CRWMS/M&O

Non-Q Design Analysis Cover Sheet

Complete only applicable items.

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Page: 1 Of: 67

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TBV-226 Applies to this analysis. The TBV process is not required for Non-Q Analysis but it is used here to provide traceability and indicate that the input from References 5.4 and 5.5 are based on preliminary data.			

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Complete only applicable items.

1.

2. DESIGN ANALYSIS TITLE	
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1.0 PURPOSE

The main purpose and objective of this analysis is to analyze the stability of the Thermal Test Facility Heated Drift and to design a ground support system. The stability of the Heated Drift is analyzed considering in situ, seismic, and thermal loading conditions. A ground support system is recommended to provide a stable opening for the Heated Drift.

This report summarizes the results of the analyses and provides the details of the recommended ground support system for the Heated Drift. The details of the ground support system are then incorporated into the design output documents for implementation in the field.

2.0 QUALITY ASSURANCE

The heated drift portion of the Thermal Test Facility is located beyond the transition zone. The transition zone is defined as the area extending into the alcove where permanent function ground support is installed to supplement tunnel ground support. For ESF alcoves, the transition zone is conservatively defined as the area into the alcove equivalent to the 20 m zone measured perpendicular from the ramp centerline (Reference 5.1). The ground support installed beyond the transition zone is not Q based on Reference 5.9. The temporary function ground support does not require classification (Reference 5.9). The ground support recommended here does not include the ground support components which will be installed for potential repository testing purposes.

3.0 METHOD

Empirical and analytical methods are used to evaluate the stability of the Heated Drift under in situ, seismic, and thermal loading conditions. The application of empirical and analytical methods and computational details are presented in Section 7.

4.0 DESIGN INPUTS

4.1 DESIGN PARAMETERS

Heated Drift Dimensions:

The Thermal Test Alcove layout is presented in Figure 1 (Reference 5.3). The Heated Drift is a full circle cross-section, with a nominal 5 meter diameter (Reference 5.3).

In addition to 5 m diameter opening, a 6 m diameter drift was analyzed to bound the analyses.

Reference 5.10 indicates that a portion of the Heated Drift will be a minimum of 5.6 m in diameter. The analyses were performed for a 6 m diameter opening to bound this portion of the Heated Drift. The smaller opening is inherently more stable than the larger one.

Rock Mass Properties:

The rock mass properties for TSw2 unit from Reference 5.1 are used as inputs in computer analyses. The same TSw2 unit properties were used in the design of the ESF Main Loop ground support (Reference 5.1). Rock mass properties for all five rock mass Categories are presented, from which the Categories 1, 3, and 5 rock mass properties are used in the analyses.

The Quality (Q) and average Rock Mass Rating (RMR) values obtained from the ESF drilling program are used in this analysis. For detailed description of the rock mass quality categories and parameters refer to Reference 5.1.

For the TSw2 unit, Q ratings of 0.3, 0.65, 1.91, 3.75, and 8.44 are used for rock mass quality categories of 1 through 5, respectively, Reference 5.1.

For the TSw2 unit, average RMR ratings of 42, 48, 54, 59, and 65 are used for rock mass quality categories of 1 through 5, respectively, Reference 5.1.

The following rock mass values have been used for TSw2 unit in performing the computer analysis:

Category 1:

Elastic modulus = 6.37 GPa (Source: Reference 5.1)
Poisson's ratio = 0.21 (Source: Reference 5.1)
Density = 2274 Kg/m³ (Source: Reference 5.1)
Cohesion = 1.3 MPa (Source: Reference 5.1)
Friction angle = 49° (Source: Reference 5.1)
Tensile strength = 0.97 MPa (Source: Reference 5.1)

Category 2:

Elastic modulus = 8.96 GPa (Source: Reference 5.1)
Poisson's ratio = 0.21 (Source: Reference 5.1)
Density = 2274 Kg/m³ (Source: Reference 5.1)
Cohesion = 1.6 MPa (Source: Reference 5.1)
Friction angle = 49° (Source: Reference 5.1)
Tensile strength = 1.20 MPa (Source: Reference 5.1)

Category 3:

Elastic modulus = 12.55 GPa (Source: Reference 5.1)
Poisson's ratio = 0.21 (Source: Reference 5.1)
Density = 2274 Kg/m³ (Source: Reference 5.1)
Cohesion = 2.2 MPa (Source: Reference 5.1)
Friction angle = 50° (Source: Reference 5.1)
Tensile strength = 1.60 MPa (Source: Reference 5.1)

Category 4:

Elastic modulus = 17.11 GPa (Source: Reference 5.1)
Poisson's ratio = 0.21 (Source: Reference 5.1)
Density = 2274 Kg/m³ (Source: Reference 5.1)
Cohesion = 2.8 MPa (Source: Reference 5.1)
Friction angle = 50° (Source: Reference 5.1)
Tensile strength = 2.04 MPa (Source: Reference 5.1)

Category 5:

Elastic modulus = 23.51 GPa (Source: Reference 5.1)
Poisson's ratio = 0.21 (Source: Reference 5.1)
Density = 2274 Kg/m³ (Source: Reference 5.1)
Cohesion = 3.8 MPa (Source: Reference 5.1)
Friction angle = 50° (Source: Reference 5.1)
Tensile strength = 2.77 MPa (Source: Reference 5.1)

Seismic Parameters:

Seismic criteria is used from Reference 5.8. Mean peak horizontal and vertical acceleration of 0.37g is used in the analysis. The ground support designed here does not preclude the option to supplement the installed ground support in the Heated Drift to satisfy more stringent seismic criteria (higher mean peak accelerations and velocities).

Input For Thermal Calculations:

The temperature profiles used as an input in the numerical calculations are from Reference 5.4 (TBV-226). The thermal conductivity of 2.1 W/m°C for TSw2 unit, initial rock temperature of 23 °C, and volumetric heat capacity of 1.93E6 Joules/m³.K from Reference 5.5 (TBV-226) is used in the analyses. The thermal expansion coefficient of 8.97E-6 /°C from Table B-4, Reference 5.7 is used in the analyses.

Input Parameters for Ground Support Calculations:

Numerical representation of Swellex rock bolts using FLAC computer software is described in detail in Reference 5.1. The rock bolts are installed in the model after 65% relaxation is allowed.

Bolt Type: The Swellex Bolting System (see Reference 5.1 for details)

Length = 3 m

A = 258 mm² (Reference 5.1)

E = 200 GPa (Reference 5.1)

T = 110 KN (Reference 5.1)

SBO = 73.3 KN/m (= T/bolt length = 110/1.5 = 73.3 KN/m) (Reference 5.1)

KBO = 0.733 GN/m/m (= $\Delta SBO/\Delta U = 73.3/0.1 \times 10^{-3} = 0.733$ GN/m/m) (Reference 5.1)

4.2 CRITERIA

The following design criteria are used in the design of the Heated Drift ground support which address applicable ESFDR requirements.

- 4.2.1 The seismic loading conditions (to the extent known at this time) are considered in the design of the Heated Drift ground support system (see Section 7.4.3). The ESF seismic design basis is presented in Appendix A (A.4 and A.5) of the ESFDR (Reference 5.8). (ESFDR 3.2.1.2.1.2.A)
- 4.2.2 The use of pressure grouting at the Heated Drift is coordinated and communicated with the Test Coordination Office (TCO) to obtain its approval before usage (see Section 8.0). (ESFDR 3.7.3.1.B)
- 4.2.3 The ground support system used in the Heated Drift is compatible with the excavation methods and existing equipment at the ESF. The ground support system will comprise of items which have already been used in the ESF construction (see Section 8.0 for component details). (ESFDR 3.7.3.1.D)

4.3 ASSUMPTIONS

- 4.3.1 The overburden thickness used in the FLAC model is estimated from the available data for Station 28+27 m at the Alcove/Main Ramp intersection. This depth is estimated to be 268380 mm from ground surface (see Figure 1). The FLAC model extends 60000 mm into the overburden, measured from the centerline of the Heated Drift, and the remaining 208380 mm overburden is numerically accounted for by applying an equivalent pressure on the top of the model. The estimated overburden is assumed to be accurate enough for

the purpose of the calculations presented here because the minor variations of overburden at such depth does not have any significant affect in the outcome of the results.

- 4.3.2 For the in situ stress field, a horizontal to vertical ratio of 0.5 ($K_0=0.5$) is used in the analyses. Detailed description of the in situ loading conditions are presented in References 5.1 and 5.2. The range of $K_0=0.25$ to $K_0=1$ is used in References 5.1 and 5.2. For the Heated Drift the K_0 value of 0.5 is conservatively assumed based on the depth of the Drift. This ratio is considered to be a valid and conservative number based on the discussions provided in References 5.1 and 5.2.

4.4 CODES AND STANDARDS

Not Used.

5.0 REFERENCES

- 5.1 Bonabian, S., "ESF Ground Support Design Analysis," BABEE0000-01717-0200-00002 REV 00.
- 5.2 Bonabian, S., "ESF Alcove Ground Support Analysis," BABEE0000-01717-0200-00001 REV 03.
- 5.3 Engineering Change Request (ECR), E96-0080, Sketch 40230SK1.FCR, Titled: TS Main Drift Thermal Testing Facility Plan," BABEAF000-01717-2100-40230 REV 00.
- 5.4 "Transmittal of Temperature Gradient Profiles for Design and Construction of the Exploratory Studies Facility Thermal Testing Facility Drift Scale Test," From J. Hollins, LANL, To: A. Segrest, CRWMS M&O, LA-EES-13-LV-07-96-028, July 26, 1996.
- 5.5 "Transmittal of Preliminary Thermal Properties of TSw2 Unit for Design and Construction of the Exploratory Studies Facility Thermal Testing Facility Drift Scale Test," From J. Hollins, LANL, To: A. Segrest, CRWMS M&O, LA-EES-13-LV-09-96-006, September 3, 1996.
- 5.6 "Transmittal of Design and Test-Related Information for Design and Construction of the Exploratory Studies Facility Thermal Testing Facility Connecting Drift and Heated Drift," From: J. Hollins, LANL, To: A. Segrest, CRWMS M&O, LA-EES-13-LV-06-96-005, June 5, 1996.
- 5.7 "Mined Geologic Disposal System Advanced Conceptual Design Report," Volume II of

IV, B00000000-01717-5707-00027 REV 00.

- 5.8 Yucca Mountain Site Characterization Project, "Exploratory Studies Facility Design Requirements," YMP/CM-0019 Rev. 2.
- 5.9 "QA Classification Analysis of Ground Support Systems (CI: BABEE0000)," Document Identifier: BABEE0000-01717-2200-00001 REV 04.
- 5.10 "Transmittal of Updated Design and Test-Related Information for Design and Construction of the Thermal Testing Facility Heated Drift," From J. Hollins, LANL, To: A. Segrest, CRWMS M&O, LA-EES-13-LV-09-96-028, September 17, 1996.
- 5.11 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.
- 5.12 Bieniawski, Z. T., "Rock Mass Classification in Rock Engineering," Proceedings, Symposium on Exploration for Rock Engineering (Johannesburg, South Africa, November 1976), Pages 97-106.

6.0 USE OF COMPUTER SOFTWARE

Fast Lagrangian Analysis of Continua (FLAC), Version 3.22 (CSCI # 20.93.3001-AAu3.22) is used to perform the analyses. The analyses were performed on a 486 base computer. FLAC software is appropriate for the applications used in this analysis. A complete listing of the input files used in the design analysis are provided in Attachment I. The outputs are presented and described in Section 7.0 and its subsections.

7.0 DESIGN ANALYSIS

7.1 INTRODUCTION

The in situ thermal test is designed to be conducted in the ESF to provide an experimental basis for the thermal-hydrological-geomechanical-geochemical studies at the site. In addition, the response of the host rock and ground support components in temperatures comparable to potential repository conditions will be tested. The test includes a drift-scale test that represents in-drift emplacement of large waste packages. The drift-scale test will be conducted in the heated drift portion of the Thermal Test Alcove. The Heated Drift will contain a row of large heaters, and will be flanked, on either side, by arrays of borehole-emplaced "wing" heaters.

The objective of this design analysis is to evaluate the stability of the heated drift portion of the Thermal Test Alcove under the in situ, thermal, and seismic loading conditions. As a result of this analysis, a ground support system will be recommended for the Heated Drift. The ground support recommended here does not include the ground support components which will be tested and emplaced by the TCO for potential repository testing purposes.

The design methodology for ESF alcoves is presented in detail in Reference 5.2 and it will not be repeated here. The layout of the Thermal Test Alcove is presented in Reference 5.3 (see Figure 1). The design of the heated drift portion of the Thermal Test Alcove introduces new challenges due to the presence of very high temperatures to the rock surrounding the drift and resultant thermal loading conditions. There are many unknown factors involved in the design of such a drift and presently no known tunnels exist or operate under such high temperatures. One of the main objectives of conducting this test is to gain knowledge and learn about some of these unknown factors. The analyses performed here are unique in nature, incorporate state-of-the-art techniques and utilize one of the best available computational tools. The initial thermal conditions, including temperature profiles which will be generated during heating, are provided in Reference 5.4. Here, the thermal calculations are performed by incorporating the initial temperature profiles from Reference 5.4 and then the thermal-mechanical coupling is invoked to determine the influence of temperature change on the volumetric change of the medium.

The analyses performed here, include computer simulation of the excavation of the Heated Drift in a gravity-stressed rock medium followed by introduction of high temperatures to simulate the heating process. The resultant thermal stresses are superimposed onto the stresses due to the excavation and finally the model is subjected to seismic loading. The recommended ground support components are incorporated into the model during the excavation process and therefore are subjected to in situ, thermal, and seismic loading.

This design will be complemented by a monitoring and inspection program during construction. Adjustments to the ground support system will be made during construction, as required due to field conditions.

The rock properties and geologic conditions at the alcove location are required to perform the analysis. In this report the rock mass quality estimates from the NRG drilling program for the TSw2 unit are used to provide a basis for empirical and analytical design of the Heated Drift.

Detailed discussions on a number of design issues are presented in Reference 5.1 and will not be repeated in this analysis. These design issues are applicable to all ESF underground excavations and are handled in accordance with the discussions presented in Reference 5.1.

7.2 THERMAL TEST ALCOVE LAYOUT

The layout of the Thermal Test Alcove is provided in Reference 5.3 which is shown in Figure 1. The heated drift portion of the alcove will be circular-shaped. The opening dimensions are provided in Reference 5.10.

7.3 EMPIRICAL METHODS

The empirical approach relies on rock mass classification systems. Generally, these systems allow the rock properties and geologic conditions shown in samples taken from boreholes and certain outcrops at the planned site to be compared with similar information compiled and categorized from existing underground facilities. Based on this comparison, support requirements and stand-up time can be estimated. The empirical approach only addresses the in situ rock loads due to the excavation of the Heated Drift. The empirical approach is used in this analysis to estimate a ground support system that would be required to provide a stable opening under in situ loading conditions. The thermal and seismic loading conditions are addressed using analytical design approach.

Two common classification systems are recommended in the Drift Design Methodology report for the Yucca Mountain Site Characterization project (Reference 5.1). These two classification systems are the South African Council for Scientific and Industrial Research (CSIR) Geomechanics Classification System developed by Bieniawski (1976), and the Norwegian Geotechnical Institute (NGI) Classification System developed by Barton et al. (1974). The Geomechanics classification and the NGI system are empirical methods for the selection of modern tunnel reinforcement measures such as rock bolts, wire mesh, and shotcrete. These two classification systems are used to provide basis for the empirical design of the Heated Drift.

The Geomechanics classification system is used to establish the stand-up time for the alcove excavation. The NGI classification system is used to estimate a ground support system for the Heated Drift.

A detailed description of the empirical methods including the Geomechanics and the NGI Classification Systems is provided in References 5.1 and 5.2.

7.3.1 EMPIRICAL DESIGN RESULTS

The Q and average RMR values for TSw2 unit are presented in Table 1. The corresponding stand-up times (based on average RMR values) and support categories (based on Q values) for a 5 m opening in TSw2 unit are provided in Table 2.

To date, the Access/Observation Drift portion of the Thermal Test Alcove (Figure 1) has been constructed. The preliminary indications from the observations of the rock conditions at the Access/Observation Drift suggests that the rock mass is competent and could be estimated as Category 3 or better. Similar type ground conditions are expected to be encountered in the Heated Drift based on its location and orientation with respect to the Access/Observation Drift (see Figure 1).

For Category 3 rock type the stand-up time is estimated to be 600 hours as shown in Table 2 (using Figure 2 of Reference 5.2). Using Figure 3 of Reference 5.2, for alcove opening of 5 m span ground support category of 21 is obtained. Using Table 1 of Reference 5.2, for Category 21 ground support, and for $J_r/J_a > 0.75$ (Reference 5.2, Attachment II), untensioned grouted rock bolts on a 1 m spacing is recommended. Because the use of grouted rock bolts in the Heated Drift is prohibited by the TCO (Reference 5.10), therefore, it is recommended that Super Swellex rock bolts be installed. The rock bolts will be 3 m long based on discussions presented in Section 8.0 of Reference 5.2. In addition to the rock bolts, 75 mm by 75 mm Welded Wire Fabric (WWF) will be installed to reduce potential for rock falls and provide a safe working environment. The recommended ground support estimates for the rock mass Categories of 1, 2, 4, and 5 are presented in Table 2. For Category 1 rock mass conditions the use of shotcrete is recommended as an option in addition to the rock bolts (use Table 2 in conjunction with Table 1 of Reference 5.2). The use of shotcrete if required to address localized conditions or to address personnel safety must be coordinated with TCO and can be carried out only after obtaining approval from TCO (Reference 5.6). It is also recommended that the constructor have the capability to install light steel sets (e.g., W6X20) to prevent raveling if for some reason the use of shotcrete is found not to be acceptable. For Category 4 and 5 type rock the use of 3 m long rock bolts and WWF (75 mm X 75 mm) is found to be sufficient based on Category 3 rock type ground support recommendations.

7.4 ANALYTICAL METHODS

The application of the analytical methods in determining the stability of the Heated Drift is addressed in this section.

In designing the Heated Drift, stresses resulting from three sources must be considered: in situ, thermal, and seismic. In situ stresses are present before the excavation and will be altered in the vicinity of the opening during construction. Thermal stresses will occur after the drift and wing heaters are switched on and the drift scale test has been initiated. Seismic induced stress magnitudes and duration are a function of the intensity of the earthquake or Underground Nuclear Explosions (UNE), the distance from the event to the ESF alcoves, and the direction and size of the seismic wave relative to the alcove.

7.4.1 IN SITU DESIGN LOAD ANALYSIS

In order to evaluate the effects of alcove excavation, a model representing the rock at the Heated Drift location was built. Far field mesh boundaries were set about ten tunnel diameters away from the drift centerline to eliminate the effects of the boundary conditions on the numerical results. Next, the boundary and initial conditions were set and the model was run to equilibrium. Then the drift was excavated and the model was run to reach new equilibrium state. At this stage, the state of the stress due to the drift excavation was determined. The analyses are performed considering Categories 1, 3, and 5 rock mass properties. The results in terms of stress, failure zone, and safety factors were evaluated and are presented in this analysis.

Figure 2 shows the mesh used for the 5 m diameter Heated Drift opening analyses. Close-up of the 5 m diameter Heated Drift grid around the opening is presented in Figure 3. The grid used for the 6 m Heated Drift analyses and the close-up of the mesh refinement is presented in Figures 4 and 5 respectively.

The boundary conditions are set with the bottom of the model fixed in vertical direction. The top of the model is set as a pressure boundary to represent the overburden. Both sides of the model boundaries are fixed in horizontal direction.

For the in situ loading condition, the Mohr-Coulomb failure criterion is used to capture the post-elastic rock behavior. The Mohr-Coulomb criterion for rock matrix in FLAC is shown in Figure 12. The in situ stress field is gravitational, with the horizontal to vertical stress ratio set at 0.5 (see Section 4.3.2). The vertical stress is measured as the weight of the overburden as discussed in detail in References 5.1 and 5.2.

The results of the in situ loading analyses for the 5 m diameter Heated Drift are presented in Figures 13 through 18. The plasticity zone around the opening due to Heated Drift excavation is presented in Figure 13. As was expected for Category 5, no plastic zone is indicated (Figure 13c). A very small plastic zone around the Heated Drift opening for the Category 1 rock mass type is developed (Figure 13a) which is easily controlled by installation of rock bolts and WWF. Figure 13b indicates a stable opening for Category 3 type rock mass. Figure 14 shows that no failure is expected for any of the three rock mass types. Safety factors after the Heated Drift excavation are demonstrated in Figure 15 which indicate stable openings. Safety factor of 2 near the skin of the Heated Drift opening is obtained for Category 1 rock mass type (Figure 15a). Axial loads and safety factors of the 3 m long Swellex rock bolts installed on a 1 m square pattern is shown in Figures 16 and 17. The results indicate that the rock bolts carry loads well below their capacity. Shear stress contours around the Heated Drift opening are presented in Figure 18. Similar results are obtained for the 6 m diameter Heated Drift opening as shown in Figures 31 through 36. Therefore, based on the analytical results it can be concluded that the 3 m long Swellex rock bolts on a 1 m square pattern provide sufficient support for both 5 and 6 m Heated Drift opening under in situ loading conditions.

7.4.2 THERMAL DESIGN LOAD ANALYSES (TBV-226)

Thermally induced stresses are generated by the thermal expansion of the rock mass due to the thermal energy released from the drift and wing heaters during the heating period. The temperature profiles during the heating period are provided in Reference 5.4 (TBV-226). In the analyses presented here, thermal loads generated by heaters are modeled by specifying temperature gradients at the mesh boundaries. The temperatures at the drift wall and at the wing heater boreholes are set in accordance with the data provided in Reference 5.4. The rock temperature for the remainder of the mesh is set at the initial temperature of 23 °C. The two vertical sides of the mesh boundaries are set to be at adiabatic condition. The top and the bottom boundaries start with initial rock temperature of 23 °C. Through thermal conduction under thermal gradient, the temperature of the rock surrounding the drift will experience a rapid increase in temperature, which in turn induces high stress concentration around the drift. Temperature profiles generated using FLAC for both 5 and 6 m Heated Drift openings are shown in Figures 6 through 12. The rock temperatures range from 300 °C to initial temperature of 23 °C. The high temperatures are at the wing heaters and at the skin of the Heated Drift opening.

The results of the thermal calculations for 5 m diameter Heated Drift are shown in Figures 19 through 24. Figure 19 shows that the plasticity zone increases for rock mass Categories 1, 3, and 5 extending to 1 to 1.5 m into the rock. Plot 21 shows that near the skin of the opening the potential for rock failure exists for all three Categories analyzed. Figure 21 shows that the safety factors decrease with comparison to in situ loading conditions (Figure 15), as expected, but still remain stable. Axial loads on the rock bolts increase and the safety factors decrease indicating higher loads due to thermal loading (Figures 22 and 23). Figure 24 indicates high horizontal stress concentrations around the opening. The results for the 6 m diameter Heated Drift opening are presented in Figures 37 through 42. The results are similar to the 5 m opening.

As indicated earlier, there are no precedents for tunnels operating in such high temperatures. This makes it difficult to anticipate how the ground will react to such high temperatures. It is also not clear what effect the high temperatures will have on the performance of the rock bolts. One of the main objectives of this test is to observe how the surrounding rock will react to high temperatures and induced stresses. By examining the results of the analyses, it is clear that the rock surrounding the Heated Drift will be subjected to very high stresses. The results indicate that the opening should remain stable using the rock bolts and WWF as primary ground support. Potential for rock failure near the skin of the opening exists which will be controlled by bolting and WWF support. The rock bolts and WWF are carried below the spring line to enhance stability by minimizing potential for damage to the ribs due to high stress concentrations near the skin of the opening.

The thermal analyses performed in this report address the heated drift portion of the Thermal Test Alcove as it is shown in Figure 1. From the temperature profile data presented in Reference 5.4,

it can be seen that the drift extended from the Connecting Drift to the Heated Drift including the Plate Loading Niche will experience relatively high temperatures mainly due to wing heaters. These temperatures extend all the way to the west rib of the Connecting Drift. The ground support for the Connecting Drift and the drift extending from it to the Heated Drift including the Plate Loading Niche is addressed in Reference 5.1. Due to higher temperatures and resultant increase in stresses, it is recommended that the rock bolts and WWF installed in the Connecting Drift to be carried down below the spring line such that the nominal distance between the floor of the drift and the first row of the rock bolts does not exceed 2 m. It is also recommended that the rock bolts and WWF be carried below the spring line for the drift extended from the Connecting Drift to the Heated Drift and the Plate Loading Niche in the same manner.

It should be noted that the analysis performed here does not include the effects of the cooling down process after the heaters are turned off. At present, the cooling down process has not been established. For a natural cooling down process, if the heaters are turned off and the drift is allowed to be cooled down slowly, the recommended ground support is expected to be sufficient. During the natural cool down period the ground should be monitored to address any localized conditions. On the other hand, if a more aggressive cooling down process is desired, then the affects of rapid decrease in rock temperatures should be analyzed. The destressing of the ground due to sudden cool down may cause loosening of rock around the opening which has to be addressed for the specific cool down approach.

7.4.3 SEISMIC ANALYSIS OF THE HEATED DRIFT

Design methodology for seismic analyses of the ESF alcove are discussed in detail in Reference 5.2 and is not repeated here.

In the design of the Heated Drift the seismic loads are quasi-statically accounted for in the FLAC model by superimposing the earthquake-induced ground acceleration of 0.37g onto the gravitational field in both the horizontal and vertical directions. The basis of quasi-static methodology is that the size of the structure (in this case 5 and 6 m in diameter alcove) is much smaller than the predominate wave length of the seismic event (~ 240 m, Reference 5.2). The shock or distortion caused by an earthquake to an underground opening is generally small because the earthquake-induced wave length and the amplitude of earthquake displacement are generally large. Therefore, the application of a static load corresponding to the peak dynamic load would lead to a rational approximation to the actual dynamic response. The quasi-static analyses were performed on the supported Heated Drift opening. The model experiences a 37% increase in the vertical and horizontal gravitational stress components upon application of seismic loads. The stress concentration around the opening as a result is increased due to seismic loading.

The results of the seismic loading conditions for the 5 m opening are presented in Figures 25 through 30. Comparing the results of the seismic loading condition to thermal results it can be

seen that the seismic effects are much smaller as expected. Figures 28 and 29 show that negligible changes on rock bolt loads are recorded due to seismic loads. The results for 6 m Heated Drift opening are presented in Figures 43 and 48 which show similar results to the 5 m diameter opening. Based on the results of the analyses it is concluded that the rock bolts and WWF should provide adequate support for seismic loading conditions.

TABLE 1 Estimates of Q and RMR Values for TSw2 Unit (Reference 5.1)

TSw2 UNIT	ROCK MASS QUALITY CATEGORY				
	1	2	3	4	5
Q	0.3	0.65	1.91	3.75	8.44
AVERAGE RMR	42	48	54	59	65

TABLE 2 Stand-up Time and Rock Support Categories for Heated Drift (Reference 5.2)

TSw2 UNIT	ROCK MASS QUALITY CATEGORY				
	1	2	3	4	5
STAND-UP TIME (HOURS) (5 m Roof Span) USING FIGURE 2 of Ref. 5.2	25	150	600	2000	8000
SUPPORT CATEGORY (5 m Roof Span) USING FIGURE 3 of Ref. 5.2	30	26	21	21	17

Figure 1. ESF Thermal Test Alcove Layout (Reference 5.3).

Fig. 2 Finite Difference Mesh Used for the 5 m Diameter Thermal Test Alcove Heated Drift Analyses. Grid Dimensions Are in Meters.

Fig. 3 Close-up of the Grid Around the 5 m Diameter Heated Drift Opening. Grid Dimensions Are in Meters.

Fig. 4 Finite Difference Mesh Used for the 6 m Diameter Thermal Test Alcove Heated Drift Analyses. Grid Dimensions Are in Meters.

Fig. 5 Close-up of the Grid Around the 6 m Diameter Heated Drift Opening. Grid Dimensions Are in Meters.

Fig. 6 Temperature Profiles Around the 5 m Diameter Heated Drift Opening After 3 Years of Heating for Category 1 Rock Mass. Profiles Are Generated Based on Inputs from References 5.4 and 5.5. Grid Dimensions Are in Meters and Temperatures Are in °C.

Fig. 7 Temperature Profiles Around the 5 m Diameter Heated Drift Opening After 3 Years of Heating for Category 3 Rock Mass. Profiles Are Generated Based on Inputs from References 5.4 and 5.5. Grid Dimensions Are in Meters and Temperatures Are in $^{\circ}\text{C}$.

Fig. 8 Temperature Profiles Around the 5 m Diameter Heated Drift Opening After 3 Years of Heating for Category 5 Rock Mass. Profiles Are Generated Based on Inputs from References 5.4 and 5.5. Grid Dimensions Are in Meters and Temperatures Are in °C.

Fig. 9

Temperature Profiles Around the 6 m Diameter Heated Drift Opening After 3 Years of Heating for Category 1 Rock Mass. Profiles Are Generated Based on Inputs from References 5.4 and 5.5. Grid Dimensions Are in Meters and Temperatures Are in °C.

Fig. 10 Temperature Profiles Around the 6 m Diameter Heated Drift Opening After 3 Years of Heating for Category 3 Rock Mass. Profiles Are Generated Based on Inputs from References 5.4 and 5.5. Grid Dimensions Are in Meters and Temperatures Are in °C.

Fig. // Temperature Profiles Around the 6 m Diameter Heated Drift Opening After 3 Years of Heating for Category 5 Rock Mass. Profiles Are Generated Based on Inputs from References 5.4 and 5.5. Grid Dimensions Are in Meters and Temperatures Are in °C.

MFS = MATRIX FACTOR-OF-SAFETY = $\frac{AC}{BC}$
 IF MFS ≥ 1 (NO ROCK FRACTURING)
 IF MFS < 1 (POTENTIAL ROCK FRACTURING)

Fig. 12 Mohr-Coulomb Criterion for Rock Matrix in FLAC.

a)

b)

c)

Fig. 13

Plasticity Indicators Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 14

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 15

Strength/Stress Ratio Contours Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 16

Axial Loads in 3 m Swellex Rock Bolts Installed Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 17

Ratio of Axial Load to Yield Strength of 3 m Swellex Rock Bolts Installed Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 18

Shear Stress Contours Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Stresses Are in Pa. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 19

Plasticity Indicators Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 20

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 21

Strength/Stress Ratio Contours Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 22

Axial Loads in 3 m Swellex Rock Bolts Installed Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 23

Ratio of Axial Load to Yield Strength of 3 m Swellex Rock Bolts Installed Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 24

Shear Stress Contours Around the 5 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Stresses Are in Pa. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 25 Plasticity Indicators Around the 5 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 26

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space Around the 5 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 27

Strength/Stress Ratio Contours Around the 5 m diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 28

Axial Loads in 3 m Swellex Rock Bolts Installed Around the 5 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 29

Ratio of Axial Load to Yield Strength of 3 m Swellex Rock Bolts Installed Around the 5 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 30

Shear Stress Contours Around the 5 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Stresses Are in Pa. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 3/

Plasticity Indicators Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 32

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 33

Strength/Stress Ratio Contours Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 34

Axial Loads in 3 m Swellex Rock Bolts Installed Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 35

Ratio of Axial Load to Yield Strength of 3 m Swellex Rock Bolts Installed Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 36

Shear Stress Contours Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Stresses Are in Pa. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 37

Plasticity Indicators Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 38

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 39

Strength/Stress Ratio Contours Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 40

Axial Loads in 3 m Swellex Rock Bolts Installed Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 4/

Ratio of Axial Load to Yield Strength of 3 m Swellex Rock Bolts Installed Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 42

Shear Stress Contours Around the 6 m Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Stresses Are in Pa. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 43 Plasticity Indicators Around the 6 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters.

a)

b)

c)

Fig. 44

Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space Around the 6 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 45

Strength/Stress Ratio Contours Around the 6 m diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. The Envelope Is Defined by Cohesion of 1.3, 2.2, and 3.8 MPa, Friction Angle of 49°, 50°, and 50°, and Tension Limit of 0.97, 1.60, and 2.78 MPa for Rock Mass Categories of 1, 3, and 5 Respectively.

a)

b)

c)

Fig. 46

Axial Loads in 3 m Swellex Rock Bolts Installed Around the 6 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 47

Ratio of Axial Load to Yield Strength of 3 m Swellex Rock Bolts Installed Around the 6 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Grid Dimensions Are in Meters. Forces Are in Newton.

a)

b)

c)

Fig. 48

Shear Stress Contours Around the 6 m Diameter Heated Drift Opening, Mohr-Coulomb Plasticity Model, Static + Thermal + Seismic Loading Condition, (a) Category 1 Rock Mass, (b) Category 3 Rock Mass, (c) Category 5 Rock Mass. Stresses Are in Pa. Grid Dimensions Are in Meters.

8.0 CONCLUSIONS

Empirical and analytical methods are applied to estimate ground support recommendations for the heated drift portion of the ESF Thermal Test Alcove. The Heated Drift opening for the most part will be a 5 m diameter circular opening with flaring out to a 5.6 m diameter opening at the back end. In order to bound the analyses, a 5 m and a 6 m diameter opening are considered in numerical calculations using FLAC. The analyses are performed considering Categories 1, 3, and 5 rock mass types to evaluate the stability of the Heated Drift subjected to in situ, thermal, and seismic loading conditions. From the preliminary observations at the Thermal Test Alcove Access/Observation Drift, Category 3 or better rock mass type is to be expected in the Heated Drift. Therefore, analyses incorporating Category 3 rock mass properties probably represent closely what should be experienced in the Heated Drift. The results of the in situ loading analysis show that the Heated Drift will remain within the elastic range of deformation (Figure 14). The lowest factor of safety is about 2 near the skin of the opening and increases rapidly moving into the rock surrounding the 5 m Heated Drift for Category 1 rock mass type (Figure 15a). The safety factors are higher for Categories 3 and 5 as expected (Figures 15b and 15c). The axial loads on the rock bolts are well below their capacity (Figures 16 and 17).

The thermal loading condition is analyzed by introduction of temperature gradients at the mesh boundaries and at the wing heater locations. The input data for thermal calculations are supplied by TCO in References 5.4 and 5.5 (TBV-226). The input data used in thermal calculations are based on preliminary data as indicated in References 5.4 and 5.5. The results of thermal loading calculations for the 5 m diameter Heated Drift show high stress concentrations around the opening for all three rock mass Categories. Figures 19 and 20 indicate potential for small failure zones near the skin of the opening. The safety factors decrease around the alcove opening due to presence of higher stresses for all three rock mass Categories (Figure 21). The axial loads in the rock bolts increase and safety factors decrease as can be seen from Figures 22 and 23. The resultant loads are still below the rock bolt capacity. It should be noted that the effects of high temperatures on the rock bolts is not considered in these calculations. From evaluation of the overall results of the thermal loading conditions it is concluded that 3 m long swellex rock bolts and 75 mm by 75 mm WWF should provide sufficient support for the Heated Drift during the heating processes. The rock bolts and WWF are extended below the spring line to provide additional support and safety along the ribs. This would minimize chance of rock fall outs near the skin of the opening that may be caused due to the presence of high stress concentrations. It should be noted that the analysis performed here does not include the effects of the cooling down process after the heaters are turned off. At present, the cooling down process has not been established. For a natural cooling down process, if the heaters are turned off and the drift is allowed to be cooled down slowly, the recommended ground support is expected to be sufficient. During the natural cool down period the ground should be monitored to address any localized conditions. On the other hand, if a more aggressive cooling down process is desired, then the affects of rapid decrease in rock temperatures should be analyzed. The destressing of the ground due to sudden cool down may cause loosening of rock around the opening which has to be

addressed for the specific cool down approach.

The results of the seismic loading analyses for the 5 m diameter Heated drift opening indicate that minimal impact is expected in the case of an event. The seismic loads were analyzed by superimposing the earthquake-induced particle acceleration of 0.37g (Reference 5.8) onto the gravitational stress field in both the horizontal and vertical directions. There are minimal changes in the rock bolt loads due to seismic loading (Figures 28 and 29 in comparison to Figures 22 and 23).

The results of the FLAC analyses for the 6 m Heated Drift opening (Figures 31 through 48) are similar to those for the 5 m one, therefore, similar conclusions are made and the same ground support recommendations are made. For the 6 m opening 2 more rock bolts are needed to carry the ground support below the spring line. The rock bolts below spring line for the 5 m diameter opening were analyzed by installing them in a radial direction (see Figure 16). For the 6 m diameter Heated Drift these rock bolts were installed horizontally (see Figure 34). The results indicate that both cases are acceptable, meaning that the rock bolts below the spring line can be installed either horizontally or in the radial direction. For constructibility purposes, the horizontally installed rock bolts are preferred because it is more difficult to clean out the holes for rock bolts installed in down hole directions. Moreover, the TCO approval is required prior to the installation of any rock bolts below the spring line in the Thermal Test Facility (Reference 5.6). The final direction of the rock bolts will be shown on design drawing(s) which will have the flexibility to accommodate testing needs.

The ground support for the Connecting Drift and the drift extending from it to the Heated Drift including the Plate Loading Niche is addressed in Reference 5.1. Due to higher temperatures and resultant increase in stresses, it is recommended that the rock bolts and WWF installed in the Connecting Drift be carried down below the spring line such that the nominal distance between the floor of the drift and the first row of rock bolts does not exceed 2 m. It is also recommended that the rock bolts and WWF be carried below the spring line for the drift extended from the Connecting Drift to the Heated Drift and the Plate Loading Niche in the same manner.

The transition zone for the ESF alcoves is conservatively determined to be 20 m measured perpendicular from the centerline of the Main Drift ramp into the rock at the alcove location (approximately two ramp diameters measured perpendicular from the rib at the alcove side). The ground support installed beyond the transition zone is not Q based on Reference 5.9. Therefore, the ground support installed in the Heated Drift portion of the Thermal Test Facility is not Q based on Reference 5.9. The ground support recommended here does not include the ground support components which will be tested and emplaced by the TCO for potential repository testing purposes.

Finally, after considering testing constraints and the results of the analyses, 3 m long Super Swellex type rock bolts on a nominal 1 m square pattern with 75 mm by 75 mm WWF is

recommended for the heated drift portion of the Thermal Test Facility which will be extended below the spring line. Installation of the rock bolts below the spring line must be carried out only after obtaining approval from the TCO (Reference 5.6). In order to accommodate testing needs to install the wing heaters, the spacing of the rock bolts installed below the spring line may be greater than 1 m but may not exceed 1.5 m. If during construction the ground conditions require the use of shotcrete or other means of support such as steel sets to address localized conditions for personnel safety, the constructor must obtain TCO approval prior their use (Reference 5.6). It is also recommended that the constructor have the capability to install light steel sets (e.g., W6X20) to prevent raveling if for some reason the use of shotcrete is found not to be acceptable. As always, observation and monitoring during and after construction are considered essential to verify rock properties and opening performance, and to implement ground support modifications, if required.

9.0 ATTACHMENTS

ATTACHMENT I: Input Files for Computer Analyses

Pages: I-1 to I-20

ATTACHMENT I

**INPUT FILES FOR THERMAL ALCOVE HEATED DRIFT GROUND SUPPORT ANALYSES
FLAC VERSION 3.22:**

new

* Location: Heated Drift
* Properties: Category 5
* Ko = 0.50
* Drift: Supported
* Loadings: Excavation +
* Thermal +
* Seismic

call kc_value.fis
call tcw.fis
call ptn.fis
call tsw1.fis
call tsw2.fis
call boltxy6.fis
set ko=0.50 cat_m=5 * grn_typ=1
call m2827_6.dat
step 180 * at 65% ground relaxation
call tsw2_sw6.dat
step 3900
sav 156st0d0.sav
call tsw2_lo.dat
sav 156st3d0.sav
call tsw2_ses.fis
tsw2_ses
step 5000
sav 156st3d1.sav

*

new

* Location: Heated Drift
* Properties: Category 3
* Ko = 0.50
* Drift: Supported

* Loadings: Excavation +
* Thermal +
* Seismic

call kc_value.fis
call tcw.fis
call ptn.fis
call tsw1.fis
call tsw2.fis
call boltxy6.fis
set ko=0.50 cat_m=3 * grn_typ=1
call m2827_6.dat
step 180 * at 65% ground relaxation
call tsw2_sw6.dat
step 3900
sav l36st0d0.sav
call tsw2_lo.dat
sav l36st3d0.sav
call tsw2_ses.fis
tsw2_ses
step 5000
sav l36st3d1.sav
*

new

* Location: Heated Drift
* Properties: Category 1
* Ko = 0.50
* Drift: Supported
* Loadings: Excavation +
* Thermal + Seismic

call kc_value.fis
call tcw.fis
call ptn.fis
call tsw1.fis
call tsw2.fis
call boltxy6.fis
set ko=0.50 cat_m=1 * grn_typ=1
call m2827_6.dat
step 180 * at 65% ground relaxation
call tsw2_sw6.dat

```
step 3900
sav l16st0d0.sav
call tsw2_lo.dat
sav l16st3d0.sav
call tsw2_ses.fis
tsw2_ses
step 5000
sav l16st3d1.sav
*
```

```
def boltxy6
  ib=ibb
  jb=jbb
  xx=x(ib,jb)
  yy=y(ib,jb)
  dd=sqrt(xx*xx + yy*yy)
  ang=atan2(yy,xx)
  xe=x(ib,jb) + blength*cos(ang)
  ye=y(ib,jb) + blength*sin(ang)
  if jb=35 then
    if ib=41 then
      xe=x(ib,jb)+3
      ye=y(ib,jb)
    else
      xe=x(ib,jb)-3
      ye=y(ib,jb)
    end_if
  end_if
  command
    stru cable beg xx, yy end xe, ye seg 10 prop 1
  end_command
end
```

```
*****
* File Name:   M2827_6.dat                      *
* Description: Heated Drift Mesh Construction *
*****
```

config thermal dyn extra 3

* Mesh construction

```
def mesh_grd
rat1=1.25
rat2=1./rat1
end
mesh_grd
```

```
gr 70 70
model m th_iso
gen -60,-60 -60, 60 60, 60 60,-60
gen -60,-60 -60,-15 -15,-15 -15,-60 r=rat2,rat2 I= 1,11 J= 1,11
gen -60,-15 -60, 15 -15, 15,-15,-15 r=rat2,1 I= 1,11 J=11,61
gen -60, 15 -60, 60 -15, 60 -15, 15 r=rat2,rat1 I= 1,11 J=61,71
gen -15, 15 -15, 60 15, 60 15, 15 r=1, rat1 I=11,61 J=61,71
gen -15,-15 -15, 15 15, 15 15,-15 I=11,61 J=11,61
gen -15,-60 -15,-15 15,-15 15,-60 r=1, rat2 I=11,61 J= 1,11
gen 15, 15 15, 60 60, 60 60, 15 r=rat1,rat1 I=61,71 J=61,71
gen 15,-15 15, 15 60, 15 60,-15 r=rat1,1 I=61,71 J=11,61
gen 15,-60 15,-15 60,-15 60,-60 r=rat1,rat2 I=61,71 J= 1,11
gen circle 0 0 3.0
```

* Vertical coordinate adjustment for proper elevation

```
def ycrd_adj
new_ori= yelv_spr
sigv_top = 0.
sigv_suf =0.
command
ini y add new_ori
end_command
end
```

* Assign material properties and initial stresses according to layers

kc_value

```
def mat_ini
if yelv_bot >= (yelv_spr+60) then
sigv_top = sigv_top + 9.81*dn_m*(yelv_top-yelv_bot)
sigv_suf = sigv_top
else
command
gen line -60 yelv_bot 60 yelv_bot
```

```
end_command
loop j (1,jgp)
  if abs(y(1,j)-yelv_bot) < 0.01 then
    jpbot=j
    jzbot=j
  end_if
end_loop
;
if yelv_top >=(yelv_spr+60) then
  jptop = jgp
  jztop = jptop-1
  sigv_top = sigv_top + 9.81*dn_m*(yelv_top-(yelv_spr+60))
  sigv_suf = sigv_top
else
  command
    gen line -60 yelv_top 60 yelv_top
  end_command
  loop j (1,jgp)
    if abs(y(1,j)-yelv_top) < 0.01 then
      jptop=j
      jztop=jptop-1
    end_if
  end_loop
end_if
;
e_m=e_sc*e_m
ch_m=ch_sc*ch_m
fr_m=fr_sc*fr_m
dila_m=dila_sc*dila_m
sh_m=0.5*e_m/(1.+v_m)
bk_m=(1./3.)*e_m/(1.-2.*v_m)
ang=fr_m*pi/180.
tn_m=2.*ch_m*cos(ang)/(1.+sin(ang))
grad_v=9.81*dn_m*(y(1,jptop)-y(1,jpbot))
grad_h=ko_m*grad_v
sigv=-(sigv_top+grad_v)
sigh=ko_m*sigv
command
  prop s=sh_m b=bk_m d=dn_m j=jzbot,jztop
  prop coh=ch_m fri=fr_m dila=dila_m ten=tn_m j=jzbot,jztop
  ini syy sigv var 0 grad_v j=jzbot,jztop
  ini sxx sigh var 0 grad_h j=jzbot,jztop
```

```
      ini szz sigh var 0 grad_h j=jzbot,jztop
      ini temp 23
      end_command
      if abs(yelv_bot - y(1,1)) < 0.01 then
      command
        apply pressure sigv_suf j=71
      end_command
      end_if
      sigv_top = sigv_top +grad_v
    end_if
  end
```

```
set grav=9.81
```

```
* generate specific models by activating FISH functions
```

```
set yelv_spr 0
ycrd_adj
set yelv_top=268.38 yelv_bot=195.67 dn_m=2169
tcw
mat_ini
set yelv_top=195.67 yelv_bot=156.11 dn_m=1299
ptn
mat_ini
set yelv_top=156.11 yelv_bot=21.38 dn_m=2163
tsw1
mat_ini
set yelv_top=21.38 yelv_bot=-60 dn_m=2274
tsw2
mat_ini
*
prop cond 2.1 spec 942 thexp 8.97e-6
fix x i=1
fix x i=71
fix y j=1
```

```
his unbal
```

```
set dyn off thermal off
```

```
step 100
ini xdisp 0 ydisp 0
```

```
def vcl
  vcl=ydisp(36,30)-ydisp(36,42)
end
def hcl
  hcl=xdisp(30,36)-xdisp(42,36)
end
his vcl
his hcl
his sxx i 36 j 42
his sxx i 36 j 29
his syy i 42 j 36
his sxy i 40 j 40
his sxy i 40 j 31
m n reg 35,35
```

*tsw2_blt.fis for the single thermal drift model

```
  struc prop 1 e 200e9 yield 110e3 a 2.58e-4 sbond 7.33e4 kbond 7.33e8
*  call boltxy6.fis
  set ibb=41 jbb=35 blength=3
  boltxy6
  set ibb=41 jbb=37 blength=3
  boltxy6
  set ibb=40 jbb=38 blength=3
  boltxy6
  set ibb=40 jbb=40 blength=3
  boltxy6
  set ibb=38 jbb=40 blength=3
  boltxy6
  set ibb=37 jbb=41 blength=3
  boltxy6
  set ibb=35 jbb=41 blength=3
  boltxy6
  set ibb=34 jbb=40 blength=3
  boltxy6
  set ibb=32 jbb=40 blength=3
  boltxy6
  set ibb=32 jbb=38 blength=3
  boltxy6
  set ibb=31 jbb=37 blength=3
```

boltxy6
set ibb=31 jbb=35 blength=3
boltxy6

```
new
*****
*      Location:      Heated Drift
*      Properties:    Category 3
*      Ko =           0.50
*      Drift:         Supported
*      Loadings:     Excavation +
*                    Thermal +
*                    Seismic
*****

call kc_value.fis
call tcw.fis
call ptn.fis
call tsw1.fis
call tsw2.fis
call tsw2_swl.fis
call boltxy.fis
set ko=0.50 cat_m=3 grn_typ=1
call m2827.dat
step 180 * at 65% ground relaxation
call tsw2_swl.dat
step 3900
sav l32st0d0.sav
call tsw2_lo.dat
sav l32st3d0.sav
call tsw2_ses.fis
tsw2_ses
step 5000
sav l32st3d1.sav
*

new
*****
*      Location:      Heated Drift
*      Properties:    Category 1
*      Ko =           0.50
*      Drift:         Supported
*      Loadings:     Excavation +
```

```
*              Thermal +
*              Seismic
*****
call kc_value.fis
call tcw.fis
call ptn.fis
call tsw1.fis
call tsw2.fis
call tsw2_swl.fis
call boltxy.fis
set ko=0.50 cat_m=1 grn_typ=1
call m2827.dat
step 180 * at 65% ground relaxation
call tsw2_swl.dat
step 3900
sav l12st0d0.sav
call tsw2_lo.dat
sav l12st3d0.sav
call tsw2_ses.fis
tsw2_ses
step 5000
sav l12st3d1.sav
*
new
*****
*      Location:      Heated Drift
*      Properties:    Category 5
*      Ko =           0.50
*      Drift:         Supported
*      Loadings:      Excavation +
*                    Thermal +
*                    Seismic
*****
call kc_value.fis
call tcw.fis
call ptn.fis
call tsw1.fis
call tsw2.fis
call tsw2_swl.fis
call boltxy.fis
set ko=0.50 cat_m=5 grn_typ=1
call m2827.dat
```

```
step 180 * at 65% ground relaxation
call tsw2_swl.dat
step 3900
sav l52st0d0.sav
call tsw2_lo.dat
sav l52st3d0.sav
call tsw2_ses.fis
tsw2_ses
step 5000
sav l52st3d1.sav
*
```

```
*****
```

```
*tsw1.fis
```

```
*****
```

```
def tsw1
```

```
case_of cat_mat
```

```
;
```

```
case 1
```

```
command
```

```
set e_m=5.66e9 v_m=0.30 ch_m=0.7e6 fr_m=41 dn_m=2163
```

```
end_command
```

```
;
```

```
case 2
```

```
command
```

```
set e_m=8.78e9 v_m=0.30 ch_m=0.9e6 fr_m=42 dn_m=2163
```

```
end_command
```

```
;
```

```
case 3
```

```
command
```

```
set e_m=11.71e9 v_m=0.30 ch_m=1.0e6 fr_m=42 dn_m=2163
```

```
end_command
```

```
;
```

```
case 4
```

```
command
```

```
set e_m=17.86e9 v_m=0.30 ch_m=1.3e6 fr_m=43 dn_m=2163
```

```
end_command
```

```
;
```

```
case 5
```

```
command
```

```
set e_m=18.90e9 v_m=0.30 ch_m=1.9e6 fr_m=43 dn_m=2163
```

```
end_command
;
end_case
end
```

*tsw2.fis

```
def tsw2
case_of cat_mat
;
case 1
command
set e_m=6.37e9 v_m=0.21 ch_m=1.3e6 fr_m=49 dila_m=25 dn_m=2274
end_command
;
case 2
command
set e_m=8.96e9 v_m=0.21 ch_m=1.6e6 fr_m=49 dila_m=25 dn_m=2274
end_command
;
case 3
command
set e_m=12.55e9 v_m=0.21 ch_m=2.2e6 fr_m=50 dila_m=25 dn_m=2274
end_command
;
case 4
command
set e_m=17.11e9 v_m=0.21 ch_m=2.8e6 fr_m=50 dila_m=25 dn_m=2274
end_command
;
case 5
command
set e_m=23.51e9 v_m=0.21 ch_m=3.8e6 fr_m=50 dila_m=25 dn_m=2274
end_command
;
end_case
end
```

* Stage 2. Introducing the thermal loading

*

```
*           Max. temperature at drift and borehole           *
*           walls from Sandia report is imposed to           *
*           the model and the model is run for               *
*           three years for temperature distribution.          *
*                                                                 *
*****
*
*ini temp 23
*fix temp=22.6  i=1,71 j=71  * Prescribe Mesh top temperature
*fix temp=24.8  i=1,71 j=1   * Prescribe mesh bottom temperature

prop cond 2.1 spec 942 thexp 8.97e-6 reg 1,1
prop cond 2.1 spec 942 thexp 8.97e-6 reg 1,70

*prop cond 2.1 spec 942 thexp 17.94e-6 reg 1,1
*prop cond 2.1 spec 942 thexp 17.94e-6 reg 1,70

free temp i=1,71 j=71
free temp i=1,71 j=1
unmark i=1,71 j=64
unmark i=1,71 j=1

fix temp=275 mark          * Prescribe drift wall temperature

fix temp 275 i=44,56 j=35  *Right Wing heater borehole wall
fix temp=300 i=44,56 j=36  *Right Wing heater borehole center
fix temp=275 i=44,56 j=37  *Right Wing heater borehole wall

fix temp 275 i=16,28 j=35  *Left Wing heater borehole wall
fix temp=300 i=16,28 j=36  *Left Wing heater borehole center
fix temp=275 i=16,28 j=37  *Left Wing heater borehole wall

his thtime
set thdt=28800 clo=6e8  * run for three years
set implicit on        * use implicit approach
set therm on
set mech off
set step 3285
solve temp 400
set therm off
set mech on
step 5000
```

```
def tsw2_ses
  sigv_suf=1.37*sigv_suf
  command
    apply pressure sigv_suf j=71
    set grav 13.92 15.11
  end_command
end
```

*tsw2_blt.fis for the single thermal drift model

```
  struc prop 1 e 200e9 yield 110e3 a 2.58e-4 sbond 7.33e4 kbond 7.33e8
*  call boltxy.fis
  set ibb=40 jbb=35 blength=3
  boltxy
*  set ibb=40 jbb=36 blength=3 * along the springline
*  boltxy
  set ibb=40 jbb=37 blength=3
  boltxy
  set ibb=39 jbb=38 blength=3
  boltxy
  set ibb=38 jbb=39 blength=3
  boltxy
  set ibb=37 jbb=40 blength=3
  boltxy
  set ibb=35 jbb=40 blength=3
  boltxy
  set ibb=34 jbb=39 blength=3
  boltxy
  set ibb=33 jbb=38 blength=3
  boltxy
  set ibb=32 jbb=37 blength=3
  boltxy
*  set ibb=32 jbb=36 blength=3 * along the springline
*  boltxy
  set ibb=32 jbb=35 blength=3
  boltxy
```

```
*****
*tsw2_blt.fis for the single thermal drift model
*****

def tsw2_sw1
  grn_inst=int(grn_typ)
;
case_of grn_inst
;
case 1 ;Super Swellex bolts on 1 m spacing
command
  struc prop 1 e 200e9 yield 110e3 a 2.58e-4 sbond 7.33e4 kbond 7.33e8
* call boltxy.fis
  set ibb=40 jbb=35 blength=3
  boltxy
* set ibb=40 jbb=36 blength=3 * along the springline
* boltxy
  set ibb=40 jbb=37 blength=3
  boltxy
  set ibb=39 jbb=38 blength=3
  boltxy
  set ibb=38 jbb=39 blength=3
  boltxy
  set ibb=37 jbb=40 blength=3
  boltxy
  set ibb=35 jbb=40 blength=3
  boltxy
  set ibb=34 jbb=39 blength=3
  boltxy
  set ibb=33 jbb=38 blength=3
  boltxy
  set ibb=32 jbb=37 blength=3
  boltxy
* set ibb=32 jbb=36 blength=3 * along the springline
* boltxy
  set ibb=32 jbb=35 blength=3
  boltxy
end_command
end_case
end
```

*tcw.fis

def tcw

case_of cat_mat

;

case 1

command

set e_m=6.70e9 v_m=0.20 ch_m=1.2e6 fr_m=53 dila_m= 26 dn_m=2169

end_command

;

case 2

command

set e_m=8.92e9 v_m=0.20 ch_m=1.3e6 fr_m=53 dila_m=26 dn_m=2169

end_command

;

case 3

command

set e_m=13.33e9 v_m=0.20 ch_m=1.7e6 fr_m=54 dila_m=26 dn_m=2169

end_command

;

case 4

command

set e_m=21.20e9 v_m=0.20 ch_m=2.4e6 fr_m=55 dila_m=26 dn_m=2169

end_command

;

case 5

command

set e_m=27.71e9 v_m=0.20 ch_m=3.0e6 fr_m=55 dila_m=26 dn_m=2169

end_command

;

end_case

end

*ptn.fis

def ptn

case_of cat_mat

;

case 1

command

```
set e_m=2.50e9 v_m=0.20 ch_m=0.3e6 fr_m=40 dn_m=1299
end_command
;
case 2
command
set e_m=2.50e9 v_m=0.20 ch_m=0.3e6 fr_m=41 dn_m=1299
end_command
;
case 3
command
set e_m=2.50e9 v_m=0.20 ch_m=0.3e6 fr_m=42 dn_m=1299
end_command
;
case 4
command
set e_m=2.50e9 v_m=0.20 ch_m=0.4e6 fr_m=43 dn_m=1299
end_command
;
case 5
command
set e_m=2.50e9 v_m=0.20 ch_m=0.5e6 fr_m=44 dn_m=1299
end_command
;
end_case
end
```

```
*****
* File Name:   M2827.dat                      *
* Description: Heated Drift Mesh Construction
*****
```

config thermal dyn extra 3

* Mesh construction

```
def mesh_grd
rat1=1.25
rat2=1./rat1
end
mesh_grd
```

```
gr 70 70
model m th_iso
gen -60,-60 -60, 60 60, 60 60,-60
gen -60,-60 -60,-15 -15,-15 -15,-60 r=rat2,rat2 I= 1,11 J= 1,11
gen -60,-15 -60, 15 -15, 15,-15,-15 r=rat2,1 I= 1,11 J=11,61
gen -60, 15 -60, 60 -15, 60 -15, 15 r=rat2,rat1 I= 1,11 J=61,71
gen -15, 15 -15, 60 15, 60 15, 15 r=1, rat1 I=11,61 J=61,71
gen -15,-15 -15, 15 15, 15 15,-15 I=11,61 J=11,61
gen -15,-60 -15,-15 15,-15 15,-60 r=1, rat2 I=11,61 J= 1,11
gen 15, 15 15, 60 60, 60 60, 15 r=rat1,rat1 I=61,71 J=61,71
gen 15,-15 15, 15 60, 15 60,-15 r=rat1,1 I=61,71 J=11,61
gen 15,-60 15,-15 60,-15 60,-60 r=rat1,rat2 I=61,71 J= 1,11
gen circle 0 0 2.5
```

* Vertical coordinate adjustment for proper elevation

```
def ycrd_adj
  new_ori= yelv_spr
  sigv_top = 0.
  sigv_suf =0.
  command
    ini y add new_ori
  end_command
end
```

* Assign material properties and initial stresses according to layers

kc_value

```
def mat_ini
  if yelv_bot >= (yelv_spr+60) then
    sigv_top = sigv_top + 9.81*dn_m*(yelv_top-yelv_bot)
    sigv_suf = sigv_top
  else
    command
      gen line -60 yelv_bot 60 yelv_bot
    end_command
    loop j (1,jgp)
      if abs(y(1,j)-yelv_bot) < 0.01 then
        jpbot=j
        jzbot=j
      end_if
  end
```

```
end_loop
;
if yelv_top >=(yelv_spr+60) then
  jptop = jgp
  jztop = jptop-1
  sigv_top = sigv_top + 9.81*dn_m*(yelv_top-(yelv_spr+60))
  sigv_suf = sigv_top
else
  command
    gen line -60 yelv_top 60 yelv_top
  end_command
  loop j (1,jgp)
    if abs(y(1,j)-yelv_top) < 0.01 then
      jptop=j
      jztop=jptop-1
    end_if
  end_loop
end_if
;
e_m=e_sc*e_m
ch_m=ch_sc*ch_m
fr_m=fr_sc*fr_m
dila_m=dila_sc*dila_m
sh_m=0.5*e_m/(1+v_m)
bk_m=(1./3.)*e_m/(1.-2.*v_m)
ang=fr_m*pi/180.
tn_m=2.*ch_m*cos(ang)/(1.+sin(ang))
grad_v=9.81*dn_m*(y(1,jptop)-y(1,jpbot))
grad_h=ko_m*grad_v
sigv=-(sigv_top+grad_v)
sigh=ko_m*sigh
command
  prop s=sh_m b=bk_m d=dn_m j=jzbot,jztop
  prop coh=ch_m fri=fr_m dila=dila_m ten=tn_m j=jzbot,jztop
  ini syy sigv var 0 grad_v j=jzbot,jztop
  ini sxx sigh var 0 grad_h j=jzbot,jztop
  ini szz sigh var 0 grad_h j=jzbot,jztop
  ini temp 23
end_command
if abs(yelv_bot - y(1,1)) < 0.01 then
  command
    apply pressure sigv_suf j=71
```

```
        end_command
    end_if
    sigv_top = sigv_top + grad_v
end_if
end
```

```
set grav=9.81
```

```
* generate specific models by activating FISH functions
```

```
set yelv_spr 0
ycrd_adj
set yelv_top=268.38 yelv_bot=195.67 dn_m=2169
tcw
mat_ini
set yelv_top=195.67 yelv_bot=156.11 dn_m=1299
ptn
mat_ini
set yelv_top=156.11 yelv_bot=21.38 dn_m=2163
tsw1
mat_ini
set yelv_top=21.38 yelv_bot=-60 dn_m=2274
tsw2
mat_ini
*
prop cond 2.1 spec 942 thexp 8.97e-6
fix x i=1
fix x i=71
fix y j=1
```

```
his unbal
```

```
set dyn off thermal off
```

```
step 100
ini xdisp 0 ydisp 0
```

```
def vcl
    vcl=ydisp(36,30)-ydisp(36,42)
end
def hcl
    hcl=xdisp(30,36)-xdisp(42,36)
```

```
end
his vcl
his hcl
his sxx i 36 j 42
his sxx i 36 j 29
his syy i 42 j 36
his sxy i 40 j 40
his sxy i 40 j 31
m n reg 35,35
```

```
*****
```

```
*kc_value.fis
```

```
*****
```

```
def kc_value
  ko_m=float(ko)
  cat_mat = int(cat_m)
  e_sc=1.
  ch_sc=1.
  fr_sc=1.
  dila_sc=1.
  dn_sc=1.
end
```

```
def boltxy
  ib=ibb
  jb=jbb
  xx=x(ib,jb)
  yy=y(ib,jb)
  dd=sqrt(xx*xx + yy*yy)
  ang=atan2(yy,xx)
  xe=x(ib,jb) + blength*cos(ang)
  ye=y(ib,jb) + blength*sin(ang)
  command
    stru cable beg xx, yy end xe, ye seg 10 prop 1
  end_command
end
```