 ft at the acute-angled corner in the decline-crosscut intersection. The results indicate that rib spalling anticipated along the crosscut will get heavier in the corner due to high stress concentrations where the decline and the crosscut meet at an acute angle (45o as currently proposed). Although such yielding and resultant spalling is unlikely to destabilize the crosscut or the intersection, ground support of higher capacity and/or density in the intersection may be required due to the increased span. Yield condition and SF plots for the lowermost SWR pillars are presented in Figures 9a and 9b. The results indicate that the longer SWR mains pillars have adequately large elastic pillar cores with overall SF values of at least 2, and that rib yielding is minimal. Overall, modeling indicates that the SWR mains (lower level) pillars are unlikely to be adversely affected by the decline excavation. The SWR mains pillar configuration is indicated to be likely stable as

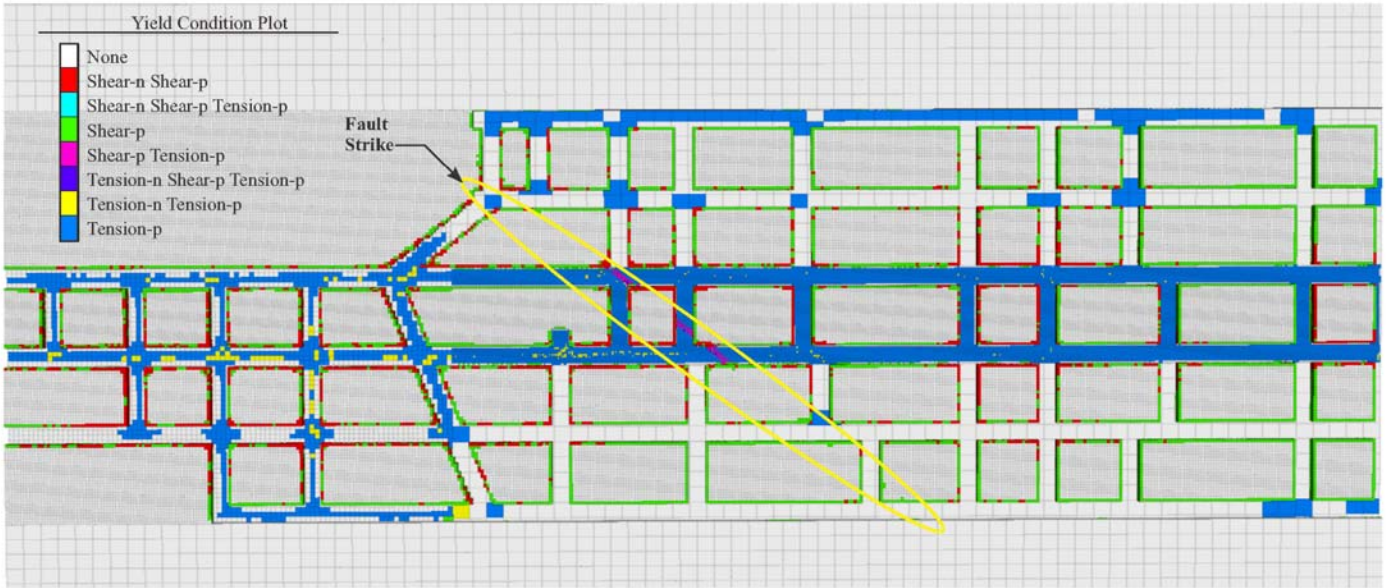


Fig. 4a. Yield condition plot in Mine-2 mains.

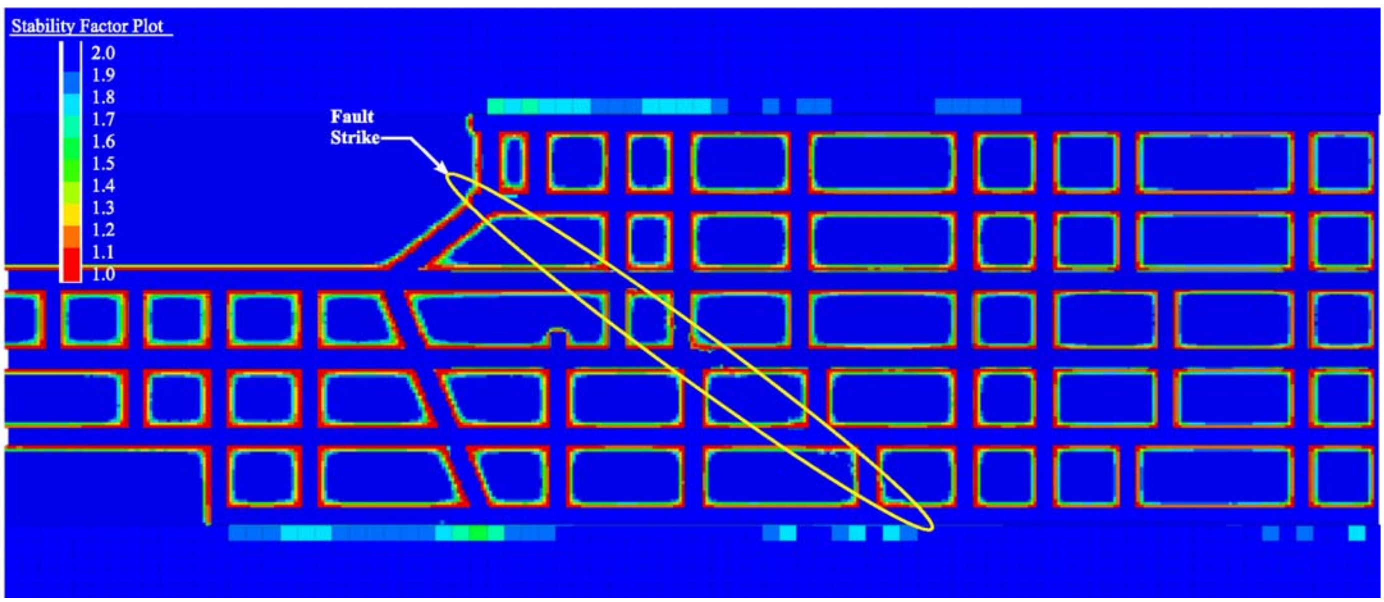


Fig. 4b. SF plot in Mine-2 mains.

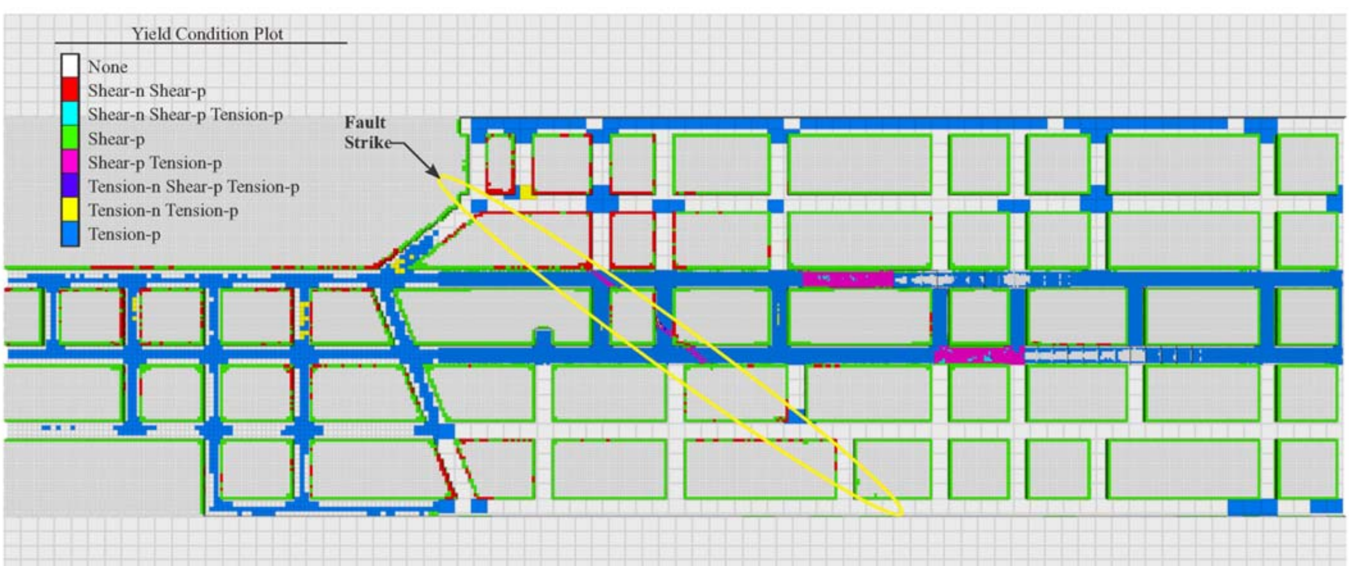


Fig. 5a. Yield condition plot in declines and Mine-2 mains, arched-support scenario.

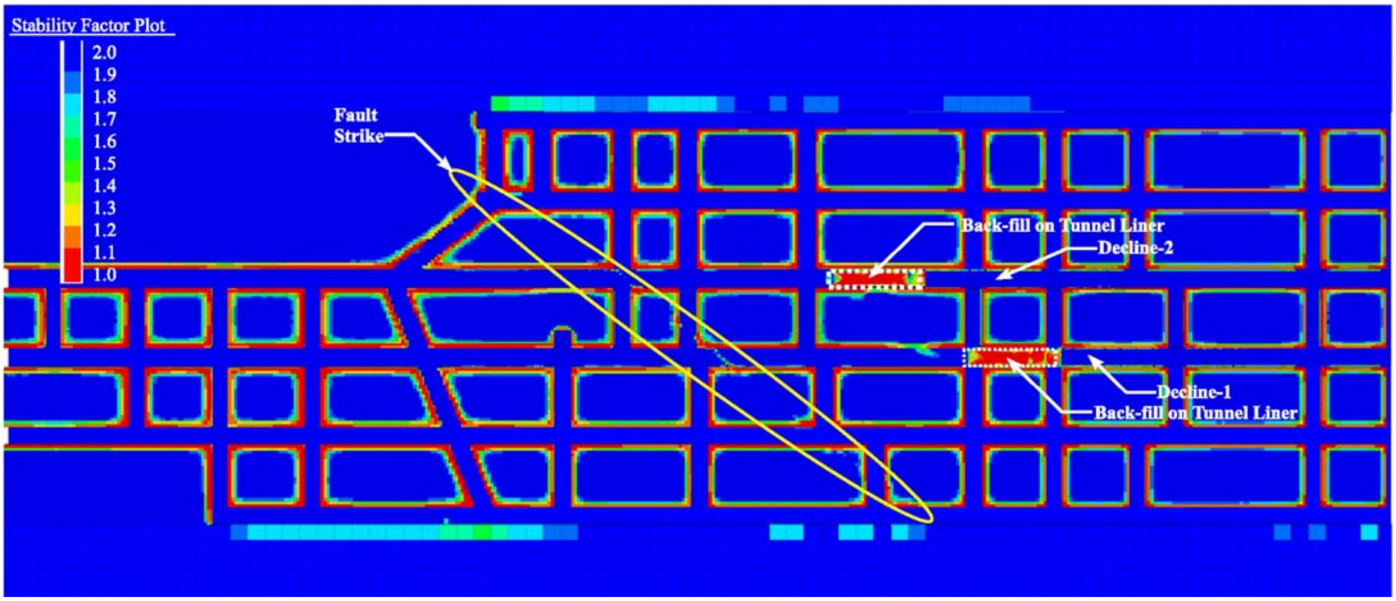


Fig. 5b. SF plot in declines and Mine-2 mains, arched-support scenario.

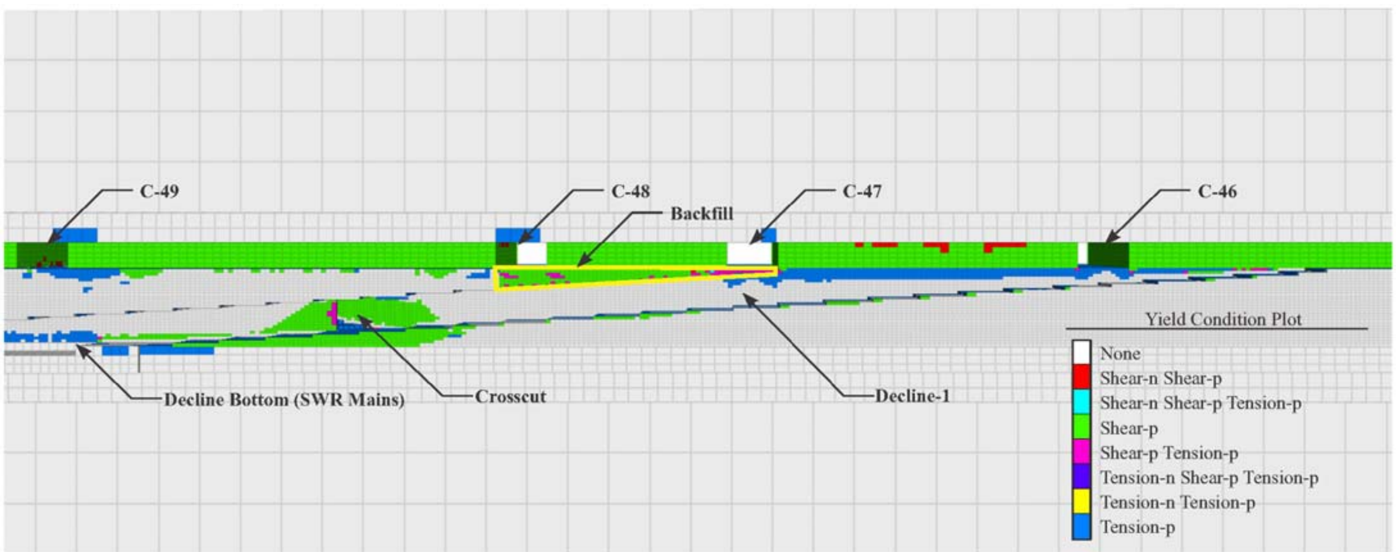


Fig. 6a. Yield condition plot in Decline-1, arched-support scenario (vertical section).

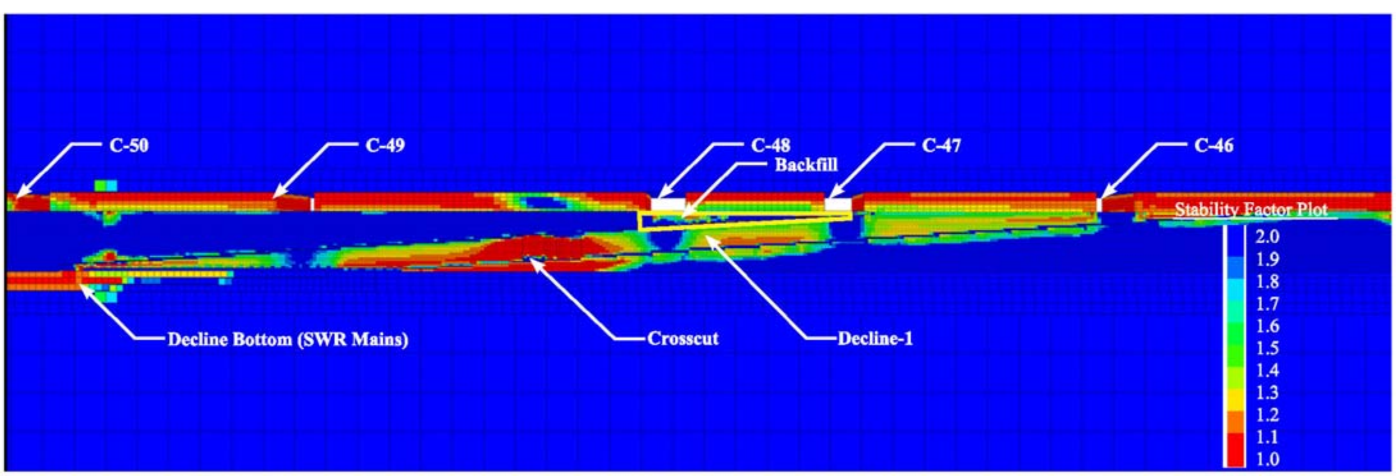


Fig. 6b. SF plot in Decline-1, arched-support scenario (vertical section).

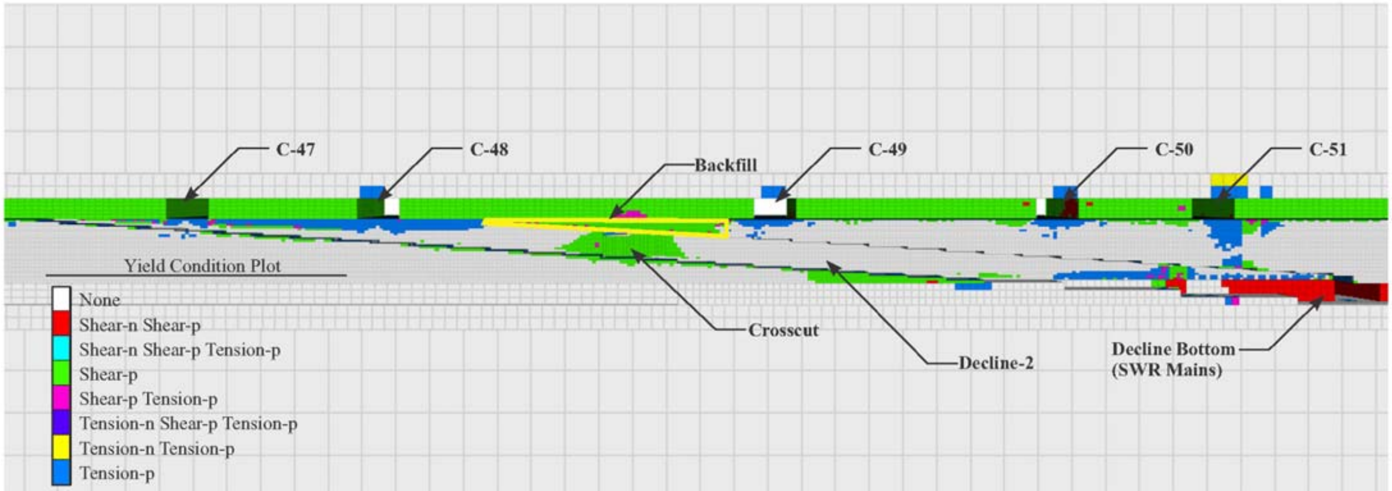


Fig. 6c. Yield condition plot in Decline-2, arched-support scenario (vertical section).

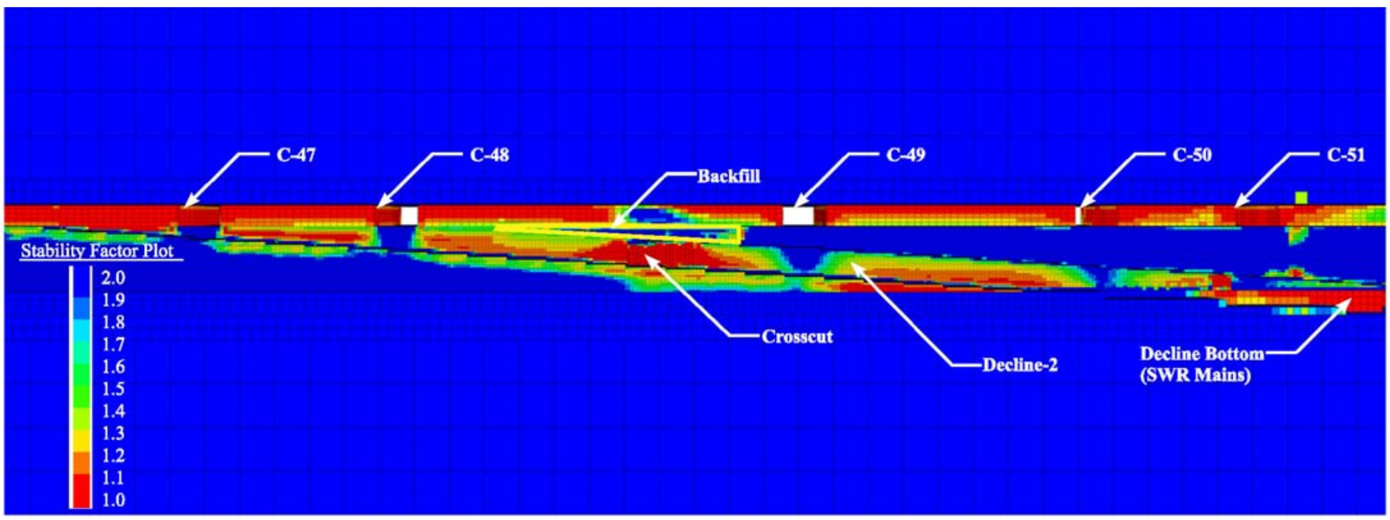


Fig. 6d. SF plot in Decline-2, arched-support scenario (vertical section).

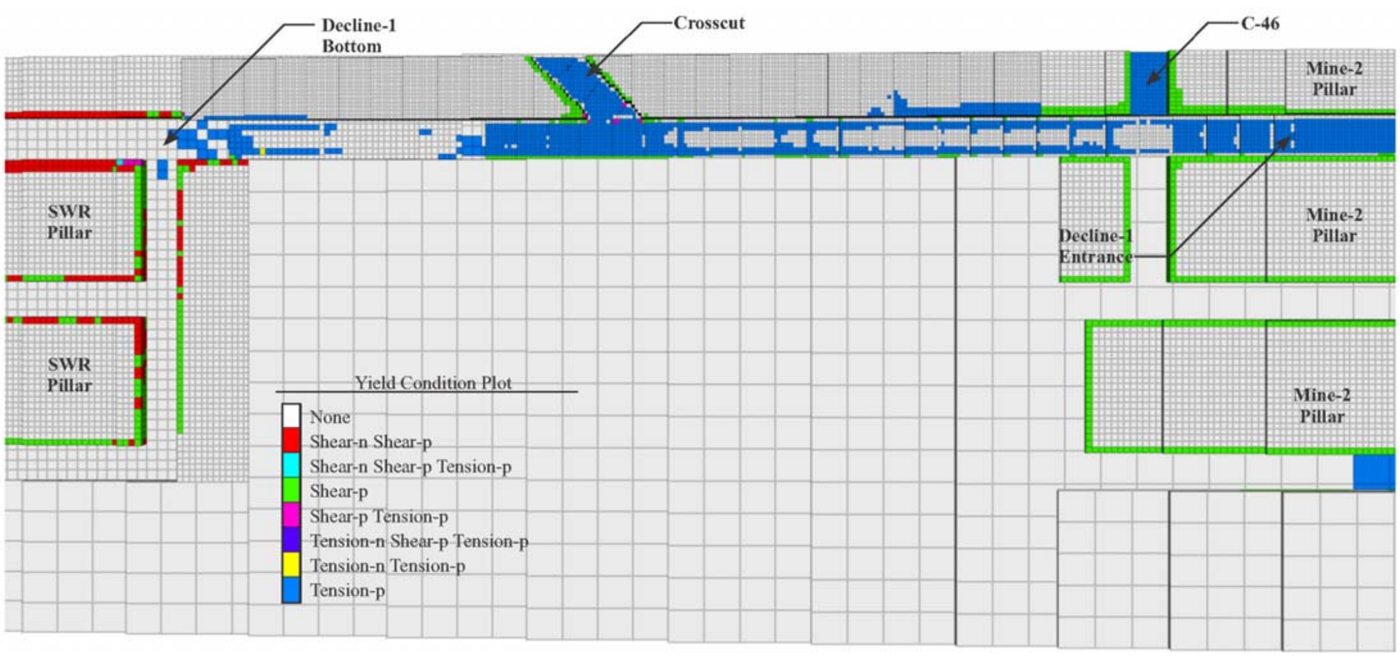
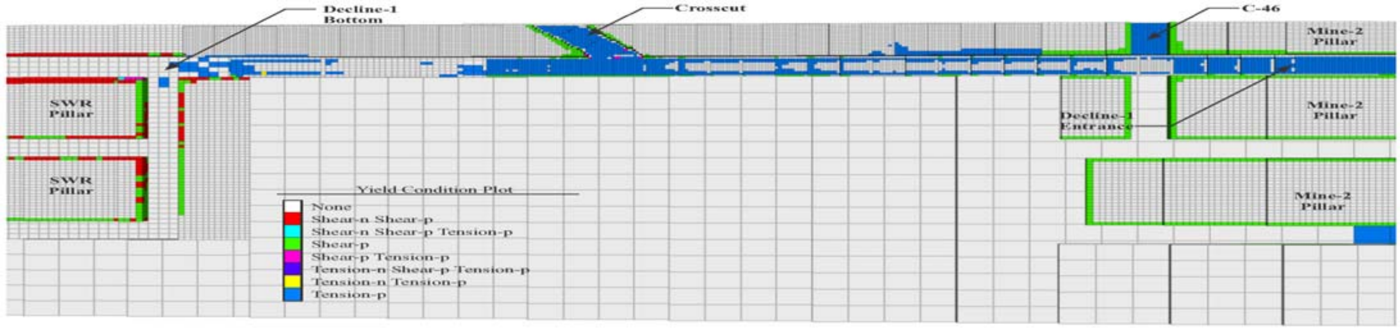


Fig. 7a. Yield condition plot in Decline-1, arched-support scenario (plane parallel to decline floor).



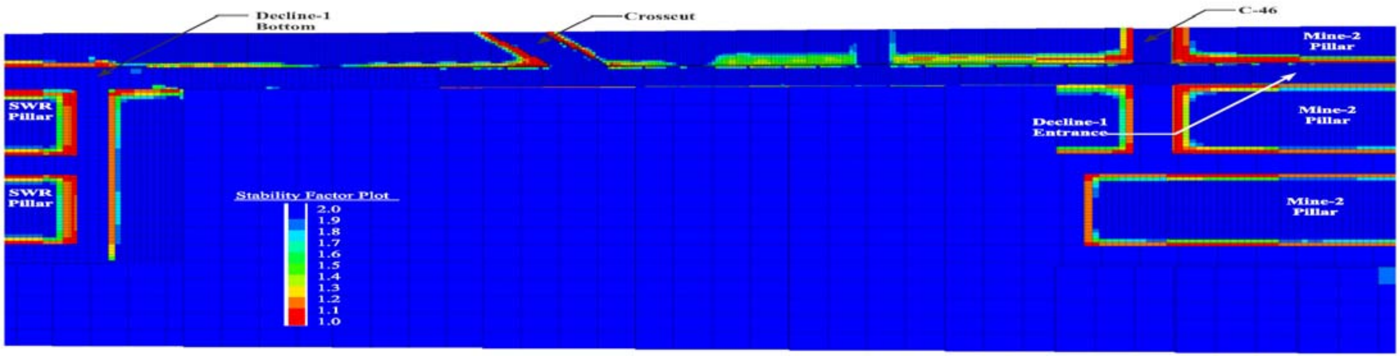


Fig. 7b. SF plot in Decline-1, arched-support scenario (plane parallel to decline floor).

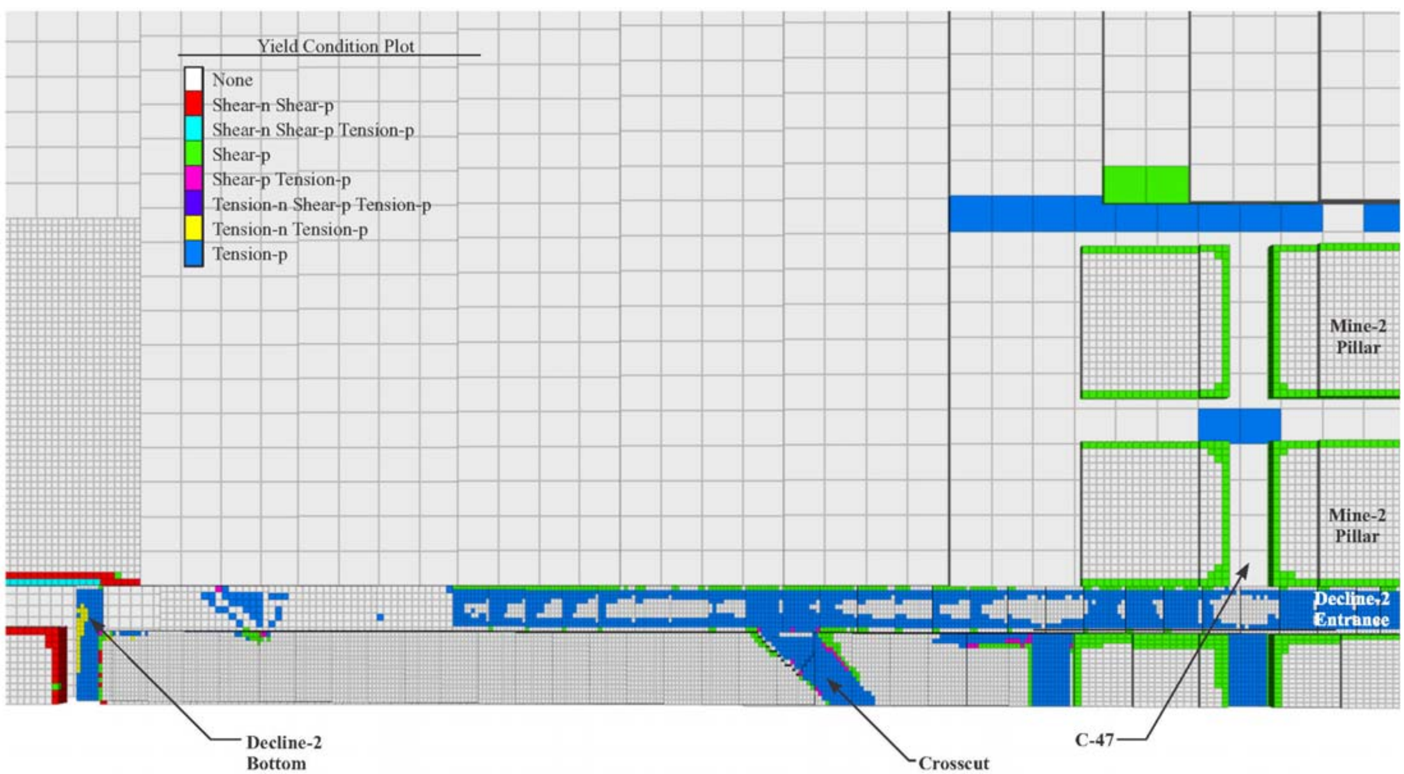


Fig. 7c. Yield condition plot in Decline-2, arched-support scenario (plane parallel to decline floor).

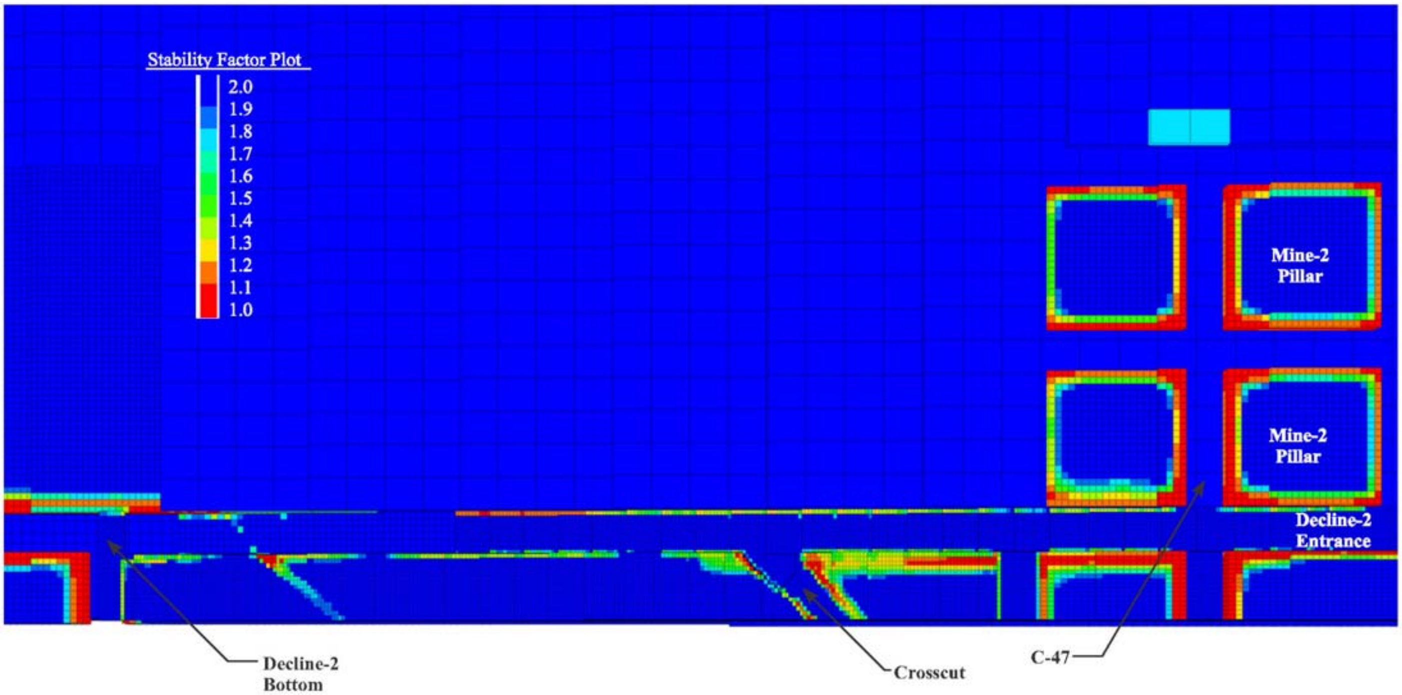
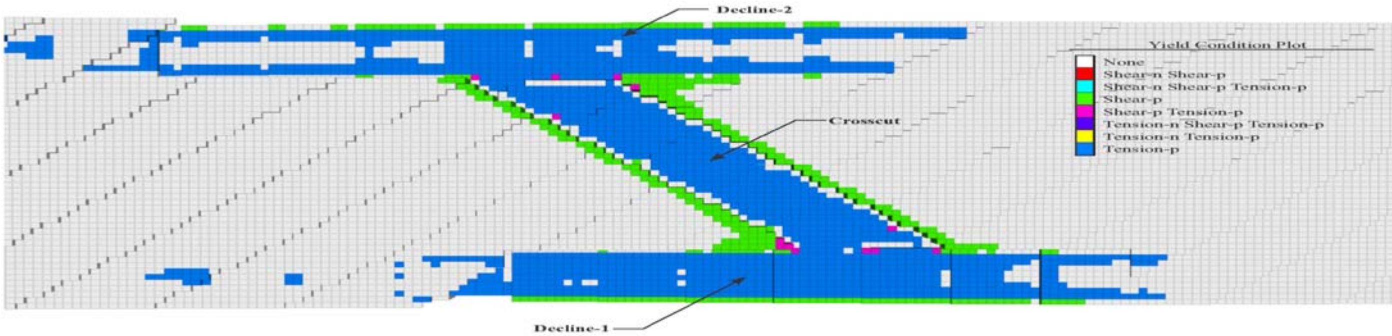


Fig. 7d. SF plot in Decline-2, arched-support scenario (plane parallel to decline floor).

Fig. 8a. Yield condition plot in inter-decline crosscut, arched-support scenario (plane parallel to crosscut floor).



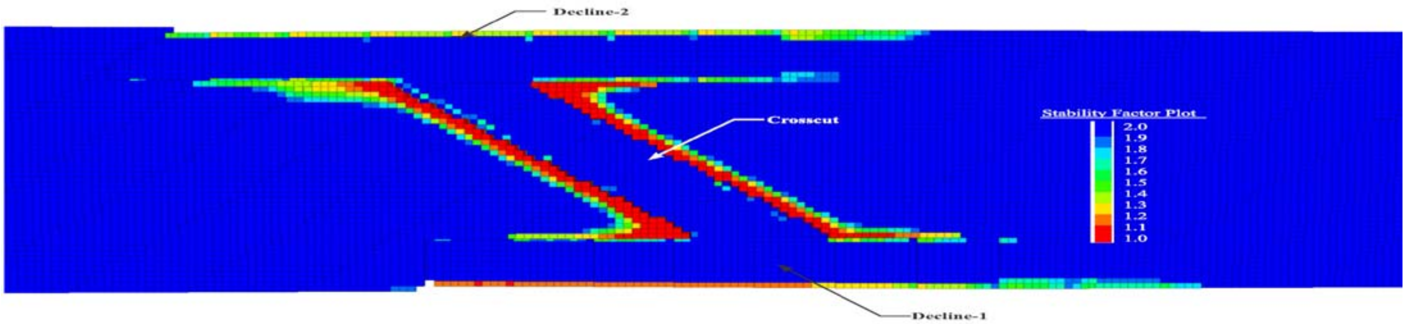


Fig. 8b. SF plot in inter-decline crosscut, arched-support scenario (plane parallel to crosscut floor).

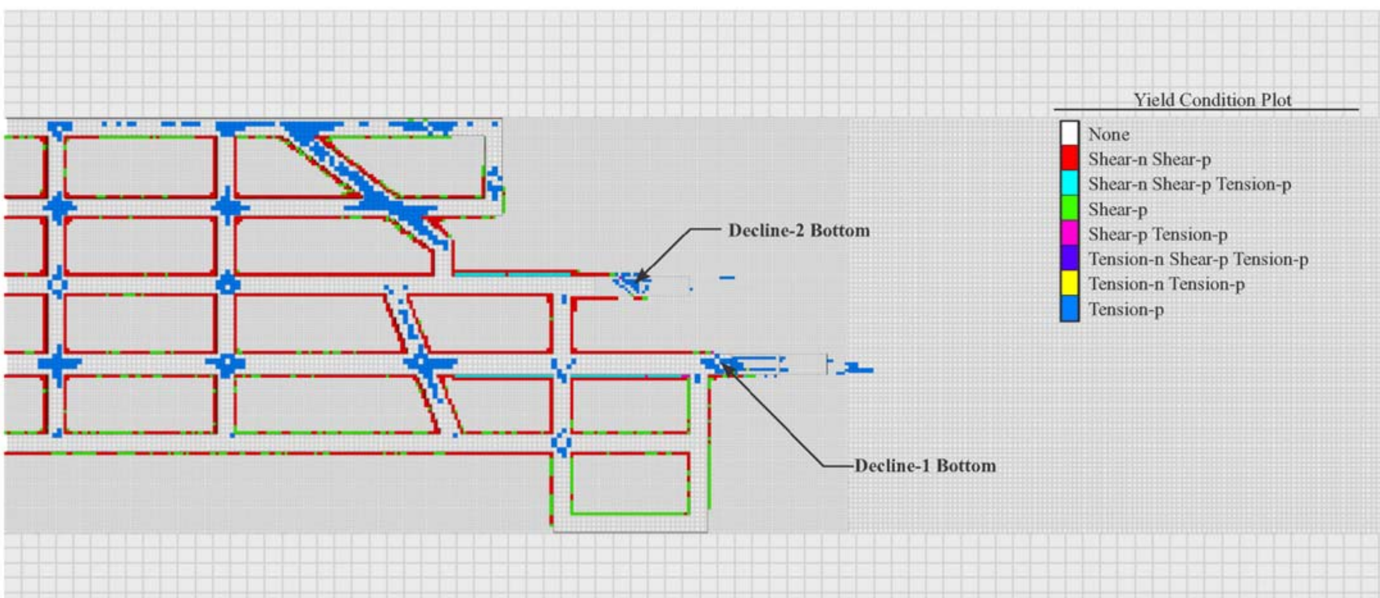


Fig. 9a. Yield condition plot in SWR Workings, arched-support scenario.

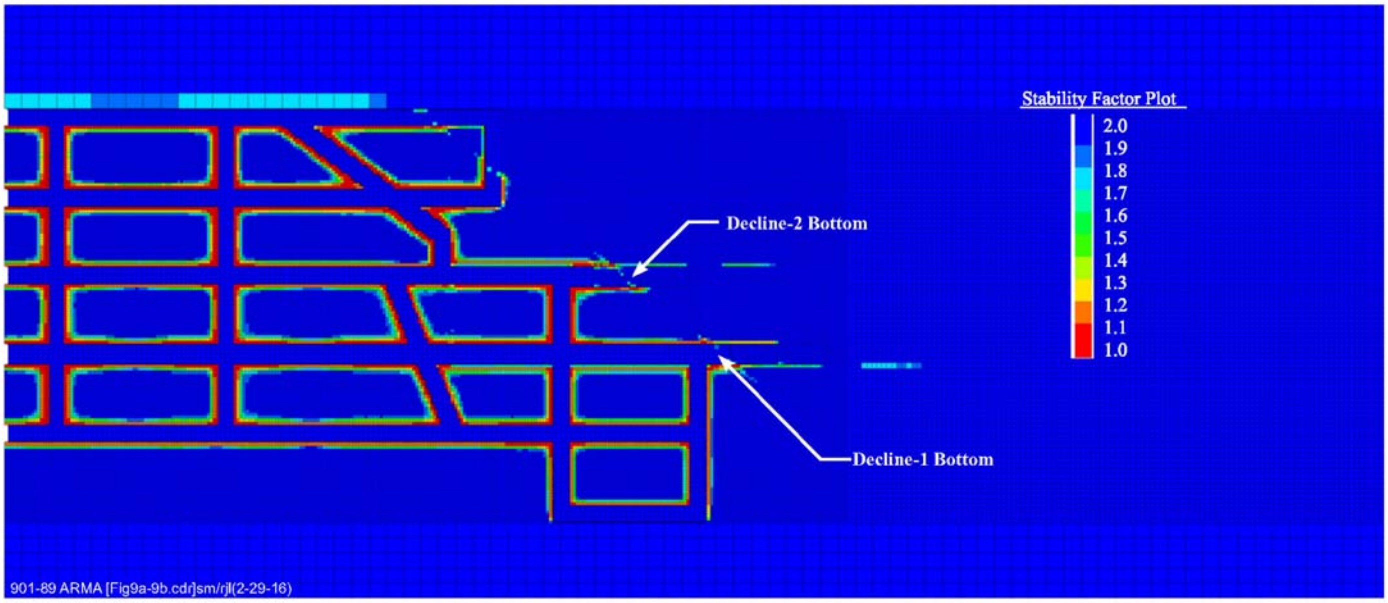


Fig. 9b. SF plot in SWR workings, arched-support scenario.

modeled with 26 ft of interburden between the Mine-2 (mid-level) and lowermost SWR workings.

In addition to the stability of the rock mass in and around the declines, the integrity of the primary support (roof bolts) and standing supports (arches) were also evaluated, which had been simulated concurrently in the decline model. The peak stress in the roof bolts was found to be less than 25,000 psi, as the peak stresses were observed at the decline-crosscut intersections. However, no bolts were observed to have fully yielded under the ground load. The peak stress in the steel sets was found to be lower than 35,000 psi; again, the peak values occurring around the decline-crosscut intersections. Though this peak stress is less than the 50,000 psi yield strength of the steel beams, the resultant support SF is less than 2, suggesting that more roof support was advisable in the decline-crosscut intersections. In contrast, the peak arch support stress values were less than 20,000 psi elsewhere along declines. The peak vertical displacement was approximately 1.5 inches in the arched supports. Overall, the proposed roof bolting and standing ground support are likely to be adequate within the declines, but a higher level of support was advised for the decline/crosscut intersections.

5. CONCLUSIONS

This study evaluated the stability of two proposed declines at Skyline, which are planned to ramp down from the LOA Seam mains in Mine-2 (mid-level) to the SWR mains (lower level). Results of the analyses indicated that the declines in the proposed geometry are likely to be stable with arched supports outby of the declines. Rib yielding and spalling is anticipated at the decline/crosscut intersections due to their initially proposed angle of contact and higher required ground support density, which resulted in a design change. Rather than the 45° design, the crosscut was actually excavated at 90°from the declines. The proposed ground support (roof bolting and standing support) was found to be adequate elsewhere in the declines and mine workings. Slight rib yielding and spalling was to be anticipated at the decline entrances. The FLAC3D modeling indicated that the excavation of the two declines was unlikely to have an adverse impact on the stability of mains in either Mine-2 or SWR mains. The results implied likely long-term service life of the mains, despite the relatively thin (26 ft) interburden between the mains. The fault as modeled is unlikely to adversely affect the stability of either decline or the SWR mains pillars.

Since the completion of the study, both the declines and joining crosscuts have been fully excavated in 2015, and ground supports have been installed as proposed. The interburden sandstone was found to be in a better state relative to the assumptions in the study, almost fully devoid of joints and discontinuities. A Segment of one of the declines experienced bad ground in the roof at the fault zone, which has been remediated with installation of arched support and backfilling with low density cementitious material. All the mains entries in the lower SWR workings have been driven from the bottom of the respective declines and no significant ground control issues have been observed in them. Overall, the declines and their adjacent structures have been performing as anticipated devoid of significant ground instabilities.

6. REFERENCES

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