Non-Q Design Analysis Cover Sheet

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1.0 PURPOSE

The main purpose and objective of this analysis is to confirm the validity of the ground support design for Busted Butte Test Facility (BBTF). The highwall stability and adequacy of highwall and tunnel ground support is addressed in this analysis. The design of the BBTF including the ground support system was performed in a separate document (Reference 5.3). Both in situ and seismic loads are considered in the evaluation of the highwall and the tunnel ground support system.

In this analysis only the ground support designed in Reference 5.3 is addressed. The additional ground support installed (still work in progress) by the constructor is not addressed in this analysis. This additional ground support was evaluated by the A/E during a site visit and its findings and recommendations are addressed in this analysis.

2.0 QUALITY ASSURANCE

This design analysis activity has been evaluated in accordance with QAP-2-0 (Activity Title: 12672450M1 Review Construction Configuration of Busted Butte) and found not to be applicable to QA program.

3.0 METHOD

The design of the BBTF was performed in Reference 5.3. In this analysis, both empirical and analytical methods are used to evaluate the designed ground support system for the highwall and the tunnel. The empirical design, the Norwegian Geotechnical Institute (NGI) classification system (Reference 5.1) is used in Reference 5.3 to estimate the ground support requirements. For analytical design, computer models are used to evaluate the stability of the highwall and the opening. The model is analyzed under in situ and seismic loading conditions to assess the rock mass behavior, highwall and opening stability, and ground support performance. The details are presented in Section 7.

4.0 DESIGN INPUTS

4.1 DESIGN PARAMETERS

4.1.1 Opening Dimensions

The opening dimensions used in this analysis are presented in Reference 5.3. The highwall dimensions are from Figure 4A (Titled: Busted Butte Facility N17W Section Looking West) in

Appendix F of Reference 5.3 indicating an approximately 10 m maximum height and near vertical face. The opening dimensions analyzed include a 5 m by 5 m opening with a slightly arched roof as shown in Figure 5 (Titled: Busted Butte Facility Underground Design) in Appendix E of Reference 5.3.

4.1.2 Rock Mass Properties

Rock mass Properties for three different units as shown in Figure 4A in Appendix F of Reference 5.3 namely: Vitrophere, Topopah Spring Non-welded and Calico Hills are used in the analyses. Rock mass properties for Vitrophere unit are presented in Section 4.3.1. Rock mass properties for Topopah Springs Non-welded and Calico Hills units are estimated as shown in Attachment I based on rock mass Quality (Q) value from NGI system. The following rock mass properties are used in computer analyses of the highwall and the opening:

Topopah Spring Non-Welded Unit:

Density = 1600 Kg/m³ (Source: Reference 5.3, Table 3.4)
Modulus of Elasticity (E) = 28.79 GPa (Source: Attachment I, Table 3)
Cohesion = 4.4 MPa (Source: Attachment I, Table 3)
Angle of Friction = 58° (Source: Attachment I, Table 3)
Tensile Strength = 2.51 MPa (Source: Attachment I, Table 3)
Bulk Modulus (B) = 16 GPa (calculated as $B=E/[3(1-2\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio)
Shear Modulus (S) = 12 GPa (calculated as $S=E/[2(1+\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio)

Calico Hills Unit:

Density = 1300 Kg/m³ (Source: Reference 5.3, Table 3.4)
Modulus of Elasticity (E) = 28.79 GPa (Source: Attachment I, Table 3)
Cohesion = 0.9 MPa (Source: Attachment I, Table 3)
Angle of Friction = 55° (Source: Attachment I, Table 3)
Tensile Strength = 0.59 MPa (Source: Attachment I, Table 3)
Bulk Modulus (B) = 16 GPa (calculated as $B=E/[3(1-2\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio)
Shear Modulus (S) = 12 GPa (calculated as $S=E/[2(1+\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio)

Poisson's ratios for Topopah Spring non-welded and Calico Hills units are presented in Section 4.3.2.

4.1.3 Seismic Loads

The highwall and opening stability and ground support performance are assessed under seismic loading conditions. Mean peak horizontal and vertical acceleration of 0.37g (Reference 5.5, Table A-2) is applied to the models statically. Seismic loads were not considered in the original design of the BBTF as presented in Reference 5.3.

4.1.4 Q Values

The site specific Quality (Q) values for the Topopah Spring and Calico Hills units are presented in Reference 5.3. The Q values were used in Reference 5.3 in estimating ground support needs by utilizing empirical design approach. The worst Q values are also used in Attachment I to rock mass properties. The lowest Q values are used for conservatism.

Topopah Springs Q Rating:

Q (Portal Zone) = 5 (Reference 5.3, Section 4.2)
Q (Drift and Test Facility) = 15 (Reference 5.3, Section 4.2)
Q (Test Room Intersection) = 2.5 (Reference 5.3, Section 4.2)

Calico Hills Q Rating:

Q (Portal Zone) = 5 (Reference 5.3, Section 4.2)
Q (Drift and Test Facility) = 15 (Reference 5.3, Section 4.2)
Q (test Room Intersection) = 2.5 (Reference 5.3, Section 4.2)

4.1.5 Input Parameters for Ground Support Calculations

Numerical representation of rock bolts by cable elements in FLAC (see Section 6.0 for definition) requires the following bolting parameters which are presented with a detailed discussion in Reference 5.2. About 60% relaxation is applied for ground support analyses based on Reference 5.2 (see Section 7.3.2 of this analysis for details).

Bolt Type: The Swellex Bolting System (Reference 5.2, Section 4.1 and Attachment I)

A = 258 mm² (Reference 5.2, Section 4.1)
E = 200 GPa (Reference 5.2, Section 4.1)
T = 110 KN (Reference 5.2, Section 4.1)
SBO = 73.3 KN/m (=T/bolt length=110/1.5=73.3 KN/m) (Reference 5.2, Section 7.15.1)
KBO = 0.733 GN/m/m (=ΔSBO/ΔU=73.3/0.1×10⁻³=0.733 GN/m/m) (Reference 5.2, Section 7.15.1)

Bolt Type: Hollow continuous threaded steel bar by Williams (Reference 5.2, Section 4.1)

$A = 439 \text{ mm}^2$ (Reference 5.2, Section 4.1)

$E = 200 \text{ GPa}$ (Reference 5.2, Section 4.1)

$T = 267 \text{ KN}$ (Reference 5.2, Section 4.1)

$SBO = 0.575 \text{ MN/m}$, $KBO = 16.34 \text{ GN/m/m}$ (Reference 5.2, Section 4.1)

The E, T, SBO, and KBO values for both rock bolt types are scaled for 1.524 m rock bolt spacing to account for 3-dimensional averaging effect in the model along the tunnel length and highwall face. The forces and moments calculated then must be multiplied by 1.524 to obtain their actual values. The rock bolt pattern and spacing is based on the information presented in Reference 5.3. Bolting pattern is actually less than 1.524 m for most cases but is considered 1.524 m conservatively.

4.2 CRITERIA

There are no requirements identified from higher tier requirements documents such as Exploratory Studies Facility Design Requirements (ESFDR) document (Reference 5.5). The test interference requirements were communicated to the original designer (Reference 5.3) and the constructor by the Test Coordination Office (TCO) during the original design and during construction and are not addressed here.

4.3 ASSUMPTIONS

4.3.1 Rock Mass properties for Vitrophyre Unit

Rock mass properties for Vitrophyre unit is not available from Reference 5.3. The rock mass properties are estimated to be similar to the TSw2 unit in the ESF. Rock mass properties corresponding to Category 3 from Reference 5.2 are assumed and used in this analysis. This assumption is based on the existing information on the different welded tuff units in Yucca Mountain and Originator's personal observations at the Busted Butte site. The following data are assumed and used in computer analysis:

Vitrophyre Unit:

Poisson's Ratio (ν) = 0.21 (Source: Reference 5.2, Section 4.1)

Modulus of Elasticity (E) = 12.55 GPa (Source: Reference 5.2, Section 4.1)

Density = 2274 Kg/m³ (Source: Reference 5.2, Attachment V)

Cohesion = 2.2 MPa (Source: Reference 5.2, Section 4.1)

Angle of Friction = 50° (Source: Reference 5.2, Section 4.1)

Tensile Strength = 1.60 MPa (Source: Reference 5.2, Section 4.1)

Bulk Modulus (B) = 7.21 GPa (calculated as $B = E/[3(1-2\nu)]$; where E is the Modulus

Shear Modulus (S) = 5.19 GPa of Elasticity and ν represents Poisson's Ratio)
(calculated as $S=E/[2(1+\nu)]$; where E is the Modulus of Elasticity and ν represents Poisson's Ratio)

4.3.2 Poisson's Ratio

Poisson's ratio for the Topopah Springs Non-Welded and Calico Hills units is assumed to be 0.2. This value is based on the PTn unit properties in Reference 5.2, Section 4.1. It is assumed that properties of these units are similar to non-welded PTn unit at the site.

4.3.3 Initial Stresses

Initial stresses used in the computer model are estimated based on the gravitational stresses induced by the weight of the overburden ($\sum h_i \rho_i g$, where h_i and ρ_i are thickness and density for each rock mass unit). The depth of the opening analyzed is estimated from the geologic cross sections presented in Reference 5.3. The horizontal to vertical in situ stress ratios of 0.25, 0.5, and 1.0 are used in this analysis. This range was recommended in Reference 5.2 and has been used in portal and underground designs in the project. It should be noted that the changes to the overburden estimates in the order of few meters will not affect the outcome of the computer analysis results. The estimated initial stresses are considered to be appropriate and representative of the Busted Butte site and will not require reverification. The initial stresses are used throughout the computer analysis.

Vertical Stress for Highwall Model:

The cross sectional depth in the model is assumed to include of 32 m of Vitrophyre, 5 m of Calico Hills, and 43 m of Non-Welded Topopah Spring units.

$$\text{Vertical Stress (Bottom of the Model)} = [(1300 \times 43) + (1600 \times 5) + (2274 \times 32)] \times 9.81 = 1.341 \times 10^6$$

Vertical Stress for the Tunnel Model:

The cross sectional depth in the model is assumed to include 37.5 m of Non-Welded Topopah Springs and 62.5 m of Calico Hills units.

$$\text{Vertical Stress (Bottom of the Model)} = [(1300 \times 62.5) + (1600 \times 37.5)] \times 9.81 = 1.386 \times 10^6$$

Where Stresses are in Pa and 9.81 is the gravitational load.

4.4 CODES AND STANDARDS

Not Used.

5.0 REFERENCES

- 5.1 Barton, N., Lien, R., and Lunde, J., "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, Vol. 6, No. 4, pp. 189-236, 1974.
- 5.2 CRWMS M&O Design Analysis, "ESF Ground Support Design Analysis," Document Identifier: BABEE0000-01717-0200-00002 REV 00.
- 5.3 "Design Report for the UZ Transport Test, Busted Butte Test Facility," by Sub Terra, Inc., Dated: 03/06/98.
- 5.4 Qualification Documentation for Fast Lagrangian Analysis of Continua (FLAC) Version 3.30, Document Identifier: 30022-2003 REV 0.
- 5.5 Yucca Mountain Site Characterization Project, "Exploratory Studies Facility Design Requirements," YMP/CM-0019 Revision 2, ICN 1.
- 5.6 Fast Lagrangian Analysis of Continua (FLAC) Version 3.30, Computer Software User's Manual, Volumes I, II, III, and IV, Itasca Consulting Group, Inc., Minneapolis, Minnesota, 1996.
- 5.7 Hoek, E., Kaiser, P. K., and Bawden, W. F., Support of Underground Excavations in Hard Rock, Balkema, Rotterdam, 1995.
- 5.8 CRWMS M&O, "Confirmation of Empirical Design Methodologies," BABEE0000-01717-5705-00002 REV 00.
- 5.9 Jager, J. C. and Cook, N. G. W., Fundamentals of Rock Mechanics, Third Edition, Chapman and Hall, London, pp. 95-97, 1979.
- 5.10 CRWMS M&O, "Yucca Mountain Site Geotechnical Report," B000000000-01717-5705-00043 REV 01.

6.0 USE OF COMPUTER SOFTWARE

Fast Lagrangian Analysis of Continua (FLAC), Version 3.30 (CSCI: 30022 V3.30) is used to perform the analyses. The analyses were performed on a computer with a Pentium microprocessor. FLAC is approved for use in design in accordance with M&O Computer Software Quality Assurance procedures. FLAC software is appropriate for the applications used in this analysis. FLAC was obtained from the Software Configuration Management (SCM) in accordance with the applicable

M&O procedures. FLAC software was used **within the range of validation** as specified in software qualification documentation (Reference 5.4). A **complete** listing of the input files used in the design analysis are provided in Attachment II. The **outputs** are presented and described in Section 7.0 and its subsections. Detailed description of the **FLAC** and its fields of application are presented in Reference 5.6.

7.0 DESIGN ANALYSIS

7.1 INTRODUCTION

The Busted Butte Test Facility (BBTF) was **designed and constructed** to study the lower portion of Topopah Springs and Calico Hills Formations. Design criteria was provided by the Test Coordination Office (TCO) to Sub Terra, Inc. A **portal** and underground design was prepared and on-site support was provided throughout construction by Sub Terra that is documented in Reference 5.3. This analysis is performed to **confirm the validity** of the design of the highwall and the underground portion of the BBTF and to **evaluate the adequacy** of the installed ground support throughout the facility.

The stratigraphy exposed at Busted Butte **has been** correlated to be similar to the rock units underlying beneath the proposed repository horizon at Yucca Mountain. The Busted Butte site was considered to be an easily accessible area for **testing** the migration of radio-nuclides within the unsaturated zone beneath the potential repository. In order to minimize the surface weathering effects, the hydraulic tests proposed at the **Busted Butte** were planned to be carried out underground, beneath a minimum of 25 m of rock cover (Reference 5.3). To provide access underground, an approximately 35 m long and 3 m in diameter **tunnel plus** a 25 m long and 5 m diameter extension was designed and constructed at **Busted Butte site** (Reference 5.3). In addition, a 15 m long, 5 m wide, and 5 m tall test alcove was required to **be driven** perpendicular to the tunnel at about 13 m from the end of the main adit (Reference 5.3).

The ground support system for the facility was **designed by** Sub Terra as documented in Reference 5.3. After the completion of the facility, the **constructor** installed additional support underground to enhance stability. In this analysis only the **ground support** designed in Reference 5.3 is analyzed. The additional ground support installed by the **constructor** is not analyzed here. Both in situ and seismic loads are considered in the evaluation of **the highwall** and the tunnel ground support system.

Rock mass properties from Reference 5.3 were **used in the analyses**. In areas where no data was available, assumptions were made based on **previous** experiences at the ESF site and were documented in Section 4.3.

7.2 SITE GEOLOGY

The geology of the BBTF was presented in detail in Reference 5.3 and, therefore, it is not repeated here.

7.3 PORTAL AREA DESIGN CONFIRMATION AND ANALYSES OF THE HIGHWALL

The designed portal consisted of a highwall approximately 10.3 m to 14.9 m high and two side walls tapering down from the highwall to the point where pad intersected original ground level (Reference 5.3). The width of the highwall was designed to be 25 m. The slope at the highwall was designed to be 74° (3.5 V:1H), Reference 5.3.

During the construction, the upper half of the highwall was broken along a cooling joint which was near-vertical. The lower half was constructed with a small bench and at the designed slope (see Reference 5.3, Appendix F, Figure 4A). The constructed highwall height is approximately 10 m based on Figure 4A in Appendix F of Reference 5.3. The computer analyses are performed assuming a vertical slope at this highwall in order to simulate the constructed conditions at the field. A detailed description of the wedge analyses of the slopes at the portal box-cut are presented in Reference 5.3. The factors of safety for supported and unsupported critical wedges at the slopes are presented in Reference 5.3. The support design was based on the ubiquitous joint philosophy using pattern bolting rather than spot-bolting to address all potential wedges.

In this analysis, a two dimensional model of the highwall was generated and analyzed using FLAC software. Both supported and unsupported highwall were analyzed subjected to in situ and seismic loading conditions.

7.3.1 Results of the In Situ Loading Condition of the Highwall

In order to evaluate the stability of the BBTF highwall immediately after excavation, a two dimensional model representing the rock mass at the highwall was built. Figure 2 shows the grid used in the analyses after the box-cut excavation. Far field mesh boundaries were set sufficiently away from the highwall and finer grid was used near the highwall to achieve accuracy in numerical calculations. The surface was sloped to approximate the existing conditions in the field. Figure 3 shows the close up of the grid near the highwall. The geology of the site was based on Figure 4A in Appendix F of Reference 5.3.

For the in situ loading condition, the Mohr-Coulomb failure criterion was used to capture the post-elastic rock behavior (see Figure 1). The in situ stress field is gravitational, with the vertical and

horizontal stresses approximated as discussed in detail in Reference 5.2. The vertical stresses were computed using overburden rock mass loads and the horizontal stresses are estimated using horizontal to vertical stress ratios (K_0) of 1.0, 0.5, and 0.25, which give the most extreme stress conditions around the opening (see Reference 5.2 for detailed discussion). The results of the analyses are presented in terms of the safety factors and Mohr-Coulomb failure envelop at the highwall. The strength/stress ratio contours are presented in Figure 4, indicating stable conditions near the highwall. For $K_0=1.0$, and 0.5 a small stress zone is indicated near the foot of the highwall mainly due to existence of the sharp corner at the toe of the wall. The safety factors are registered equal to 8 and higher indicating stable conditions at the highwall. This can also be concluded from the Mohr-Coulomb failure envelope plot in Figure 5.

7.3.2 Ground Support Analyses at the Highwall Under In Situ Loads and Installation of Rock Bolts

The in situ loading condition was analyzed after installation of the ground support system in order to assess their performance. Both fully grouted and Swellex type rock bolts were installed as shown in Figure 6. Three 3 m long Swellex rock bolts and two 5 m long fully grouted rock bolts were installed in the model to represent the ground support installed at the highwall in the field. The rock bolts represent a square pattern as shown in Figure 3A in Appendix F of Reference 5.3. A 60% initial ground relaxation was applied in the analyses based on the discussion presented in Section 7.12.4.1 of Reference 5.2. This estimates that 60% of the initial relaxation takes place prior to the installation of rock bolts in the highwall. This is a conservative estimate based on the fact that the elastic response of the rock due to the excavation is almost instantaneous and actually takes place prior to installation of the ground support system. For more detail on the subject refer to the discussion presented in Section 7.12.4.1 of Reference 5.2.

The results of the rock bolts subjected to in situ loads are presented in Figures 6 and 7 in terms of axial forces and safety factors. The results show that the safety factors are very high as expected. In summary, the results of the analyses of the unsupported and supported highwall under in situ loads indicate stable conditions. Any potential for loosening of small pieces was mitigated by installation of patterned rock bolts and welded wire fabric at the highwall.

7.3.3 Seismic Analysis of the Highwall

The seismic design philosophy for the ESF is addressed in detail in Reference 5.2. The seismic input parameters are provided in Reference 5.5. For the seismic design of the BBTF highwall, the supported slope is subjected to quasi-static seismic loads after the in situ loading has been applied to the model. The state of stresses at the Highwall is then estimated. In addition, the effects of the seismic loads on the ground support components are determined. Maximum seismic loadings of 0.37g from potential earthquakes were considered for both horizontal and vertical directions where g is the gravitational acceleration. The maximum amplitude of seismic loadings were considered

in a quasi-static manner. Specifically, the seismic accelerations of 0.37g were superimposed onto the gravitational acceleration.

The results indicate that the model remains elastic and no plasticity is indicated at the Highwall due to the seismic loading. Mohr-Coulomb Failure envelope plot for shear stress-normal stress space is plotted and shown in Figure 8 that indicates no failure due to seismic loading. The results of the rock bolts subjected to seismic loads are presented in Figures 9 and 10. By comparing Figure 9 to Figure 6 it can be seen that the axial loads are only slightly increased (for $K_o=0.5$, and $K_o=1$) due to seismic loads. For the $K_o=0.25$ case the loads are almost doubled but are still well below the rock bolt's loading capacity. Figure 10 indicates that the safety factors still remain very high. In summary, the results of the analyses of the supported highwall under in situ plus seismic loading conditions show that the slope should remain stable during an earthquake. Any potential for loosening of small pieces during the passage of the seismic wave is minimized by installation of patterned rock bolts and welded wire fabric at the highwall. In addition to the patterned rock bolts and welded wire fabric at the portal face, five steel sets have been installed at the portal entrance and shotcrete has been applied around the portal opening to further enhance stability near the opening.

7.4 BBTF UNDERGROUND DESIGN CONFIRMATION

The empirical design and the analyses of the opening due to wedge failure is presented in Reference 5.3 and will not be repeated here. Empirical assessment of the rock support requirements were obtained from the Q values using the Norwegian Geotechnical Institute (NGI) classification system developed by Barton et al. (1974), Reference 5.1. The results were summarized in Reference 5.3, Table 4. Based on the estimated Q values only the Access Drift/Test Alcove Intersection required installation of rock bolts on 1.5 m centers with 50 mm of steel fiber reinforced shotcrete application (Reference 5.3, Table 4). The initial design by Sub Terra was modified as construction proceeded and was documented in Reference 5.3. The final design of the underground portion, in Reference 5.3, required application of shotcrete above the springline throughout the facility in addition to the installation of patterned rock bolts and welded wire fabric (Reference 5.3, Section 5.3). The ribs were recommended to be treated with an application of sodium silicate throughout (Reference 5.3). To provide stability of rock ribs and roof this was approved by the Principal Investigator as it helped limit water loss from the formation during test operations (Reference 5.3, Section 5.4).

In this analysis, the underground portion is analyzed under in situ and seismic loads and stability of the opening is assessed. The installed rock bolts are analyzed to evaluate their performance. The opening is analyzed using a Mohr-Coulomb model similar to the highwall analyses.

7.4.1 Results of the In Situ Loading Analysis of the Tunnel

A two dimensional model in FLAC was created and used to perform the analyses. The opening

dimension analyzed represents a 5 m by 5 m tunnel with a slightly arched roof as shown in Figure 5 (Titled: Busted Butte Facility Underground Design) in Appendix E of Reference 5.3. The upper portion of the opening was placed in brown non-welded tuff unit (Topopah Springs) and the bottom portion was placed in whitish bedded tuff unit (Calico Hills). The model is representative of the majority of the underground portion especially that of the test alcove.

Figure 11 shows the grid used in the analyses with a close-up provided in Figure 12. The results of the in situ loading analyses are presented in Figures 13 through 17 for unsupported opening and K_0 values of 1, 0.5, and 0.25. Figure 13 shows the displacement vectors around the unsupported opening and as it can be seen the displacements are in the order of tenth of one millimeter. The safety factor plots for the unsupported opening are shown in Figure 14 indicating minimum safety factor of 6. The mohr-Coulomb failure envelope plot also indicates a stable opening under in situ loads. Vertical and horizontal closures due to tunnel excavation were estimated in the model by placing monitoring stations at the crown, invert, and both ribs. Vertical and horizontal closure measurements are estimated to be less than one millimeter in the model.

In summary, the results of the unsupported opening indicate a stable opening under excavation induced loads. This was also experienced during the construction.

7.4.2 Ground Support Analyses of the Tunnel Under In Situ Loads and Installed Rock Bolts

The in situ loading condition was analyzed after installation of ground support system to assess their performance. Four Swellex type rock bolts were installed as shown in Figure 18 and analyzed subjected to in situ loads. The results indicate minimal loads on the rock bolts as expected from the results of the unsupported opening. The safety factor estimates are presented in Figure 19.

7.4.3 Seismic Analysis of the Tunnel

The seismic analyses were performed similar to the highwall analyses and as explained in Section 7.3.3. The results indicate that the model remains elastic and no plasticity is indicated around the opening due to the seismic loading. Figure 20 shows that the safety factors decrease slightly due to the seismic loads in comparison to Figure 14. The minimum safety factor in Figure 20 approaches 5 for the $K_0=0.25$ case compared to 6 for the in situ loading case in Figure 14. The closure measurements in Figures 21 and 22 indicate that displacements will slightly increase but the closure is estimated to be still less than one millimeter. The results of the rock bolt analyses under seismic loading conditions (Figures 23 and 24) show minimal changes compared to the in situ loading results (Figures 18 and 19).

In summary, the analyses indicate that the opening should remain stable under seismic loading conditions. For underground structures, in general, only the portal areas are susceptible to damage

due to earthquake loads. The portal area in BBTF was further reinforced by installation of five steel sets extending outward from the opening. Additional rock bolts and shotcrete were applied to the highwall surrounding the portal area that further stabilize rock wedges and should minimize damage and chance of loosening of these wedges during an earthquake event.

7.5 INSTALLED GROUND SUPPORT SYSTEM

A site visit was conducted to observe the installed ground support at BBTF. During the visit, it was noticed that additional ground support is being installed underground by the constructor to address personnel safety. Subsequently, a letter was generated and sent to Construction Management Office (CMO) based on the findings of the site visit (Attachment III). The highwall ground support system was installed as it was required by Sub Terra design and appeared to be adequate pending the completion of the grouting of the rock bolts. Rock bolts (Swellex type) and wire mesh was installed underground and met the patterned design requirements. The shotcrete application above spring line was not completed as required by the design. Additional ground support was installed by the constructor apparently to address personnel safety that included a number of shotcrete pillars along the ribs and rebar at the crown at the test alcove and at the intersection area. The rebar was attached to the wire mesh with intentions to be used as a reinforcement to the shotcrete. The shotcreting of the rebars and the crown was unfinished at the time of the site visit. There were some concern at the part of the visitors (see Attachment III) about the concept of having a relatively thick rebar reinforced shotcrete at a practically flat crown. The results of the findings and A/E recommendations based on the site visit were addressed in detail in the letter to the CMO (Attachment III) and will be added in the conclusions. The additional ground support installed by the constructor (shotcrete pillars and rebars) were not considered in the analyses presented here. In other words, technically no credit was taken in this analysis to the constructor installed personnel safety ground support.

Fig. 1 Mohr-Coulomb Criterion for Rock Matrix in FLAC.

Fig. 2 Finite Difference Mesh Used for the BBTF Highwall Stability Analyses. Grid Dimensions Are in Meters. Input File: BHIK1.DAT

Fig. 3 Close-Up of the Grid Used for the BBTF Highwall Stability Analyses. Grid Dimensions Are in Meters. Input File: BHIK1.DAT

a)

b)

c)

Fig. 4

Strength/Stress Ratio Contours for the Mohr-Coulomb Plasticity Model for Unsupported BBTF Highwall, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Friction Angle Is in Degrees, and Cohesion and Tensile Strength Are in Pa. Grid Dimensions Are in Meters. Input File: (a) BHIK1.DAT, (b) BHIK2.DAT, and (c) BHIK3.DAT.

a)

b)

c)

Fig. 5

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space for Unsupported BBTF Highwall, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Friction Angle Is in Degrees, and Cohesion and Tensile Strength Are in Pa. Input File: (a) BHIK1.DAT, (b) BHIK2.DAT, and (c) BHIK3.DAT.

a)

b)

c)

Fig. 6

Axial Loads in Rock Bolts Installed at the BBTF Highwall Due to In Situ Loads, Rock Bolts 1, 2, and 5 Are Swellex Type and Rock Bolts 3 and 4 Are Fully Grouted Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a) BHIK1R.DAT, (b) BHIK2R.DAT, and (c) BHIK3R.DAT.

a)

b)

c)

Fig. 7

Ratio of Axial Load to Yield Strength of Rock Bolts Installed at the BBTF Highwall Due to In Situ Loads, Rock Bolts 1, 2, and 5 Are Swellex Type and Rock Bolts 3 and 4 Are Fully Grouted Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a) BHIK1R.DAT, (b) BHIK2R.DAT, and (c) BHIK3R.DAT.

a)

b)

c)

Fig. 8

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space for Unsupported BBTF Highwall, In Situ + Seismic Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Friction Angle Is in Degrees, and Cohesion and Tensile Strength Are in Pa. Input File: (a), (b), and (c) BHISEIS.DAT.

a)

b)

c)

Fig. 9

Axial Loads in Rock Bolts Installed at the BBTF Highwall Due to In Situ + Seismic Loads, Rock Bolts 1, 2, and 5 Are Swellex Type and Rock Bolts 3 and 4 Are Fully Grouted Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a), (b), and (c) BBSEIS.DAT.

a)

b)

c)

Fig. 10

Ratio of Axial Load to Yield Strength of Rock Bolts Installed at the BBTF Highwall Due to In Situ + Seismic Loads, Rock Bolts 1, 2, and 5 Are Swellex Type and Rock Bolts 3 and 4 Are Fully Grouted Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: Input File: (a), (b), and (c) BBSEIS.DAT.

Fig. 11 Finite Difference Mesh Used for the BBTF Tunnel Stability Analyses. Grid Dimensions Are in Meters. Input File: BHIK1.DAT

Fig. 12 Close-Up of the Grid Used for the BBTF Tunnel Stability Analyses. Grid Dimensions Are in Meters. Input File: BHIK1.DAT

a)

b)

c)

Fig. 13

Displacement Vectors Around the Unsupported BBTF Tunnel Opening for the Mohr-Coulomb Plasticity Model, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Displacements and Grid Dimensions Are in Meters. Input File: (a) BB1K1.DAT, (b) BB1K2.DAT, and (c) BB1K3.DAT.

a)

b)

c)

Fig. 14

Strength/Stress Ratio Contours for the Mohr-Coulomb Plasticity Model for Unsupported BBTF Tunnel, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Friction Angle Is in Degrees, and Cohesion and Tensile Strength Are in Pa. Grid Dimensions Are in Meters. Input File: (a) BB1K1.DAT, (b) BB1K2.DAT, and (c) BB1K3.DAT.

a)

b)

c)

Fig. 15

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space for Unsupported BBTF Tunnel, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Friction Angle Is in Degrees, and Cohesion and Tensile Strength Are in Pa. Input File: (a) BB1K1.DAT, (b) BB1K2.DAT, and (c) BB1K3.DAT.

a)

b)

c)

Fig. 16

BBTF Tunnel Vertical Closure in Meters Where Closure is Measured Between the Two Monitoring Stations Located in the Model at the Centers of the Crown and the Invert. X-Coordinate Represents Number of Numerical Steps in the Calculation and the Y-Coordinate Shows the Closure in Meters for Unsupported Opening, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Input File: (a) BB1K1.DAT, (b) BB1K2.DAT, and (c) BB1K3.DAT.

a)

b)

c)

Fig. 17

BBTF Tunnel Horizontal Closure in Meters Where Closure is Measured Between Two Monitoring Stations at the Centers of the Left and Right Ribs. X-Coordinate Represents Number of Numerical Steps in the Calculation and the Y-Coordinate Shows the Closure in Meters for Unsupported Opening, In Situ Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Input File: (a) BB1K1.DAT, (b) BB1K2.DAT, and (c) BB1K3.DAT.

a)

b)

c)

Fig. 18

Axial Loads in Rock Bolts Installed at the BBTF Tunnel Due to In Situ Loads. Rock Bolts Are Swellex Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a) BB1K1R.DAT, (b) BB1K2R.DAT, and (c) BB1K3R.DAT.

a)

b)

c)

Fig. 19

Ratio of Axial Load to Yield Strength of Rock Bolts Installed at the BBTF Tunnel Due to In Situ Loads. Rock Bolts Are Swellex Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a) BB1K1R.DAT, (b) BB1K2R.DAT, and (c) BB1K3R.DAT.

a)

b)

c)

Fig. 20

Strength/Stress Ratio Contours for the Mohr-Coulomb Plasticity Model for Unsupported BBTF Tunnel, In Situ + Seismic Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Friction Angle Is in Degrees, and Cohesion and Tensile Strength Are in Pa. Grid Dimensions Are in Meters. Input File: (a), (b), and (c) BBSEIS.DAT.

a)

b)

c)

Fig. 21

BBTF Tunnel Vertical Closure in Meters Where Closure is Measured Between the Two Monitoring Stations Located in the Model at the Centers of the Crown and the Invert. X-Coordinate Represents Number of Numerical Steps in the Calculation and the Y-Coordinate Shows the Closure in Meters for Unsupported Opening, In Situ + Seismic Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Input File: (a), (b), and (c) BBSEIS.DAT.

a)

b)

c)

Fig. 22

BBTF Tunnel Horizontal Closure in Meters Where Closure is Measured Between Two Monitoring Stations at the Centers of the Left and Right Ribs. X-Coordinate Represents Number of Numerical Steps in the Calculation and the Y-Coordinate Shows the Closure in Meters for Unsupported Opening, In Situ + Seismic Loading Condition, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Input File: (a), (b), and (c) BBSEIS.DAT.

a)

b)

c)

Fig. 23

Axial Loads in Rock Bolts Installed at the BBTF Tunnel Due to In Situ + Seismic Loads. Rock Bolts Are Swellex Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a), (b), and (c) BBSEIS.DAT.

a)

b)

c)

Fig. 24

Ratio of Axial Load to Yield Strength of Rock Bolts Installed at the BBTF Tunnel Due to In Situ + Seismic Loads. Rock Bolts Are Swellex Type, (a) $K_0=1$, (b) $K_0=0.5$, and (c) $K_0=0.25$. Forces are in Newton. Grid Dimensions Are in Meters. Input File: (a), (b), and (c) BBSEIS.DAT.

8.0 CONCLUSIONS

The A/E was tasked to perform an analysis to address the stability of the highwall and the underground structure and to assess the adequacy of the ground support system in the Busted Butte Test Facility (BBTF). The original design of the BBTF was performed by a TCO consultant, SubTerra, Inc. The design called for rock bolts (both Swellex type and grouted rebar type) at the highwall. The underground portion required pattern bolting (Swellex type) with wire mesh in addition to shotcrete above the spring line based on the SubTerra Design.

Sub Terra design included empirical design approach using Q rating in addition to the wedge analysis of the box-cut slopes and the underground portion. The results of the Sub Terra Design and their recommendation are presented in Reference 5.3. The facility was constructed based on the Sub Terra design.

The analyses presented here included computer simulation of the box-cut and tunnel opening subjected to in situ and seismic loads. First, the stability of the highwall and tunnel were analyzed under excavation induced loads. Then the designed ground support was installed in the models and their performance was evaluated. Finally, the supported highwall and tunnel were subjected to seismic loads to address stability and assess ground support performance.

The results of the analyses of the highwall indicated that the designed ground support as installed was adequate in addressing the highwall stability under both in situ and seismic loads. The results of the analyses of the opening also indicate that the ground support design comprising rock bolts and welded wire fabric at the crown addresses the in situ and seismic loading requirements.

The Sub Terra design also called for shotcrete above the spring line throughout the facility. The shotcrete above the springline was not analyzed. The shotcrete application was determined to be required at the intersection of the Access Drift and the Test alcove based on Q values using the empirical design approach. The shotcrete application above springline then was recommended by Sub Terra in order to ensure stability and to mitigate loosening of the wedges at the crown. The shotcrete application has been completed along the access drift and the intersection area but was not installed throughout the facility. Based on the site visit (see Attachment III) a number of recommendations were made concerning the existing ground support at the BBTF. The following conclusions and recommendations are made based on the results of this analysis and the results of the site visit as discussed in detail in Attachment III.

- 1 - The highwall ground support system is installed as it was required by Sub Terra design and appears to be adequate if the grouting of the bolts has been completed. Addition of the five steel sets and shotcrete application around the portal opening further enhanced the portal stability. No further ground support is recommended to the highwall.

-
- 2 - Rock bolts (Swellex type) and wire mesh has been installed throughout the underground portion and meets the design requirements. The shotcrete application above spring line has not been completed as required by the design. Additional ground support was installed by the constructor apparently to address personnel safety that included a number of shotcrete pillars along the ribs and rebar at the crown. The rebar was attached to the wire mesh with intentions to reinforce the shotcrete. Even though the shotcrete is not installed in the crown in some areas as required by Sub Terra design, its application over the rebar in the crown is not recommended. The shadow areas behind the rebar cannot be adequately filled, the rebar is too far from the rock in most areas, and more importantly the additional weight of the added shotcrete would be self defeating. Removing the rebar entirely is not an option at this time and in some areas it may be enhanced or the smaller pieces removed if it does not interfere with testing. The shotcrete pillars provide no effective support but should be left alone at this time with no additional work required. No additional shotcrete is recommended underground at this point.
 - 3 - It is recommended that, at least three areas underground should be instrumented (using convergence pins) immediately to provide some measure of monitoring of the opening convergence. The instrumentation should have been done much earlier but it may still be an informative and effective way of monitoring.
 - 4 - The facility should be monitored routinely by qualified individuals. Any changes in ground conditions should be reported to the CMO immediately if noticed by the testing personnel.
 - 5 - Testing is underway and should not be disrupted by additional work unless absolutely necessary. There may be a small window between test phases that may allow for some additional work in the facility by future monitoring.

9.0 ATTACHMENTS

Attachment I - BBTF Rock Mass Properties

Pages: I-1 to I-4

Attachment II - Input Files for FLAC Analyses

Pages: II-1 to II-27

Attachment III - E-Mail to CMO, Subject: Busted Butte Test
Facility Ground Support

Pages: III-1 to III-2

BBTF ROCK MASS PROPERTIES

Rock mass mechanical properties for the Busted Butte Test Facility (BBTF) are calculated based on the Geological Strength Index (GSI) (Reference 5.7). GSI is an empirical method for assessing rock mass strength (considering water pressure as being negligible):

$$GSI = 9 \ln Q' + 44 \quad (1)$$

where $Q' = \left(\frac{RQD}{J_n} \right) \times \left(\frac{J_r}{J_a} \right)$,

RQD = rock quality designation,
 J_n = joint set number,
 J_r = joint roughness number,
 J_a = joint alteration number,

Calculation Method

The procedure for estimating rock mass properties using GSI is based on the approach by Hoek et al. (Reference 5.7, pp. 89–98) and is documented in the Task 3 design confirmation activity (Reference 5.8). The rock mass properties estimated in Reference 2 include rock mass modulus (E), cohesion (C), friction angle (ϕ), unconfined compressive strength (σ_{cm}) and tensile strength (σ_{tm}).

Rock mass modulus was determined based on the correlation of rock mass modulus and rock mass rating (RMR), with GSI substituted for RMR, such that

$$E = 10^{[(GSI - 10)/40]} \quad (2)$$

where E is the rock mass modulus (GPa).

The strength of the rock mass was determined based on the Hoek-Brown failure criterion for jointed rock masses as follows:

$$\sigma_1 = \sigma_3 + \sqrt{m_b \sigma_c \sigma_3 + s \sigma_c^2} \quad (3)$$

where σ_1 = strength of the jointed rock mass (MPa),
 σ_3 = confining stress (MPa),
 σ_c = intact unconfined compressive strength of the rock (MPa).

Parameters m_b and s are constants which depend on the characteristics of the rock mass. For undisturbed rock masses (e.g., machine-excavated rock), m_b and s are related to GSI as follows:

$$m_b = m_i e^{(GSI - 100)/28}, \text{ and} \quad (4)$$

$$s = e^{(GSI - 100)/9}. \quad (5)$$

The parameter m_i is the value of m_b for intact rock, and is determined based on laboratory test data (Reference 5.10).

Rock mass strength (σ_1) values were determined for a range of confining stress (σ_3) values. Using a Mohr-Coulomb approach (Reference 5.9), a least-square linear fit of σ_1 and σ_3 data sets was performed such that the slope and y-axis intercept of the linear fit corresponds to the confinement factor, N , and the rock mass unconfined compressive strength, σ_{cm} , respectively:

$$\sigma_1 = N \sigma_3 + \sigma_{cm}. \quad (6)$$

Mohr-Coulomb parameters cohesion (C) and friction angle (ϕ) are related to N and σ_{cm} as follows:

$$C = \frac{\sigma_{cm}}{2\sqrt{N}} \quad (7)$$

$$\phi = 2(\tan^{-1}\sqrt{N} - 45^\circ). \quad (8)$$

Rock mass tensile strength, σ_{tm} , was calculated according to the following relationship (Reference 5.7):

$$\sigma_{tm} = \frac{2C \cos \phi}{1 + \sin \phi}. \quad (9)$$

Input Data

GSI is estimated using the Q parameters determined from field observations in the BBTF. Worst case estimates of Q values are shown in Table 1 (Reference 5.3). The stratigraphic units in the BBTF include the Tptpv1/2 and the Calico Hills. For this assessment of rock mass properties, the intact material properties for Tptpv1/2 were assumed to be equal to the mean TSw2 values. The intact material properties for the Calico Hills were assumed to be equal to the mean PTn values. Intact material properties were based on Reference 5.10 and are shown in Table 2.

Results

Using the data in Tables 1 and 2, the GSI values based on Equation 1 are shown in Table 3. Rock mass properties for both the Tptpv1/2 and Calico Hills were calculated using the procedure described above, and are provided in Table 3.

Table 1. Worst Case Q Values in the Busted Butte Test Facility (Reference 5.3)

Stratigraphic Unit	RQD	Jn	Jr	Ja	Jw	SRF	Q
Portal Zone							
Tptpv1/2	90	12	2	3	1	1	5.0
Calico Hills	90	12	2	3	1	1	5.0
Drift and Test Facility							
Tptpv1/2	90	6	2	2	1	1	15.0
Calico Hills	90	6	2	2	1	1	15.0
Test Room Intersections							
Tptpv1/2	90	36	2	2	1	1	2.5
Calico Hills	90	36	2	2	1	1	2.5

Table 2. Intact Material Properties for the Busted Butte Test Facility¹

Stratigraphic Unit	Mean Intact Unconfined Compressive Strength, σ_c (MPa)	Hoek & Brown Intact Material Constant, m_i
Tptpv1/2	167.90	19.68
Calico Hills	6.37	150.97

¹The intact material properties for Tptpv1/2 were assumed to be equal to the mean TSw2 values. The intact material properties for the Calico Hills were assumed to be equal to the mean PTn values. Intact material properties were based on Reference 5.10.

Table 3. Rock Mass Material Properties in the Busted Butte Test Facility

Stratigraphic Unit	Geological Strength Index, GSI	Rock Mass Modulus, E (GPa)	Rock Mass Unconfined Compressive Strength, σ_{cm} (MPa)	Cohesion (Mpa)	Friction Angle (Degrees)	Tensile Strength (Mpa)
<u>Portal Zone</u>						
Tptpv1/2	58.5	16.30	19.49	2.8	58	1.64
Calico Hills	58.5	16.30	4.82	0.8	52	0.56
<u>Drift and Test Facility</u>						
Tptpv1/2	68.4	28.79	31.02	4.4	58	2.51
Calico Hills	68.4	28.79	5.93	0.9	55	0.59
<u>Test Room Intersections</u>						
Tptpv1/2	52.2	11.38	14.94	2.2	57	1.31
Calico Hills	52.2	11.38	4.26	0.8	51	0.54

Input Files for FLAC Analyses

```
*****
* File Name:  BHIK1.dat                *
* Description: Analysis at Highwall    *
* Support:  Unsupported                *
* Loads:  In Situ Loads Only (K0=1)    *
*****
```

CONFIG DYN EXTRA 1

* Mesh construction

gr 101,97

m m

```
gen -55,-30 -55 50 45 50 45,-30
gen -55,-30 -55 0 0,0 0,-30 r=0.909,0.909 i=1,27 j=1,21
gen -55 0 -55 30 0 30 0,0 r=0.909,1 i=1,27 j=21,81
gen -55 30 -55 50 0 50 0 30 r=0.909,1.1 i=1,27 j=81,98
gen 0 30 0 50 30 50 30 30 r=1,1.1 i=27,87 j=81,98
gen 0 0 0 30 30 30 30 0 r=1,1 i=27,87 j=21,81
gen 0,-30 0,0 30,0 30,-30 r=1,0.909 i=27,87 j=1,21
gen 30,-30 30,0 45,0 45,-30 r=1.1,0.909 i=87,102 j=1,21
gen 30,0 30,30 45,30 45,0 r=1.1,1 i=87,102 j=21,81
gen 30,30 30,50 45,50 45,30 r=1.1,1.1 i=87,102 j=81,98
gen line -55 50 45 10
m n reg 87,81
```

gen line 15,13 15,22

gen line 15,13 45,12.98

* Material Properties for Vitrophere

prop S=5.19e9 B=7.21e9 d=2274 coh=2.2e6 fric=50 ten=1.6e6 I=1,102 J=57,98

* Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I

Prop S=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,102 J=47,57

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,102 J=1,47

SET GRAV=9.81

* Set Initial Stresses

INI SYY=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

INI Sxx=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

INI Szz=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

* Set Boundary Conditiond

fix x i=1

fix x i=102

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

ini xdisp=0 ydisp=0

HIS XDIS I=57 J=65

HIS XDIS I=57 J=57

HIS YDIS I=57 J=65

HIS YDIS I=57 J=57

HIS XDIS I=56 J=62

HIS YDIS I=56 J=62

MOD NULL REG=59,62

STEP 8000

SAVE bhik1.SAV

RET

* File Name: BHIK2.dat *
* Description: Analysis at Highwall *
* Support: Unsupported *
* Loads: In Situ Loads Only (K0=0.5) *

CONFIG DYN EXTRA 1

* Mesh construction

gr 101,97

m m

gen -55,-30 -55 50 45 50 45,-30
gen -55,-30 -55 0 0,0 0,-30 r=0.909,0.909 i=1,27 j=1,21
gen -55 0 -55 30 0 30 0,0 r=0.909,1 i=1,27 j=21,81
gen -55 30 -55 50 0 50 0 30 r=0.909,1.1 i=1,27 j=81,98
gen 0 30 0 50 30 50 30 30 r=1,1.1 i=27,87 j=81,98
gen 0 0 0 30 30 30 30 0 r=1,1 i=27,87 j=21,81
gen 0,-30 0,0 30,0 30,-30 r=1,0.909 i=27,87 j=1,21
gen 30,-30 30,0 45,0 45,-30 r=1.1,0.909 i=87,102 j=1,21
gen 30,0 30,30 45,30 45,0 r=1.1,1 i=87,102 j=21,81
gen 30,30 30,50 45,50 45,30 r=1.1,1.1 i=87,102 j=81,98
gen line -55 50 45 10
m n reg 87,81

gen line 15,13 15,22

gen line 15,13 45,12.98

* Material Properties for Vitrophere

prop S=5.19e9 B=7.21e9 d=2274 coh=2.2e6 fric=50 ten=1.6e6 I=1,102 J=57,98

* Material Properties for Brown Nonwelded Tuff (Tptpv 1/2) from Attachment I

Prop S=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,102 J=47,57

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,102 J=1,47

SET GRAV=9.81

* Set Initial Stresses

INI SYY=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

INI Sxx=-0.671e6 var 0,0.671e6 i=1,102 j=1,98

INI Szz=-0.671e6 var 0,0.671e6 i=1,102 j=1,98

* Set Boundary Conditiond

fix x i=1

fix x i=102

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

ini xdisp=0 ydisp=0

HIS XDIS I=57 J=65

HIS XDIS I=57 J=57

HIS YDIS I=57 J=65

HIS YDIS I=57 J=57

HIS XDIS I=56 J=62

HIS YDIS I=56 J=62

MOD NULL REG=59,62

STEP 8000

SAVE bhik2.SAV

RET

* File Name:	BHIK3.dat	*
* Description:	Analysis at Highwall	*
* Support:	Unsupported	*
* Loads:	In Situ Loads Only (K0=0.25)	*

CONFIG DYN EXTRA 1

* Mesh construction

gr 101,97

m m

gen -55,-30 -55 50 45 50 45,-30
gen -55,-30 -55 0 0,0 0,-30 r=0.909,0.909 i=1,27 j=1,21
gen -55 0 -55 30 0 30 0,0 r=0.909,1 i=1,27 j=21,81
gen -55 30 -55 50 0 50 0 30 r=0.909,1.1 i=1,27 j=81,98
gen 0 30 0 50 30 50 30 30 r=1,1.1 i=27,87 j=81,98
gen 0 0 0 30 30 30 30 0 r=1,1 i=27,87 j=21,81
gen 0,-30 0,0 30,0 30,-30 r=1,0.909 i=27,87 j=1,21
gen 30,-30 30,0 45,0 45,-30 r=1.1,0.909 i=87,102 j=1,21
gen 30,0 30,30 45,30 45,0 r=1.1,1 i=87,102 j=21,81
gen 30,30 30,50 45,50 45,30 r=1.1,1.1 i=87,102 j=81,98
gen line -55 50 45 10
m n reg 87,81

gen line 15,13 15,22

gen line 15,13 45,12.98

* Material Properties for Vitrophere

prop S=5.19e9 B=7.21e9 d=2274 coh=2.2e6 fric=50 ten=1.6e6 I=1,102 J=57,98

* Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I

Prop S=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,102 J=47,57

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,102 J=1,47

SET GRAV=9.81

* Set Initial Stresses

INI SYX=-1.341e6 var 0,1.341e6 i=1,102 j=1,98
INI Sxx=-0.335e6 var 0,0.335e6 i=1,102 j=1,98
INI Szz=-0.335e6 var 0,0.335e6 i=1,102 j=1,98

* Set Boundary Conditiond

fix x i=1
fix x i=102
fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

ini xdisp=0 ydisp=0

HIS XDIS I=57 J=65
HIS XDIS I=57 J=57
HIS YDIS I=57 J=65
HIS YDIS I=57 J=57
HIS XDIS I=56 J=62
HIS YDIS I=56 J=62

MOD NULL REG=59,62

STEP 8000
SAVE bhik3.SAV
RET

* File Name: BH1K1R.dat *

* Description: Analysis at Highwall	*
* Support: Rock Bolts installed	*
* Loads: In Situ Loads Only (K0=1)	*

CONFIG DYN EXTRA 1

* Mesh construction

gr 101,97

m m

gen -55,-30 -55 50 45 50 45,-30
gen -55,-30 -55 0 0,0 0,-30 r=0.909,0.909 i=1,27 j=1,21
gen -55 0 -55 30 0 30 0,0 r=0.909,1 i=1,27 j=21,81
gen -55 30 -55 50 0 50 0 30 r=0.909,1.1 i=1,27 j=81,98
gen 0 30 0 50 30 50 30 30 r=1,1.1 i=27,87 j=81,98
gen 0 0 0 30 30 30 30 0 r=1,1 i=27,87 j=21,81
gen 0,-30 0,0 30,0 30,-30 r=1,0.909 i=27,87 j=1,21
gen 30,-30 30,0 45,0 45,-30 r=1.1,0.909 i=87,102 j=1,21
gen 30,0 30,30 45,30 45,0 r=1.1,1 i=87,102 j=21,81
gen 30,30 30,50 45,50 45,30 r=1.1,1.1 i=87,102 j=81,98
gen line -55 50 45 10
m n reg 87,81

gen line 15,13 15,22

gen line 15,13 45,12.98

* Material Properties for Vitrophere

prop S=5.19e9 B=7.21e9 d=2274 coh=2.2e6 fric=50 ten=1.6e6 I=1,102 J=57,98

* Material Properties for Brown Nonwelded Tuff (Tptpv 1/2) from Attachment I

Prop S=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,102 J=47,57

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,102 J=1,47

SET GRAV=9.81

* Set Initial Stresses

INI SYY=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

INI Sxx=-1.341e6 var 0,1.341e6 i=1,102 j=1,98
INI Szz=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

* Set Boundary Conditiond

fix x i=1
fix x i=102
fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

ini xdisp=0 ydisp=0

HIS XDIS I=57 J=65
HIS XDIS I=57 J=57
HIS YDIS I=57 J=65
HIS YDIS I=57 J=57
HIS XDIS I=56 J=62
HIS YDIS I=56 J=62

MOD NULL REG=59,62

step 30

* Install Rock Bolts

struc cable beg grid=57,64 end grid=51,64 seg 6 1
struc cable beg grid=57,62 end grid=45,60 seg 12 2
struc cable beg grid=57,59 end grid=45,57 seg 12 2
struc cable beg grid=57,57 end grid=51,57 seg 6 2
struc cable beg grid=57,55 end grid=51,55 seg 6 1
struc prop 1 yi=0.722e5 kb=0.481e9 sbo=4.81e4 e=1.31e11 a=2.58e-4
struc prop 2 yi=0.175e6 kb=1.072e10 sbo=0.377e6 e=1.31e11 a=0.439e-3

step 8000

SAVE bhik1r.SAV
RET

* File Name: BHIK2R.dat *
* Description: Analysis at Highwall *
* Support: Rock Bolts *
* Loads: In Situ Loads Only (K0=0.5) *

CONFIG DYN EXTRA 1

* Mesh construction

gr 101,97

m m

gen -55,-30 -55 50 45 50 45,-30
gen -55,-30 -55 0 0,0 0,-30 r=0.909,0.909 i=1,27 j=1,21
gen -55 0 -55 30 0 30 0,0 r=0.909,1 i=1,27 j=21,81
gen -55 30 -55 50 0 50 0 30 r=0.909,1.1 i=1,27 j=81,98
gen 0 30 0 50 30 50 30 30 r=1,1.1 i=27,87 j=81,98
gen 0 0 0 30 30 30 30 0 r=1,1 i=27,87 j=21,81
gen 0,-30 0,0 30,0 30,-30 r=1,0.909 i=27,87 j=1,21
gen 30,-30 30,0 45,0 45,-30 r=1.1,0.909 i=87,102 j=1,21
gen 30,0 30,30 45,30 45,0 r=1.1,1 i=87,102 j=21,81
gen 30,30 30,50 45,50 45,30 r=1.1,1.1 i=87,102 j=81,98
gen line -55 50 45 10
m n reg 87,81

gen line 15,13 15,22
gen line 15,13 45,12.98

* Material Properties for Vitrophere

prop S=5.19e9 B=7.21e9 d=2274 coh=2.2e6 fric=50 ten=1.6e6 I=1,102 J=57,98

* Material Properties for Brown Nonwelded Tuff (Tptpv 1/2) from Attachment I

Prop S=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,102 J=47,57

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,102 J=1,47

SET GRAV=9.81

* Set Initial Stresses

INI SYy=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

INI Sxx=-0.671e6 var 0,0.671e6 i=1,102 j=1,98

INI Szz=-0.671e6 var 0,0.671e6 i=1,102 j=1,98

* Set Boundary Conditiond

fix x i=1

fix x i=102

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

ini xdisp=0 ydisp=0

HIS XDIS I=57 J=65

HIS XDIS I=57 J=57

HIS YDIS I=57 J=65

HIS YDIS I=57 J=57

HIS XDIS I=56 J=62

HIS YDIS I=56 J=62

MOD NULL REG=59,62

STEP 30

* Install Rock Bolts

struc cable beg grid=57,64 end grid=51,64 seg 6 1
struc cable beg grid=57,62 end grid=45,60 seg 12 2
struc cable beg grid=57,59 end grid=45,57 seg 12 2
struc cable beg grid=57,57 end grid=51,57 seg 6 2
struc cable beg grid=57,55 end grid=51,55 seg 6 1
struc prop 1 yi=0.722e5 kb=0.481e9 sbo=4.81e4 e=1.31e11 a=2.58e-4
struc prop 2 yi=0.175e6 kb=1.072e10 sbo=0.377e6 e=1.31e11 a=0.439e-3

step 8000

SAVE bhik2r.SAV
RET

* File Name: BHIK3R.dat *
* Description: Analysis at Highwall *
* Support: Rock Bolts *
* Loads: In Situ Loads Only (K0=0.25) *

CONFIG DYN EXTRA 1

* Mesh construction

gr 101,97

m m

gen -55,-30 -55 50 45 50 45,-30
gen -55,-30 -55 0 0,0 0,-30 r=0.909,0.909 i=1,27 j=1,21
gen -55 0 -55 30 0 30 0,0 r=0.909,1 i=1,27 j=21,81
gen -55 30 -55 50 0 50 0 30 r=0.909,1.1 i=1,27 j=81,98
gen 0 30 0 50 30 50 30 30 r=1,1.1 i=27,87 j=81,98
gen 0 0 0 30 30 30 30 0 r=1,1 i=27,87 j=21,81
gen 0,-30 0,0 30,0 30,-30 r=1,0.909 i=27,87 j=1,21
gen 30,-30 30,0 45,0 45,-30 r=1.1,0.909 i=87,102 j=1,21
gen 30,0 30,30 45,30 45,0 r=1.1,1 i=87,102 j=21,81
gen 30,30 30,50 45,50 45,30 r=1.1,1.1 i=87,102 j=81,98
gen line -55 50 45 10
m n reg 87,81

gen line 15,13 15,22
gen line 15,13 45,12.98

*** Material Properties for Vitrophere**

prop S=5.19e9 B=7.21e9 d=2274 coh=2.2e6 fric=50 ten=1.6e6 I=1,102 J=57,98

*** Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I**

Prop S=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,102 J=47,57

*** Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I**

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,102 J=1,47

SET GRAV=9.81

*** Set Initial Stresses**

INI SYY=-1.341e6 var 0,1.341e6 i=1,102 j=1,98

INI Sxx=-0.335e6 var 0,0.335e6 i=1,102 j=1,98

INI Szz=-0.335e6 var 0,0.335e6 i=1,102 j=1,98

*** Set Boundary Conditiond**

fix x i=1

fix x i=102

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

ini xdisp=0 ydisp=0

HIS XDIS I=57 J=65

HIS XDIS I=57 J=57

HIS YDIS I=57 J=65

HIS YDIS I=57 J=57
HIS XDIS I=56 J=62
HIS YDIS I=56 J=62

MOD NULL REG=59,62

STEP 30

* Install Rock Bolts

struc cable beg grid=57,64 end grid=51,64 seg 6 1
struc cable beg grid=57,62 end grid=45,60 seg 12 2
struc cable beg grid=57,59 end grid=45,57 seg 12 2
struc cable beg grid=57,57 end grid=51,57 seg 6 2
struc cable beg grid=57,55 end grid=51,55 seg 6 1
struc prop 1 yi=0.722e5 kb=0.481e9 sbo=4.81e4 e=1.31e11 a=2.58e-4
struc prop 2 yi=0.175e6 kb=1.072e10 sbo=0.377e6 e=1.31e11 a=0.439e-3

step 8000

SAVE bhik3r.SAV
RET

*

* The following procedure initiates the seismic analyses of the supported highwall with
* horizontal and vertical component of the acceleration equivalent to 0.37g. The analyses are
* performed after completion of the in situ loading runs.

*

* File Name: BHISEIS.DAT

*

rest bhik1r.sav
set grav 13.92 15.11
step 8000
save bhik1q1.sav
ret
new
rest bhik2r.sav

```
set grav 13.92 15.11
step 8000
save bhik2q1.sav
new
rest bhik3r.sav
set grav 13.92 15.11
step 8000
save bhik3q1.sav
ret
```

```
*****
* File Name:  BB1K1.dat
* Description: Analysis at Test Alcove
* Support:  Unsupported Opening
* Loads:  In Situ Loads Only (K0=1)
*****
```

CONFIG DYN EXTRA 1

* Mesh construction

```
GR 98 96
M M
GEN -60,-60 -60,40 60,40 60,-60
GEN -60,-60 -60,-20 -20,-20 -20,-60 R=0.667,0.667 I= 1,10 J= 1,10
GEN -60,-20 -60,20 -20,20 -20,-20 R=0.667,1 I= 1,10 J=10,90
GEN -60,20 -60,40 -20,40 -20,20 R=0.667,1.5 I= 1,10 J=90,97
GEN -20,20 -20,40 20,40 20,20 R=1,1.5 I=10,90 J=90,97
GEN -20,-20 -20,20 20,20 20,-20 R=1,1 I=10,90 J=10,90
GEN -20,-60 -20,-20 20,-20 20,-60 R=1,0.667 I=10,90 J=1,10
GEN 20,20 20,40 60,40 60,20 R=1.5,1.5 I=90,99 J=90,97
GEN 20,-20 20,20 60,20 60,-20 R=1.5,1 I=90,99 J=10,90
GEN 20,-60 20,-20 60,-20 60,-60 R=1.5,0.667 I=90,99 J=1,10
* Construct the opening
gen arc 0,-1 2.5,5 49.25
gen line -2.5,0 -2.5,5
gen line -2.5 0 2.5,0
gen line 2.5,0 2.5,5
```

* Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,99 j=55,97

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,99 j=1,55

SET GRAV=9.81

* Set Initial Stresses

INI SY=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Sxx=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Szz=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

* Set Boundary Conditiond

fix x i=1

fix x i=99

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

INI XDIS=0 YDIS=0

DEF VCL

VCL=YDISP(50,50) - YDISP(50,61)

END

DEF HCL

HCL=XDISP(45,55) - XDISP(55,55)

END

HIS VCL

HIS HCL

HIS XDIS I=45 J=55

HIS XDIS I=55 J=55

HIS YDIS I=50 J=50
HIS YDIS I=50 J=61

MOD NULL REG=50,52

STEP 5000
SAVE BB1K1.SAV
RET

```
*****
* File Name:  BB1K2.dat                *
* Description: Analysis at Test Alcove  *
* Support:  Unsupported Opening         *
* Loads:  In Situ Loads Only (K0=0.5)   *
*****
```

CONFIG DYN EXTRA 1

* Mesh construction

GR 98 96
M M
GEN -60,-60 -60,40 60,40 60,-60
GEN -60,-60 -60,-20 -20,-20 -20,-60 R=0.667,0.667 I= 1,10 J= 1,10
GEN -60,-20 -60,20 -20,20 -20,-20 R=0.667,1 I= 1,10 J=10,90
GEN -60,20 -60,40 -20,40 -20,20 R=0.667,1.5 I= 1,10 J=90,97
GEN -20,20 -20,40 20,40 20,20 R=1,1.5 I=10,90 J=90,97
GEN -20,-20 -20,20 20,20 20,-20 r=1,1 I=10,90 J=10,90
GEN -20,-60 -20,-20 20,-20 20,-60 R=1,0.667 I=10,90 J=1,10
GEN 20,20 20,40 60,40 60,20 R=1.5,1.5 I=90,99 J=90,97
GEN 20,-20 20,20 60,20 60,-20 R=1.5,1 I=90,99 J=10,90
GEN 20,-60 20,-20 60,-20 60,-60 R=1.5,0.667 I=90,99 J=1,10

* Construct the opening
gen arc 0,-1 2.5,5 49.25
gen line -2.5,0 -2.5,5
gen line -2.5 0 2.5,0
gen line 2.5,0 2.5,5

* Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,99 j=55,97

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,99 j=1,55

SET GRAV=9.81

* Set Initial Stresses

INI SYy=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Sxx=-0.693e6 var 0,0.693e6 i=1,99 j=1,97

INI Szz=-0.693e6 var 0,0.693e6 i=1,99 j=1,97

* Set Boundary Conditiond

fix x i=1

fix x i=99

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

INI XDIS=0 YDIS=0

DEF VCL

VCL=YDISP(50,50) - YDISP(50,61)

END

DEF HCL

HCL=XDISP(45,55) - XDISP(55,55)

END

HIS VCL

HIS HCL

HIS XDIS I=45 J=55

HIS XDIS I=55 J=55

HIS YDIS I=50 J=50
HIS YDIS I=50 J=61

MOD NULL REG=50,52

STEP 5000
SAVE BB1K2.SAV
RET

* File Name: BB1K3.dat *
* Description: Analysis at Test Alcove *
* Support: Unsupported Opening *
* Loads: In Situ Loads Only (K0=0.25) *

CONFIG DYN EXTRA 1

* Mesh construction

GR 98 96
M M
GEN -60,-60 -60,40 60,40 60,-60
GEN -60,-60 -60,-20 -20,-20 -20,-60 R=0.667,0.667 I= 1,10 J= 1,10
GEN -60,-20 -60,20 -20,20 -20,-20 R=0.667,1 I= 1,10 J=10,90
GEN -60,20 -60,40 -20,40 -20,20 R=0.667,1.5 I= 1,10 J=90,97
GEN -20,20 -20,40 20,40 20,20 R=1,1.5 I=10,90 J=90,97
GEN -20,-20 -20,20 20,20 20,-20 r=1,1 I=10,90 J=10,90
GEN -20,-60 -20,-20 20,-20 20,-60 R=1,0.667 I=10,90 J=1,10
GEN 20,20 20,40 60,40 60,20 R=1.5,1.5 I=90,99 J=90,97
GEN 20,-20 20,20 60,20 60,-20 R=1.5,1 I=90,99 J=10,90
GEN 20,-60 20,-20 60,-20 60,-60 R=1.5,0.667 I=90,99 J=1,10
* Construct the opening
gen arc 0,-1 2.5,5 49.25
gen line -2.5,0 -2.5,5
gen line -2.5 0 2.5,0
gen line 2.5,0 2.5,5

* Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,99 j=55,97

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,99 j=1,55

SET GRAV=9.81

* Set Initial Stresses

INI SYY=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Sxx=-0.3465e6 var 0,0.3465e6 i=1,99 j=1,97

INI Szz=-0.3465e6 var 0,0.3465e6 i=1,99 j=1,97

* Set Boundary Conditiond

fix x i=1

fix x i=99

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

INI XDIS=0 YDIS=0

DEF VCL

VCL=YDISP(50,50) - YDISP(50,61)

END

DEF HCL

HCL=XDISP(45,55) - XDISP(55,55)

END

HIS VCL

HIS HCL

HIS XDIS I=45 J=55

HIS XDIS I=55 J=55

HIS YDIS I=50 J=50
HIS YDIS I=50 J=61

MOD NULL REG=50,52

STEP 5000
SAVE BB1K3.SAV
RET

* File Name: BB1K1R.dat *
* Description: Analysis at Test Alcove *
* Support: Swellex Rock Bolts *
* Loads: In Situ Loads Only (K0=1) *

CONFIG DYN EXTRA 1

* Mesh construction

GR 98 96
M M
GEN -60,-60 -60,40 60,40 60,-60
GEN -60,-60 -60,-20 -20,-20 -20,-60 R=0.667,0.667 I= 1,10 J= 1,10
GEN -60,-20 -60,20 -20,20 -20,-20 R=0.667,1 I= 1,10 J=10,90
GEN -60,20 -60,40 -20,40 -20,20 R=0.667,1.5 I= 1,10 J=90,97
GEN -20,20 -20,40 20,40 20,20 R=1,1.5 I=10,90 J=90,97
GEN -20,-20 -20,20 20,20 20,-20 R=1,1 I=10,90 J=10,90
GEN -20,-60 -20,-20 20,-20 20,-60 R=1,0.667 I=10,90 J=1,10
GEN 20,20 20,40 60,40 60,20 R=1.5,1.5 I=90,99 J=90,97
GEN 20,-20 20,20 60,20 60,-20 R=1.5,1 I=90,99 J=10,90
GEN 20,-60 20,-20 60,-20 60,-60 R=1.5,0.667 I=90,99 J=1,10
* Construct the opening
gen arc 0,-1 2.5,5 49.25
gen line -2.5,0 -2.5,5
gen line -2.5 0 2.5,0
gen line 2.5,0 2.5,5

* Material Properties for Brown Non-welded Tuff (Tptpv 1/2) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,99 j=55,97

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,99 j=1,55

SET GRAV=9.81

* Set Initial Stresses

INI SYY=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Sxx=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Szz=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

* Set Boundary Conditiond

fix x i=1

fix x i=99

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

INI XDIS=0 YDIS=0

DEF VCL

VCL=YDISP(50,50) - YDISP(50,61)

END

DEF HCL

HCL=XDISP(45,55) - XDISP(55,55)

END

HIS VCL

HIS HCL

HIS XDIS I=45 J=55
HIS XDIS I=55 J=55
HIS YDIS I=50 J=50
HIS YDIS I=50 J=61

MOD NULL REG=50,52

* Allow for Relaxation

STEP 38

* Install Rock Bolts

struc cable beg grid=48,61 end -1.5,8.5 seg 6 1
struc cable beg grid=46,60 end -2.7,8.2 seg 6 1
struc cable beg grid=52,61 end 1.5,8.5 seg 6 1
struc cable beg grid=54,60 end 2.7,8.2 seg 6 1
struc prop 1 yi=0.722e5 kb=0.481e9 sbo=4.81e4 e=1.31e11 a=2.58e-4

step 4962
save BB1K1R.SAV
ret

* File Name: BB1K2R.dat *
* Description: Analysis at Test Alcove *
* Support: Swellex Rock Bolts *
* Loads: In Situ Loads Only (K0=0.5) *

CONFIG DYN EXTRA 1

* Mesh construction

GR 98 96
M M
GEN -60,-60 -60,40 60,40 60,-60
GEN -60,-60 -60,-20 -20,-20 -20,-60 R=0.667,0.667 I= 1,10 J= 1,10
GEN -60,-20 -60,20 -20,20 -20,-20 R=0.667,1 I= 1,10 J=10.90
GEN -60,20 -60,40 -20,40 -20,20 R=0.667,1.5 I= 1,10 J=90.97

GEN -20,20 -20,40 20,40 20,20 R=1,1.5 I=10,90 J=90,97
GEN -20,-20 -20,20 20,20 20,-20 r=1,1 I=10,90 J=10,90
GEN -20,-60 -20,-20 20,-20 20,-60 R=1,0.667 I=10,90 J=1,10
GEN 20,20 20,40 60,40 60,20 R=1.5,1.5 I=90,99 J=90,97
GEN 20,-20 20,20 60,20 60,-20 R=1.5,1 I=90,99 J=10,90
GEN 20,-60 20,-20 60,-20 60,-60 R=1.5,0.667 I=90,99 J=1,10

* Construct the opening

gen arc 0,-1 2.5,5 49.25

gen line -2.5,0 -2.5,5

gen line -2.5 0 2.5,0

gen line 2.5,0 2.5,5

* Material Properties for Brown Nonwelded Tuff (Ttpv 1/2) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,99 j=55,97

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,99 j=1,55

SET GRAV=9.81

* Set Initial Stresses

INI SYX=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Sxx=-0.693e6 var 0,0.693e6 i=1,99 j=1,97

INI Szz=-0.693e6 var 0,0.693e6 i=1,99 j=1,97

* Set Boundary Conditiond

fix x i=1

fix x i=99

fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

INI XDIS=0 YDIS=0

DEF VCL
VCL=YDISP(50,50) - YDISP(50,61)
END

DEF HCL
HCL=XDISP(45,55) - XDISP(55,55)
END

HIS VCL
HIS HCL

HIS XDIS I=45 J=55
HIS XDIS I=55 J=55
HIS YDIS I=50 J=50
HIS YDIS I=50 J=61

MOD NULL REG=50,52

* Allow for Relaxation

STEP 44

* Install Rock Bolts

struc cable beg grid=48,61 end -1.5,8.5 seg 6 1
struc cable beg grid=46,60 end -2.7,8.2 seg 6 1
struc cable beg grid=52,61 end 1.5,8.5 seg 6 1
struc cable beg grid=54,60 end 2.7,8.2 seg 6 1
struc prop 1 yi=0.722e5 kb=0.481e9 sbo=4.81e4 e=1.31e11 a=2.58e-4

step 4956

SAVE BB1K2R.SAV
RET

* File Name: BB1K3R.dat *

* Description: Analysis at Test Alcove *

* Support: Swellex Rock Bolts *

* Loads: In Situ Loads Only (K0=0.25) *

CONFIG DYN EXTRA 1

* Mesh construction

GR 98 96

M M

GEN -60,-60 -60,40 60,40 60,-60

GEN -60,-60 -60,-20 -20,-20 -20,-60 R=0.667,0.667 I= 1,10 J= 1,10

GEN -60,-20 -60,20 -20,20 -20,-20 R=0.667,1 I= 1,10 J=10,90

GEN -60,20 -60,40 -20,40 -20,20 R=0.667,1.5 I= 1,10 J=90,97

GEN -20,20 -20,40 20,40 20,20 R=1,1.5 I=10,90 J=90,97

GEN -20,-20 -20,20 20,20 20,-20 R=1,1 I=10,90 J=10,90

GEN -20,-60 -20,-20 20,-20 20,-60 R=1,0.667 I=10,90 J=1,10

GEN 20,20 20,40 60,40 60,20 R=1.5,1.5 I=90,99 J=90,97

GEN 20,-20 20,20 60,20 60,-20 R=1.5,1 I=90,99 J=10,90

GEN 20,-60 20,-20 60,-20 60,-60 R=1.5,0.667 I=90,99 J=1,10

* Construct the opening

gen arc 0,-1 2.5,5 49.25

gen line -2.5,0 -2.5,5

gen line -2.5 0 2.5,0

gen line 2.5,0 2.5,5

* Material Properties for Brown Nonwelded Tuff (Tptpv 1/2) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1600 coh=4.4e6 fric=58 ten=2.51e6 I=1,99 j=55,97

* Material Properties Whitish Bedded Tuff (Calico Hills) from Attachment I

Prop s=12.0e9 B=16.0e9 d=1300 coh=0.9e6 fric=55 ten=0.59e6 I=1,99 j=1,55

SET GRAV=9.81

* Set Initial Stresses

INI SYY=-1.386e6 var 0,1.386e6 i=1,99 j=1,97

INI Sxx=-0.3465e6 var 0,0.3465e6 i=1,99 j=1,97

INI Szz=-0.3465e6 var 0,0.3465e6 i=1,99 j=1,97

* Set Boundary Conditiond

fix x i=1
fix x i=99
fix y j=1

HIS UNBAL

SET DYN OFF

STEP 500

INI XDIS=0 YDIS=0

DEF VCL
VCL=YDISP(50,50) - YDISP(50,61)
END

DEF HCL
HCL=XDISP(45,55) - XDISP(55,55)
END

HIS VCL
HIS HCL

HIS XDIS I=45 J=55
HIS XDIS I=55 J=55
HIS YDIS I=50 J=50
HIS YDIS I=50 J=61

MOD NULL REG=50,52

* Allow for Relaxation

STEP 50

* Install Rock Bolts

struc cable beg grid=48,61 end -1.5,8.5 seg 6 1
struc cable beg grid=46,60 end -2.7,8.2 seg 6 1
struc cable beg grid=52,61 end 1.5,8.5 seg 6 1
struc cable beg grid=54,60 end 2.7,8.2 seg 6 1
struc prop 1 yi=0.722e5 kb=0.481e9 sbo=4.81e4 e=1.31e11 a=2.58e-4

step 4950

SAVE BB1K3R.SAV
RET

*

* The following procedure initiates the seismic analyses of the supported tunnel with horizontal
* and vertical component of the acceleration equivalent to 0.37g. The analyses are performed
* after completion of the in situ loading runs.

*

* File Name: BBSEIS.DAT

*

rest bbl1r.sav
set grav 13.92 15.11
step 8000
save blk1qu1.sav
new
rest bblk2r.sav
set grav 13.92 15.11
step 8000
save blk2qu1.sav
new
rest bblk3r.sav
set grav 13.92 15.11
step 8000
save blk3qu1.sav
ret

E-Mail to CMO, Subject: Busted Butte Test Facility Ground Support

To: Dick McDonald@CRWMS
cc: William Kennedy@CRWMS, Larry Morrison@CRWMS, John Pye@CRWMS, Charles Garrett@CRWMS, Thomas Ricketts@CRWMS, Ralph Dresel@CRWMS, Ralph Dow@CRWMS
From: Saeed Bonabian
Date: 04/20/98 11:03:02 AM
Subject: Busted Butte Test Facility Ground Support

Attached is our evaluation of the installed ground support in the BBTF. I will be out of office for the next three weeks, so please contact John Pye or Ralph Dow if you have any questions on the subject.

Busted.wp

From: Saeed Bonabian
To: Dick McDonald

Subject: Busted Butte Test Facility Ground Support

The A/E was tasked to perform an analysis to address the stability of the highwall and the underground structure and to assess the adequacy of the ground support system in the Busted Butte Test Facility (BBTF). The original design of the BBTF was performed by a TCO consultant, SubTerra, Inc. The design called for rock bolts (both Swellex type and grouted rebar type) at the highwall. The underground portion required pattern bolting (Swellex type) with wire mesh in addition to shotcrete above the spring line based on the SubTerra Design. On Tuesday (4/14/98) Saeed Bonabian, Ralph Dow, and Marek Mrugala visited the facility to observe the ground support system installed in the BBTF. The highwall ground support system is installed as it was required by Sub Terra design and appears to be adequate once the grouting of the bolts in the highwall has been completed. Rock bolts (Swellex type) and wire mesh has been installed underground and meets the design requirements. The shotcrete application above spring line has not been completed as required by the design. Additional ground support was installed by the constructor apparently to address personnel safety, that included a number of shotcrete "pillars" along the ribs and rebar at the crown installed parallel to tunnel axis. The rebar is attached to the wire mesh with intentions to reinforce the shotcrete. However, the rebar is not covered with shotcrete, and in its current position intrudes an additional weight on the mesh and provides no such reinforcement benefit. The work seemed unfinished during our first visit on Tuesday. We were also concerned about the concept of having a relatively thick rebar reinforced shotcrete at a practically flat crown.

Chuck Garrett (Title III), Lock Spencer (CMO), John Pye (A/E), Saeed Bonabian (A/E), and Tom Ricketts (TCO) re-visited the facility again on Thursday (4/16/98). The constructor has indicated that their work (installation of ground support) was completed in the BBTF for the time being. The TCO indicated that the first phase of testing is underway presently and may not be disrupted. Following conclusions were made collectively by the visiting group based on observations of the facility on Thursday:

- 1 - Testing is underway and cannot be disrupted by additional work if it is not absolutely necessary. There may be a small window between test phases that may allow for some additional work in the facility.
- 2 - Even though the shotcrete is not installed in the crown in some areas as required by Sub Terra design, its application over the rebar in the crown is not recommended. The shadow areas behind the rebar cannot be adequately filled, the rebar is too far from the rock in most areas, and more importantly, the additional weight of the added shotcrete would be self defeating.
- 3 - Removing the rebar entirely is not an option at this time because it require extensive work. It may be better to leave it in place. In some areas it may be enhanced or the smaller pieces removed if it does not interfere with testing.
- 4 - The shotcrete pillars provide no effective support but should be left alone at this time with no additional work required.
- 5 - At least three areas underground should be instrumented by installation of convergence pins immediately to provide some measure of monitoring of the opening convergence. The instrumentation should have been done much earlier but it will be an informative and effective way of monitoring.
- 6 - For the long run, testing requirements will preclude additional extensive shotcreting or drilling for more rock bolt or cable anchors. Timber cribbing (large pieces, 12"X12", cut to fit in place) may be an option if it becomes necessary to hold up the rebar in place and provide an alternative to shotcrete. Grouting of the rock bolts at the highwall should be completed as soon as possible.

In conclusion, it is recommended to install instrumentation immediately and continue monitoring. No additional shotcrete is recommended underground at this time. Monitor the rebar closely and remove pieces that may compromise personnel safety. Any changes in ground conditions should be reported to the CMO immediately if noticed by the testing personnel.