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12. REMARKS

TBV-193-ESF APPLIES TO THIS ANALYSIS.
TBV-224 APPLIES TO THIS ANALYSIS.

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2. DESIGN ANALYSIS TITLE

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1.0 PURPOSE

The main purpose and objective of this analysis is to design a Box-Cut at the ESF South Portal to accommodate the Tunnel Boring Machine's (TBM) exit at the conclusion of the ESF Main Loop construction. The stability of the Highwall and the sidewalls at the Box-Cut are assessed using analytical methods by numerical modeling techniques. A ground reinforcement system for the South Ramp Box-Cut slopes will be recommended.

This report summarizes the results of the analyses and provides the details of the recommended ground reinforcement system for the Box-Cut slopes at the South Portal. The reinforcement design details are then incorporated into design output documents for implementation in the field. Method of excavation for the Box-Cut is also discussed and a recommendation is provided in this analysis.

2.0 QUALITY ASSURANCE

The quality assurance classification for ground support items discussed in this analysis are presented in Reference 5.4. The ground support will be installed in Box-Cut slopes (Highwall and both sidewalls). The work control evaluation for ESF design (Reference 5.2) has determined that the QA program applies to this analysis. The permanent function ground support installed at the ESF South Portal Highwall is classified as QA-1 and QA-5 in Reference 5.4 and is therefore subject to QA controls. The Highwall is defined as the rock cut surface at the back of the Box-Cut bounded by both sidewalls (Figure 26). The Highwall is referred to as Headwall in Reference 5.4. The sidewalls at the Box-Cut are not considered permanent and therefore do not require classification in Reference 5.4. Any temporary function ground support installed by the constructor for reasons of personnel safety does not require classification (Reference 5.4).

3.0 METHOD

Analytical methods are used to evaluate the stability of the Box-Cut slopes under in situ and seismic loading conditions. The analytical methods and computational details are presented in Section 7.

4.0 DESIGN INPUTS

4.1 DESIGN PARAMETERS

South Portal Coordinates (Reference 5.3): N 230614.635
E 172900.776
Elevation 1160.069 m

These coordinate correspond to the excavated invert of the tunnel as shown in Figure 26.

A 7.62 m in diameter Tunnel Boring Machine is being used to excavate the ESF Main Loop. A circular opening of 7.62 m in diameter is used to establish the ground support pattern at the South Portal Highwall.

The rock mass properties for TCw unit from Reference 5.1 are used as inputs in computer analyses (TBV-224). The same TCw unit properties were used in the design of the ESF Main Loop ground support (Reference 5.1). The site specific data from the South Portal Design Borehole (SPDB) is not available for the design but will be used to confirm the analyses presented here prior to the construction of the Box-Cut slopes (TBV-224). Rock mass properties for all five rock mass Categories are presented from which the Category 1 rock mass properties are used in the analyses for conservatism.

TCw Unit Rock Mass Properties (TBV-224)

Category 1:

Elastic modulus = 6.70 GPa (Source: Reference 5.1)
Poisson's ratio = 0.2 (Source: Reference 5.1)
Density = 2169 Kg/m^3 (Source: Reference 5.1, Attachment V)
Cohesion = 1.2 MPa (Source: Reference 5.1)
Friction angle = 53° (Source: Reference 5.1)
Tensile strength = 0.80 MPa (Source: Reference 5.1)

Category 2:

Elastic modulus = 8.92 GPa (Source: Reference 5.1)
Poisson's ratio = 0.2 (Source: Reference 5.1)
Density = 2169 Kg/m^3 (Source: Reference 5.1, Attachment V)
Cohesion = 1.3 MPa (Source: Reference 5.1)
Friction angle = 53° (Source: Reference 5.1)
Tensile strength = 0.87 MPa (Source: Reference 5.1)

Category 3:

Elastic modulus = 13.33 GPa (Source: Reference 5.1)
Poisson's ratio = 0.2 (Source: Reference 5.1)
Density = 2169 Kg/m^3 (Source: Reference 5.1, Attachment V)
Cohesion = 1.7 MPa (Source: Reference 5.1)
Friction angle = 54° (Source: Reference 5.1)
Tensile strength = 1.10 MPa (Source: Reference 5.1)

Category 4:

Elastic modulus = 21.20 GPa (Source: Reference 5.1)
Poisson's ratio = 0.2 (Source: Reference 5.1)
Density = 2169 Kg/m^3 (Source: Reference 5.1, Attachment V)
Cohesion = 2.4 MPa (Source: Reference 5.1)
Friction angle = 55° (Source: Reference 5.1)
Tensile strength = 1.51 MPa (Source: Reference 5.1)

Category 5:

Elastic modulus = 27.71 GPa (Source: Reference 5.1)
Poisson's ratio = 0.2 (Source: Reference 5.1)
Density = 2169 Kg/m^3 (Source: Reference 5.1, Attachment V)
Cohesion = 3.0 MPa (Source: Reference 5.1)
Friction angle = 55° (Source: Reference 5.1)
Tensile strength = 1.89 MPa (Source: Reference 5.1)

Seismic criteria is used from Reference 5.6. Mean peak horizontal and vertical acceleration of 0.37g is used in the analysis (TBV-193-ESF). This analysis (all parameters used for seismic analyses) needs to be re-evaluated once the seismic criteria for the ESF is finalized and more data is available (removal of TBV-193-ESF). The ground support designed here does not preclude the option to supplement the installed ground support at the Box-Cut slopes to satisfy more stringent seismic criteria (higher mean peak accelerations and velocities).

INPUT PARAMETERS FOR GROUND SUPPORT CALCULATIONS:

Numerical representation of fully-grouted rock bolts and Swellex rock bolts using FLAC computer software is described in detail in Reference 5.1.

Bolt Type: Hollow continuous threaded steel bar by Williams (Reference 5.1)
A = 439 mm^2 (Reference 5.1)

E = 200/1.5 = 133.33 GPa (Reference 5.1)
T = 267/1.5 = 178 KN (Reference 5.1)
SBO = 0.383 MN/m, KBO = 10.9 GN/m/m (Reference 5.1)

Bolt Type: The Swellex Bolting System (Reference 5.1)
A = 258 mm^2 (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 (= ΔSBO/ΔU = $73.3/0.1\times10^{-3}$ = 0.733 GN/m/m) (Reference 5.1)

4.2 CRITERIA

The following design criteria were developed to respond to ESFDR (Reference 5.6) requirements that specifically apply to this design analysis. ESF Design Requirements are cited for each criteria statement.

4.2.1 Drill core test results from ESF drill core testing are used as design inputs in analyzing the ESF South Portal Box-Cut and in the design of the ground support system. The parameters used in the analysis along with their sources are presented in Section 4.1. The ESF South Portal Box-Cut ground support system is designed such that it provides flexibility to accommodate specific site conditions identified during construction, monitoring, or testing. (ESFDR 3.7.3.1.I, 3.7.3.1.J, 3.7.3.1.K)

4.2.2 The seismic loading (TBV-193-ESF) conditions (to the extent known at this time) are considered in the design of the ESF South Portal Box-Cut ground support system (see Section 7.9). The ESF seismic design basis are presented in Appendix A (A.4 and A.5) of the ESFDR (Reference 5.6). (ESFDR 3.2.1.2.1.2.A)

4.2.3 The ground support system for the South Portal Box-Cut is designed to permit inspection and monitoring as needed to evaluate their readiness and to ensure their continued function. A sampling of the permanent function ground support components will be monitored as part of ESF monitoring program (see Section 7.1). The data collected will allow evaluation of the continued functioning of the ground support system. (ESFDR 3.7.3.1.F)

4.2.4 The use of pressure grouting at the South Portal Box-Cut 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)

4.2.5 The ground support system used in the South Portal Box-Cut 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)

4.2.6 The ESF permanent function ground support system is designed considering a 150-year maintainable life. The long term maintainability issues for ground support items are discussed in detail in Reference 5.1. Because the same type ground support components will be used to support the South Portal Box-Cut slopes, the same arguments apply here (see Section 7.1). (ESFDR 3.2.1.2.2.B)

4.2.7 Applicable sections of DOE Order 6430.1A are used in the design of the items discussed in this analysis. (ESFDR 3.2.1.2.4.C)

4.2.8 The ESF South Portal Box-Cut slopes are designed using analytical methods and by monitoring and observation during and after construction to reduce the potential for deleterious rock movement. The Box-Cut slopes will be supported to enhance their stability and reduce the potential for deleterious rock movement (see Sections 7.0 through 8.0). (ESFDR 3.7.3.1.G)

4.2.9 The Box-Cut perimeter along the Highwall and a minimum 20 meter along the sidewalls (measured from the Highwall) shall be presplit using standard presplitting techniques to control overbreak (see Section 7.3). The explosives and blasting agents will be obtained from a qualified supplier per 27 CFR 55. (ESFDR 3.2.1.2.3.G, 3.2.1.2.3.H)

4.2.10 QA records generated by the ESF South Portal Box-Cut ground support design will be handled in accordance with appropriate QA procedures (see Reference 5.2). (ESFDR 3.7.1.2.B, 3.7.2.1.2.C)

4.2.11 The ground support items used in the design of the South Portal Box-Cut incorporate use of noncombustible and heat resistant materials (see Section 8.0 for component details). (ESFDR 3.7.3.1.E)

4.3 ASSUMPTIONS

4.3.1 Poisson's ratio of the grout used in grouted rock bolt analyses is assumed to be 0.2 based on Reference 5.1. This is an universally accepted conservative value that requires no further confirmation.

4.4 CODES AND STANDARDS

4.4.1 Title 27 CFR Part 55, "Commerce in Explosives." April 1, 1993.

5.0 REFERENCES

5.1 Bonabian, S., "ESF Ground Support Design Analysis," BABEE0000-01717-0200-00002 REV 00.

5.2 "QAP-2-0 Work Control Evaluation ESF Design," Document identifier: BAB000000-01717-2200-00107 REV 03.

5.3 Kennedy, W. R., "ESF Layout Calculation," BABEAD000-01717-0200-00003 REV 04.

5.4 "QA Classification Analysis of Ground Support Systems (CI: BABEE0000)," Document Identifier: BABEE0000-01717-2200-00001 REV 04.

5.5 User's Manual, Volumes I, II, and III, Fast Lagrangian Analysis of Continua (FLAC) Version 3.2, Itasca Consulting Group, Inc., 1993.

5.6 Yucca Mountain Site Characterization Project, "Exploratory Studies Facility Design Requirements," YMP/CM-0019 Revision 2.

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 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. 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

At the South Portal, a Box-Cut is needed to be designed and constructed to allow for safe breakout of the TBM at the conclusion of the ESF Main Loop excavation. The South Portal Box-Cut design analysis presented here includes the evaluation of the stability of the Box-Cut slopes and recommendation of a ground support system. The Box-Cut slopes include the Highwall from which the TBM will breakout and two sidewalls to the left and right of the Highwall.

Generally, the stability of a rock slope is controlled by local geological conditions, the shape of the overall slope, local groundwater conditions and also by the excavation technique used in creating the slope. In a jointed rock mass such as welded tuff, slope stability is likely to be controlled by existing discontinuities or joints. The presence, or absence, of discontinuities has a very important influence upon the stability of rock slopes and the detection of these geological features is one of the most critical parts of a stability investigation. The stability of rock slopes varies with inclination of discontinuous surfaces such as faults, joints and bedding planes within the rock mass. The orientation of discontinulties relative to the face of the excavation has a dominant effect on the potential for instability due to falls of rock or slip along the discontinuities. When these discontinuities are vertical or horizontal, simple sliding cannot take place and the slope failure will involve fracture of intact blocks of rock as well as movement along some discontinuities. On the other hand, when the rock mass contains discontinuous surfaces dipping towards the slope face at angles between 30° and 70°, simple sliding can occur and the stability of these slopes is significantly lower than those in which only horizontal and vertical discontinuities are present. One of the most effective means of stabilizing blocks or slabs of rock which are likely to slide down inclined discontinuity surfaces is to install rockbolts or cables. The rockbolt force reduces the disturbing force acting down the discontinuity plane and increases the normal force and hence the frictional resistance between the base of the block and the plane.

For the South Portal, the geological data gathering will be carried out in two stages. The first stage involves an examination of the geological data which are based on surface mapping of the outcrops and the core recovered from the exploratory borehole. The second stage will involve mapping of the geologic features of the slopes after the Box-Cut excavation. The data gathered in the first stage will be used in the design of the slopes and the reinforcement system while the data gathered in the second stage will be used to confirm the final design and adequacy of the installed ground support system.

The analytical approach in evaluating the stability of rock slopes includes discontinuum and continuum analysis of the rock mass. The discontinuum approach includes kinematic analysis of potential blocks or wedges along the rock slope using available geological discontinuity data. Availability of detailed geologic discontinuity data is essential in performing discontinuum analysis. The detailed geologic data usually is not available until the slope is excavated and surface mapping is completed. Limited but very valuable geologic data can be obtained by drilling exploratory boreholes and core logging. In applying continuum mechanics approach, the rock mass is treated as a continuous medium. In relatively shallow excavations, such as South Portal Box-Cut slopes, it is often found that near a free surface the in situ stresses are small compared with the stiffness of the rock material. In such cases blocks of rock within the rock mass do not deform significantly on exposure and rarely break; this allows them to be treated as effectively rigid bodies in stability analysis. The continuum analysis provides valuable information such as state of stresses along the slope immediately after excavation, extent of the potential failure zone at the slope, and factor of safety.

The ESF South Portal Box-Cut design effort will include application of analytical methods coupled with inspection and monitoring of the slopes during and after construction. For analytical design, the stability of the Box-Cut is analyzed using computer modeling techniques for the in situ and seismic loading conditions. A ground support system for the Box-Cut slopes is determined based on the analyses. Similar to North Portal Box-Cut, the South Portal Box-Cut is located in the TCw unit. Similar ground conditions are expected to be encountered during the South Portal Box-Cut excavation. The experiences gained from the design and construction of the North Portal Box-Cut will be incorporated into the South Portal Box-Cut design. The design issues such as personnel safety and site characterization requirements are factored into the ground support recommendations. The ground support system designed for the Box-Cut slopes will provide flexibility to the constructor to address unanticipated geologic conditions. The ground support installed at the South Portal Highwall will be monitored as part of the ESF monitoring program. The purpose of such a program is to check on the rock conditions predicted by this analysis and to evaluate the behavior of the ground support measures.

The ESF permanent function ground support system is designed considering a 150-year maintainable life. The long term maintainability issues for ground support items are discussed in detail in Reference 5.1. Because the same type ground support components (i.e. rock bolts) will be used to support the South Portal Box-Cut slopes, the same arguments apply here.

Geological information from the preliminary surface mapping of the ESF South Portal area is provided in Reference 5.1. An exploratory borehole at the South Portal area is planned to be drilled to provide additional data for the design of the Box-Cut slopes. The data from the South Portal Design Borehole (SPDB) is not available for the design of the Box-Cut slopes but will be used to confirm the design presented in this analysis prior to the construction of the Box-Cut (TBV-224). In this analysis, the rock mass mechanical properties obtained from the ESF Drilling activities for the Tiva Canyon (TCw) member are used to provide the geotechnical basis for the design of the ground support system for the South Portal Box-Cut slopes. Category 1 rock mass properties from Section 4.1, which represent the worst expected ground conditions in TCw unit, are used in the analyses for conservatism.

7.2 GEOLOGY

The following general site description is presented for reference purposes and is obtained by inspection of the South Portal Box-Cut area by the Originator.

The ESF South Portal site is on the east side of the north-south trending Boundary Ridge. The portal is located above the valley floor near the nose of a ridge extending eastward from Boundary Ridge toward the north end of Bow Ridge. The portal site is in the upper cliff and upper lithophysal zones of the Tiva Canyon Member (TCw) of the Miocene age Paintbrush Tuff. The rock at the portal is upper lithophysal and upper cliff zones of the Tiva Canyon Member. Excavation of the rock generally will require drill and blast methods, however, the upper few meters of the rock may be rippable because of weathering. The relative brittleness of the rock combined with controlled drill and blasting techniques should result in stable slopes at the Box-Cut.

The ESF geology is developed and updated as more data become available from the surface-based testing and as a result of information obtained from underground excavations.

7.3 CONSTRUCTION METHOD

A combination of mechanical excavation (ripping) and controlled drill and blast techniques are recommended to excavate the South Portal Box-Cut. Mechanical excavation was used to construct the North Portal Box-Cut. This method was successful except that it provided irregularities along the cut faces due to the fractured nature of the rock. Similar rock conditions are expected at the South Portal area, therefore, mechanical excavation could be used in construction. However, in order to control the irregularities and damage to the rock at the surfaces of the slopes, it is recommended that the Box-Cut perimeter along the Highwall and for a minimum distance of 20 meters out from the Highwall along the sidewalls shall be presplit using standard presplitting techniques. The 20 meters distance along the sidewalls is conservatively selected to enhance the stability of the sidewalls in turn adding to the stability of the Highwall. The presplitting method minimizes blast damage to the perimeter surface by reducing the charge weight per meter of blast hole, decoupling the charge from the blast hole wall, and greatly reducing blast vibration from adjacent blast holes, eliminating further blast damage and creating a stable excavation surface. The presplitting of the rock slopes is performed by drilling blast holes on the slope plane, charging the blast holes with a decoupled charge, and initiating the holes simultaneously. This creates a tensile stress between the blast holes which exceeds the tensile strength of the rock. Thus, a crack is created between the blast holes which creates the rock slope surface. The presplitting drill and blast techniques are not only used to reduce blast damage to rock and achieve stable rock slopes, they are also used to allow for steeper rock slopes to be designed. The excavation of steeper rock slopes reduce cut volumes and improve project economy.

The remainder of the Box-Cut could be ripped or excavated by drill and blast methods. If blasting is used elsewhere along the perimeter in the Box-Cut, techniques shall be used to limit blast damage along the Box-Cut sidewalls.

The standard blasting techniques will be performed in construction of South Portal Box-Cut as indicated above. The constructor is required to submit a blast plan to the A/E prior to blasting at the South Portal Box-Cut to obtain its approval. The manufacturer selected to provide explosives shall be licensed under 27 CFR Part 55 Chapter 1, Subpart D and shall have a recognized technical product support program.

7.4 ANALYTICAL DESIGN

A question which frequently arises in discussions on slope stability is how high and how steep can a rock slope be cut. Based on available site data, engineering experiences (especially experiences gained during the design of the North Portal Box-Cut), and results of the computer analyses a configuration for the South Portal Box-Cut slopes is determined. As it was proven effective at the North Portal, at least one tunnel diameter of rock above the portal is required for stable opening. Therefore, a Highwall height of at least two tunnel diameters (15.24 m) is recommended. A Highwall height of greater than two tunnel diameters is achieved based on the portal coordinates presented in Reference 5.3. The sidewalls will be benched at a nominal 9.14 m (30 ft) height to increase stability and safety. The bench depth will be nominal 3.048 m (10 ft). The slope of the Highwall is chosen and analyzed at 1/4:1. The slope is similar to the North Portal Highwall slope which was proven stable. The steep cut provides less cut volume which is economical.

In the study of stability of slopes, application of numerical methods has proven useful in conjunction with conventional methods. The design presented here includes continuum analyses of the Highwall. The sidewalls are not analyzed because they are bounded by the Highwall analyses. The sidewalls are benched and have less height, thus are inherently more stable than the Highwall. The discontinuum analyses will require more detailed geologic information which will be available from the SPDB. Upon availability of geologic information from site mapping and SPDB and at the time of removal of TBV-224, the design presented here will be evaluated for impacts on the ground support system. Based on the preliminary geologic data on TCw unit including site observation by the Originator and shallow depth of excavation, the continuum approach should provide adequate analytical bases for the design. Nevertheless, the design will be confirmed once site specific geologic data is available from the borehole and core testing results. The results obtained from continuum analyses provide estimates on the overall state of the stress and magnitude of displacements along the slope. The Mohr-Coulomb plasticity model is used to assess the likelihood of stress induced failure along the Highwall. The plasticity model will indicate the approximate rock mass region that may need stabilization.

In this analysis, computer modeling is used to simulate excavation of the Box-Cut in a gravity-stressed rock medium. The stability of the Highwall then is analyzed under in situ loading conditions. The recommended ground support system is incorporated into the model and analyzed. Then the Highwall is subjected to seismic loading conditions and its stability and ground support performance is evaluated.

7.5 DESIGN PARAMETERS USED IN COMPUTER MODELING

The design of effective ground support systems for rock slopes requires site-specific data. The mechanical rock properties and characteristic joint parameters are required to perform reliable computer modeling. Data from ESF drill core testing is used to perform the analyses. These data represent information obtained for the TCw unit from existing boreholes drilled along the ESF Main Loop. Site specific data is being collected at the South Portal site and will be used to confirm the data used in this analysis (TBV-224). A design borehole is planned to be drilled at the South Portal location to obtain site specific geologic data. Data from South Portal Design Borehole (SPDB) will be complemented with geologic surface mapping data to confirm the design of the slopes. A hold on construction will be placed on the construction drawing(s) and will be removed upon receipt and review of the preliminary borehole data by the A/E.

The rock property parameters used in the analyses are representative of the TCw member of the Paintbrush Tuff in which the South Portal Box-Cut is to be located. The mechanical properties of the rock mass and their respective sources are presented in Section 4.1 from which Category 1 properties are used in the analyses for conservatism. The rock mass parameters used in computer modeling will be confirmed by testing the SPDB core samples (TBV-224).

7.6 DESIGN LOADS

In designing the ESF South Portal Box-Cut slopes, stresses resulting from three sources must be considered: in situ, thermal, and seismic. In situ stresses are present before Box-Cut excavation and will be altered in the vicinity of the Box-Cut slopes during construction. Thermal stresses will occur after waste emplacement, and the timing and magnitude of the temperature induced loads at any particular location in ESF is primarily dependent upon its position relative to the potential repository. Seismic induced stress magnitudes and duration are a function of the intensity of the earthquake, the distance from the event to the ESF, and the direction and size of the seismic wave relative to the slopes.

7.6.1 IN SITU STRESS

The virgin stress field existing before excavation is the in situ or geostatic state of stress. The in situ stress state has not been measured directly at the South Portal area. In situ stress values to be used for the design will be determined in accordance with the procedure discussed in this section.

For the initial state of stress, the vertical stress σ_v at a point is given by

$$\sigma_v = - \rho g h$$

where h is the depth of the point relative to surface, ρ is the average density of the rock mass, and g is the gravitational acceleration. Assuming that lateral displacements are prevented, linear elasticity theory predicts that for the horizontal stress σ_h is

$$\sigma_h = [\upsilon / (1 - \upsilon)]\, \sigma_v$$

in which υ is Poisson's ratio. This formula is derived from the assumption that gravity is suddenly applied to an elastic mass of material in which lateral movement is prevented. This condition hardly ever applies in practice due to repeated tectonic movements, overburden removal, material failure, and locked-in stresses due to localization and faulting. Several studies on the project have estimated the relationship between horizontal and vertical stresses. A detailed discussion of the horizontal to vertical stress ratios in ESF is presented in Reference 5.1. Based on Reference 5.1, for the analyses presented here three loading cases corresponding to smallest ($\sigma_h/\sigma_v = 0.25$), average ($\sigma_h/\sigma_v = 0.5$), and largest ($\sigma_h/\sigma_v = 1.0$) horizontal stresses, which give the most extreme stress conditions around the Box-Cut, are considered. Using the above equation (with υ values from Section 4.1) the horizontal to vertical stress ratios of 0.25 is obtained for TCw unit at ESF. In the remainder of the report, case 1 represents 0.25, case 2 represents 0.5, and case 3 represents 1.0 for horizontal to vertical stress ratios.

In situ stress measurements will be made as part of the in situ testing and monitoring program. The information will be used to confirm the range of data used in the design as a part of design confirmation effort. The analysis concerning in situ stresses is discussed in detail later in the analysis.

7.6.2 THERMAL LOADS

Thermally induced stresses will be generated by the thermal expansion of the rock mass due to the thermal energy released from the waste. Thermal stresses at any location will depend on the proximity and timing of waste emplacement, the waste heat generation, the age of the waste, packaging and emplacement configuration, and the thermomechanical properties of the rock mass.

Thermal loads on the ESF openings are primarily sensitive to the Areal Power Density (APD) and thermomechanical characteristics of the rock. The APD is a parameter which defines the average rate at which heat is generated by the nuclear waste per unit plan area of the repository. The rate of heat generation by the waste decreases continuously with time in a manner characteristic of the composition of the waste. The choice of APD for a potential repository will dictate, to a great extent, the layout and design of the repository. Details of the potential repository design are not known and the APD value has not been finalized. Moreover, repository thermal stresses will not occur during ESF construction and operation. Therefore, it can be concluded that there will be no thermal stresses applied to the South Portal during the life of the ESF. Thermal stresses will only be present during the potential repository operations. The Box-Cut ground support system is designed so it would not affect the long term thermal performance of the potential repository. If the site is found to be suitable and after the APD values have been set for the potential repository, the ground support system can be supplemented to accommodate for additional loads if needed.

7.6.3 SEISMIC LOADS

Ground motion associated with earthquakes are considered in the design of the ESF Main Loop. The seismic requirements including design parameters are presented in the ESFDR (Reference 5.6) and are used in South Portal Box-Cut Slope and ground support design. The supported Highwall is subjected to seismic loadings to evaluate their performance during an event. The methodology and results of the seismic analysis are discussed in detail later in the analysis.

7.7 IN SITU DESIGN LOAD ANALYSIS

FLAC computer software is used to analyze the stability of the Highwall at the South Portal. First, a mesh is generated and the in situ stress conditions are established using appropriate initial and boundary conditions. Then the Box-Cut is excavated and the state of the stress and potential yield zones at the Highwall are determined. The analyses are performed incorporating Category 1 rock mass properties for TCw unit. First the analyses are performed for unsupported Highwall, then the recommended ground support system is installed and the loads on the components are estimated.

7.7.1 FLAC COMPUTER SOFTWARE

FLAC is a two dimensional explicit finite difference code which simulates the behavior of structures built of soil, rock or other materials which may undergo plastic flow when their yield limit is reached. Materials are represented by elements, or zones, which form a grid that can be adjusted to fit the shape of the object to be modeled. Each element behaves according to a prescribed linear or nonlinear stress/strain law in response to the applied forces or boundary restraints. If the stresses are high enough to cause the material to yield and flow, the grid can actually deform and move with the material represented.

FLAC is based upon a "Lagrangian" scheme which is well suited for large deflections and has been used primarily for analysis and design in mine engineering and underground construction. The explicit time-marching solution of the full equations of motion, including inertial terms, permits the analysis of progressive failure and collapse.

Several basic constitutive laws are provided in FLAC. The Mohr-Coulomb Plasticity model is used in the analyses presented in this report. In the following section the model used in the analysis is discussed and the results of the analyses are presented. A detailed discussion on the general features and fields of FLAC computer software applications is presented in the User's Manual (Reference 5.5).

7.7.2 PLASTICITY MODELS

Generally, several forms of plasticity are used to represent rock behavior. In each case, a yield criterion or function is used to describe the stress conditions under which failure of the material occurs. Mohr-Coulomb is one of the most common yield criteria for rock in which the material is treated as frictional and cohesive. At present the Mohr-Coulomb model is extensively used to describe rock mass behavior when material isotropy can be assumed.

The Mohr-Coulomb plasticity model represents a material which is yielding in shear. Figure 27 (Reference 5.5) illustrates the Mohr-Coulomb failure criterion for the rock matrix for an arbitrary state of stress. This is the conventional model for plasticity in soil and rock mechanics. In FLAC, the Mohr-Coulomb model checks for tensile stresses which exceed either the plastic apex limit or the tensile strength. The Mohr-Coulomb plasticity model will indicate the approximate rock mass region that may need stabilization. Figures 1, 2 and 3 show the mesh and mesh refinement at the Highwall used in the FLAC analyses.

7.7.3 MOHR-COULOMB ANALYSES RESULTS OF THE HIGHWALL

The results of the Mohr-Coulomb Plasticity analyses of the unsupported Highwall are presented in Figures 4 through 8. Figures 1, 2, and 3 show the grid used in the computer analyses. Displacement measurements at the Highwall face (grid 63,58, see Figure 3) for the unsupported Highwall under static loading conditions is recorded and presented in Figure 4. It can be seen that the displacements are in the order of less than 1 mm. The model remains elastic and no plasticity is indicated at the Highwall due to the excavation. The principal stresses and shear stress contours immediately after excavation along the Highwall for Cases 1, 2, and 3 are presented in Figures 5 and 6 respectively. Mohr-Coulomb Failure envelope plot for shear stress-normal stress space is plotted and shown in Figure 7. The strength/stress ratio contours are plotted and show safety factors of higher than 10 for the Highwall (Figure 8). Small stress region is detected in the corner where the Highwall meets the floor of the Box-Cut due to the sharpness of the corner in the model. Based on the results of the unsupported Highwall under in situ stress loading conditions no rock mass failure is expected at the South Portal Box-Cut slopes.

7.8 GROUND SUPPORT RECOMMENDATION AND RESULTS OF THE ANALYSES

As discussed in Section 7.1, the stability of the slopes in jointed rock mass such as welded tuff is controlled by existing discontinuities and joint. One of the most effective ways for stabilizing surficial blocks and slabs due to jointing is installation of rock bolts. The North Portal Box-Cuts were reinforced by installation of rock bolts and chain link fence initially. Around the portal opening a layer of fibercrete was applied after the portal excavation. For the South Portal Box-Cut slopes, systematic bolting and Welded Wire Fabric (WWF) is recommended to enhance stability and eliminate surficial failure due to weathering and jointing. Friction type rock bolts of 3 m in length (Split Sets or Super Swellex) on a nominal 1.83 m (6 ft) square pattern is recommended for the sidewall slopes at the Box-Cut. For the Highwall, 3 meter long Super Swellex rock bolts on a 1.83 m square pattern is recommended (Figure 26). In order to enhance stability during the breakout of the TBM from the Highwall, two rows of fully grouted rock bolts of 6 m in length is recommended as shown in Figure 26. Localized geologic conditions encountered during construction will be addressed by the constructor by installation of additional rock bolts to supplement the design. A layer of fibercrete or shotcrete 50 to 75 mm in thickness may be applied to the Highwall face to enhance stability if deemed required by the constructor during the excavation or prior to the TBM breakout. Installation of rock bolts and WWF is not recommended at the face where the TBM will breakout. Fibercrete or shotcrete may be applied to that area if needed for personnel safety at the discretion of the constructor.

In order to analyze the ground support installed at the Highwall, a series of rock bolts were incorporated into the model. Figure 9 shows the ground support installed in the model which represents a section through the center of the Highwall. No rock bolts were installed in the region where it will be excavated by the TBM. The supported Highwall was subjected to in situ loading and the results are presented in Figures 10 and 11. As it was expected, from the results of the unsupported analyses, the loads on the rock bolts were well below their capacity (Figures 10 and 11).

7.9 SEISMIC ANALYSIS (TBV-193-ESF)

NOTE: All parameters used in this section will be re-evaluated at the time of the removal of TBV-193-ESF.

The seismic design philosophy for the ESF is addressed in detail in Reference 5.1. The seismic input parameters are provided in Reference 5.6. For the seismic design of the South Portal Highwall, the supported slope is subjected to quasi-static seismic loads after the in situ loading have been applied to the model. The state of stresses at the Highwall is estimated and the displacement magnitudes are measured. 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 $\pm$0.37g were superimposed onto the gravitational acceleration. The details of the applied seismic loads for both +0.37g and -0.37g are presented in input files in Attachment I.

Displacement measurements at the Highwall face (grid 63,58) for the supported Highwall under static and seismic loading conditions (+0.37g) is recorded and presented in Figure 12. It can be seen that the displacements are increased for all three Cases. The maximum displacement is shown to be for Case 3 which is about 3 mm. The model remains elastic and no plasticity is indicated at the Highwall due to the seismic loading. The principal stresses and shear stress contours along the Highwall for Cases 1, 2, and 3 are presented in Figures 13 and 14 respectively. Mohr-Coulomb Failure envelope plot for shear stress-normal stress space is plotted and shown in Figure 15 that indicates no failure due to seismic loading. The strength/stress ratio contours are plotted and show safety factors of higher than 10 for the Highwall (Figure 16). For the -0.37g seismic loading condition the results are presented in Figures 17 through 21. The results are similar to the +0.37g loading case and again no failure is detected at the Highwall.

The results of the ground support analyses for the +0.37g loading case are presented in Figures 22 and 23. It can be seen that the loads on the rock bolts are increased due to seismic loading (in comparison to in situ loading condition) but are still well below their capacity. The results for the -0.37g loading case are presented in Figures 24 and 25.

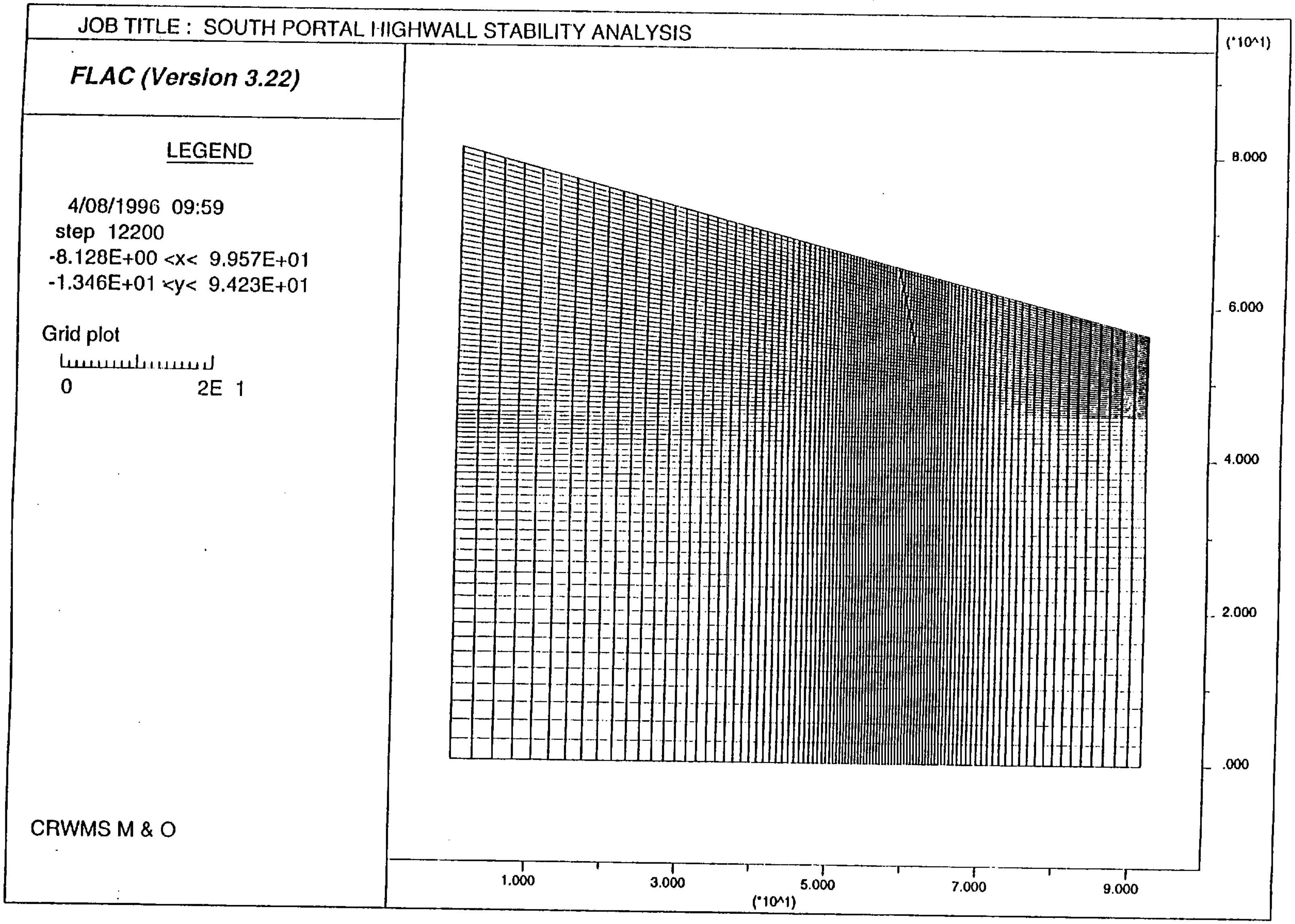


Fig. 1 Finite Difference Mesh Used for ESF South Portal Highwall Analyses Prior to Box-Cut Excavation. Grid Dimensions Are in Meters.

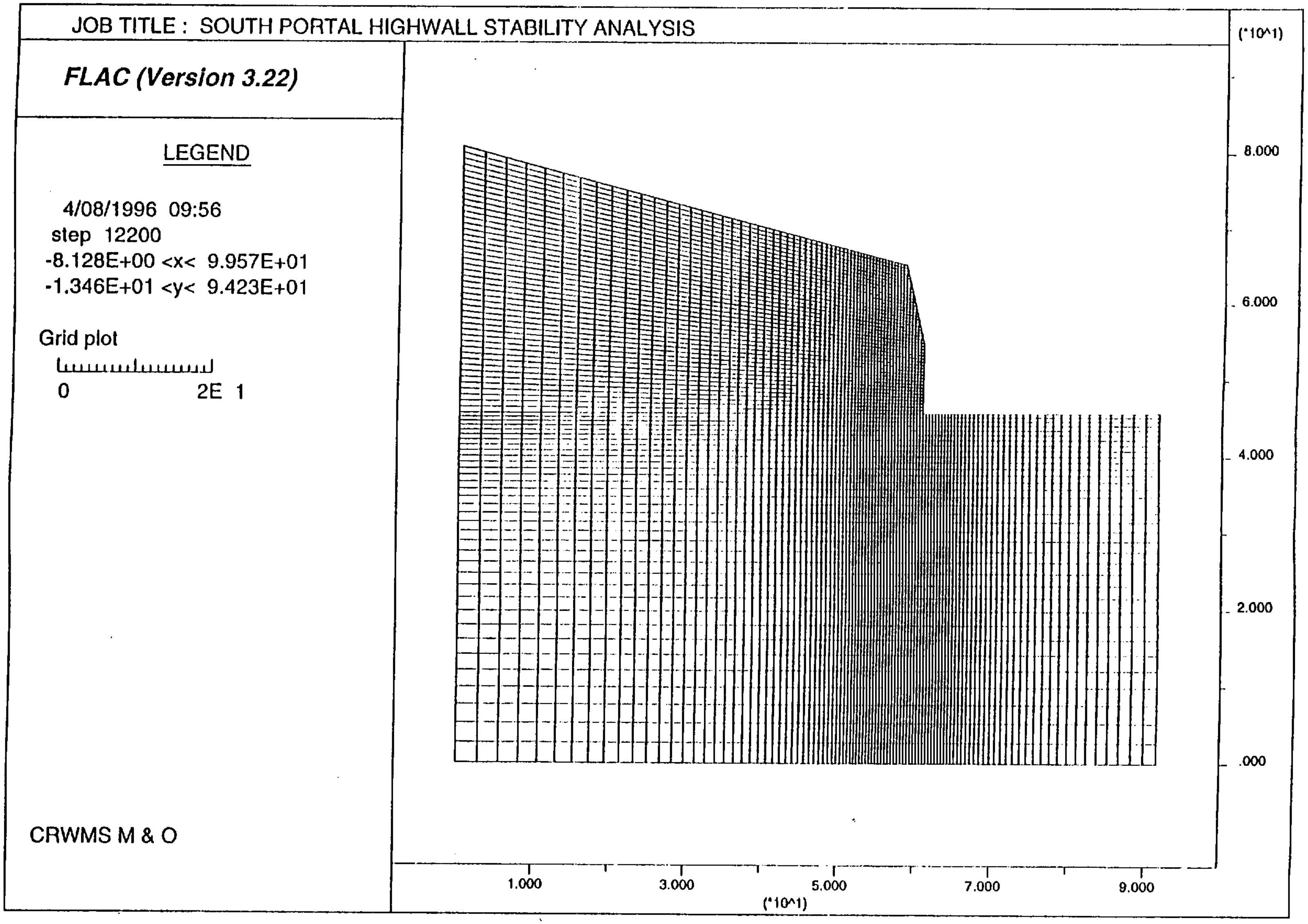


Fig. 2 Finite Difference Mesh Used for ESF South Portal Highwall Analyses After Box-Cut Excavation. Grid Dimensions Are in Meters.

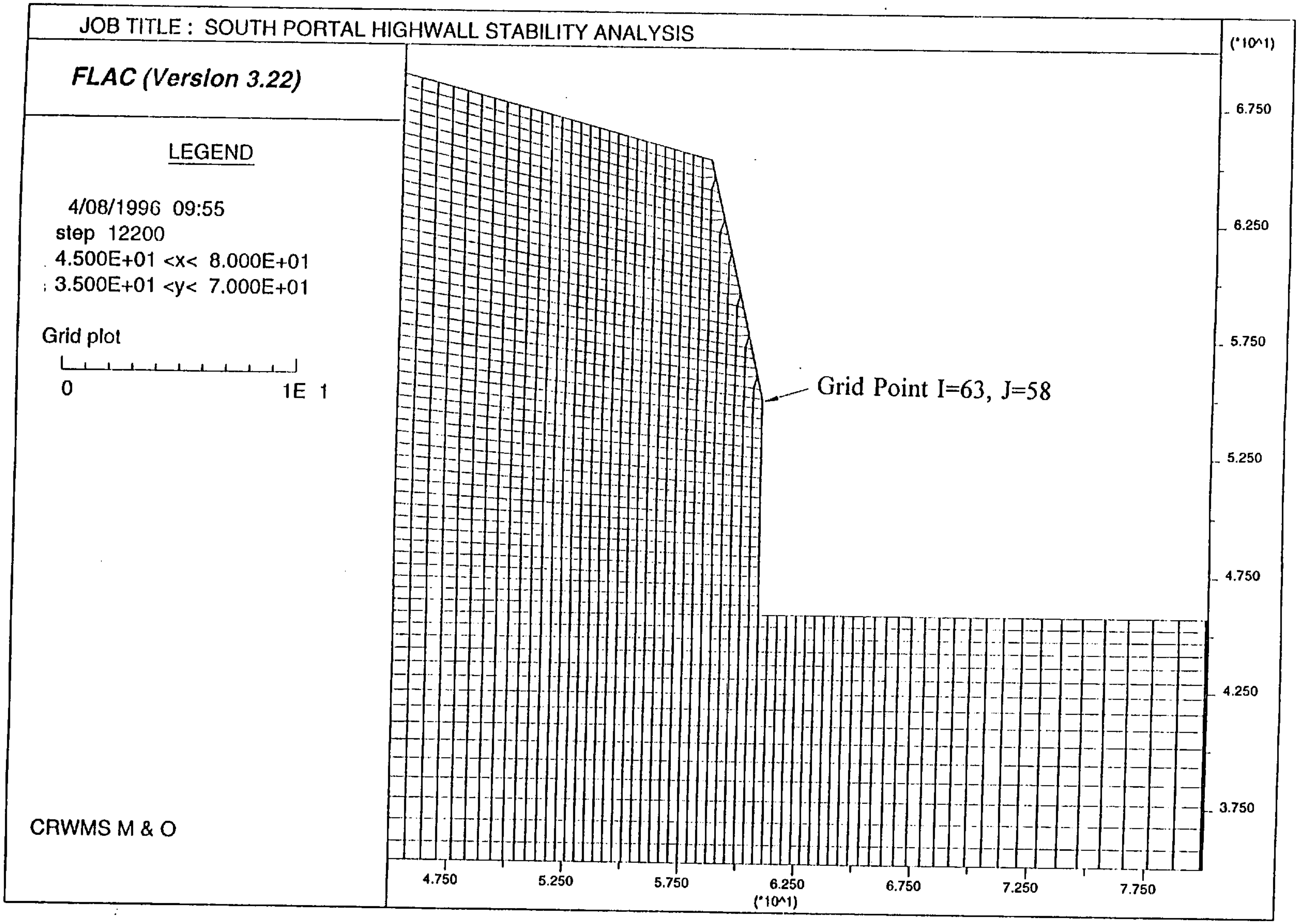
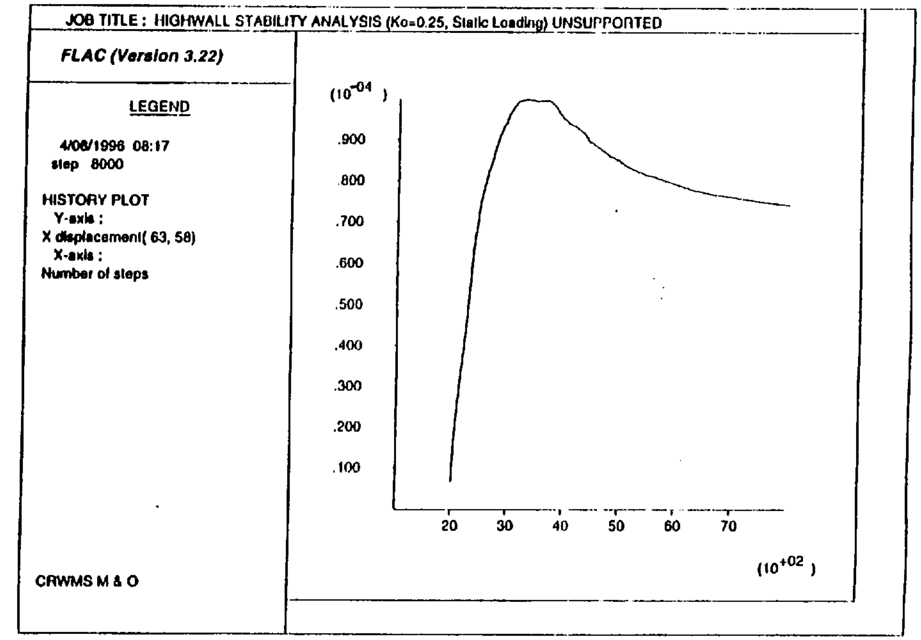


Fig. 3 Close-up of the Grid at the ESF South Portal Highwall After Box-Cut Excavation. Grid Dimensions Are in Meters.



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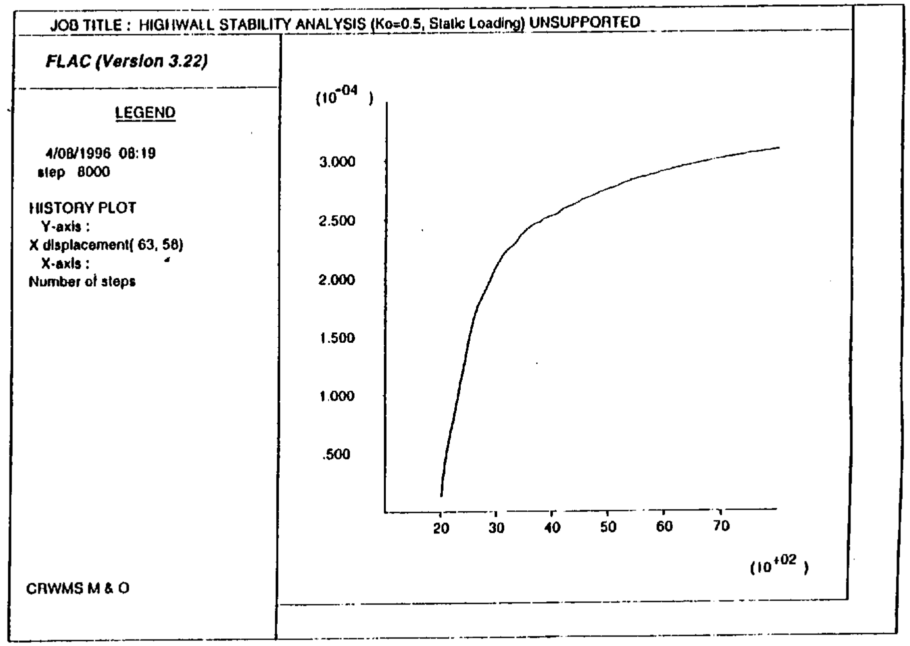

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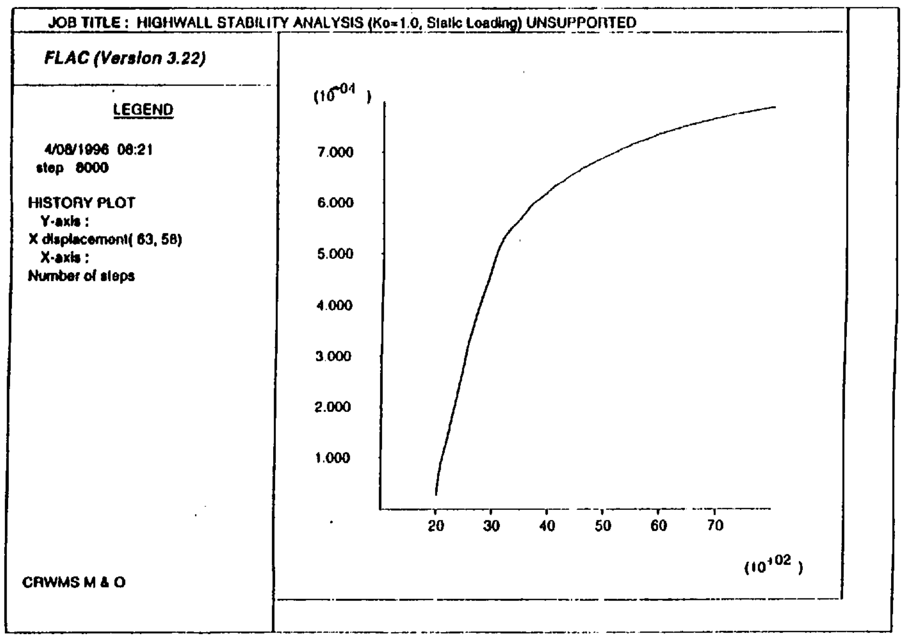


c)

Fig. 4 History Plot of X-Displacements at the South Portal Highwall, Static Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3, (Grid Location: I=63, J=58). Displacements Are in Meters Shown on Y-Axis. X-Axis Represents Number of Iterations.

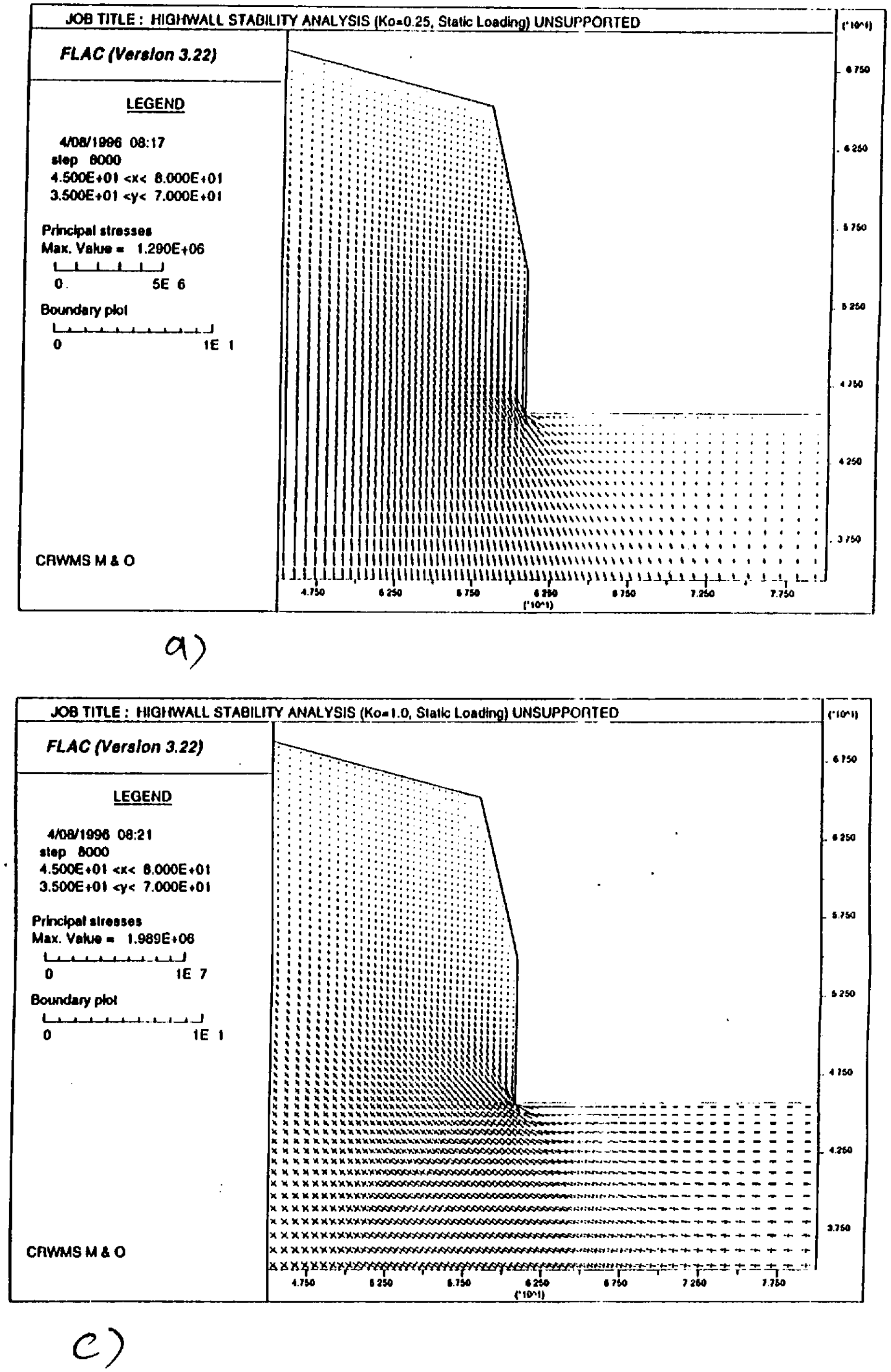
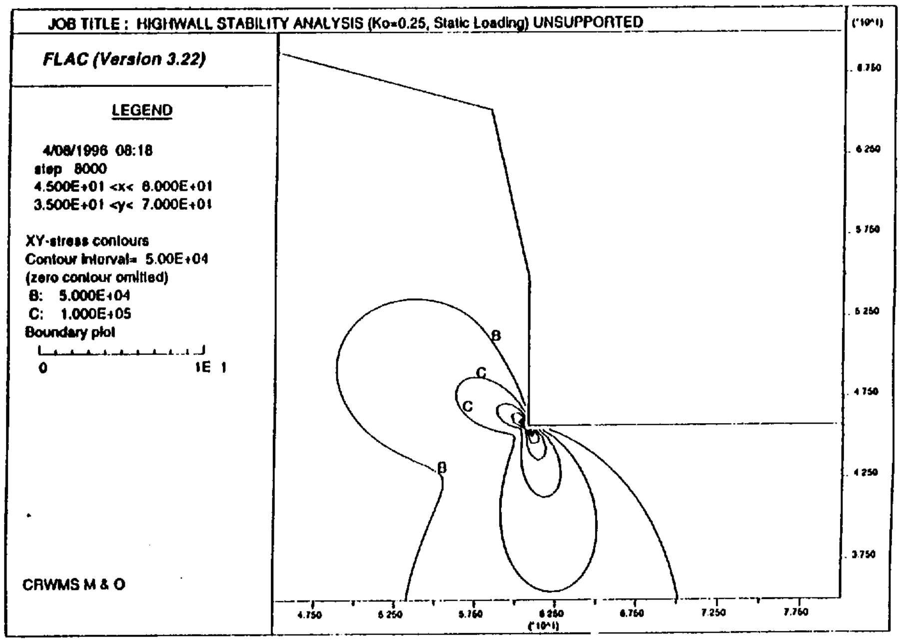
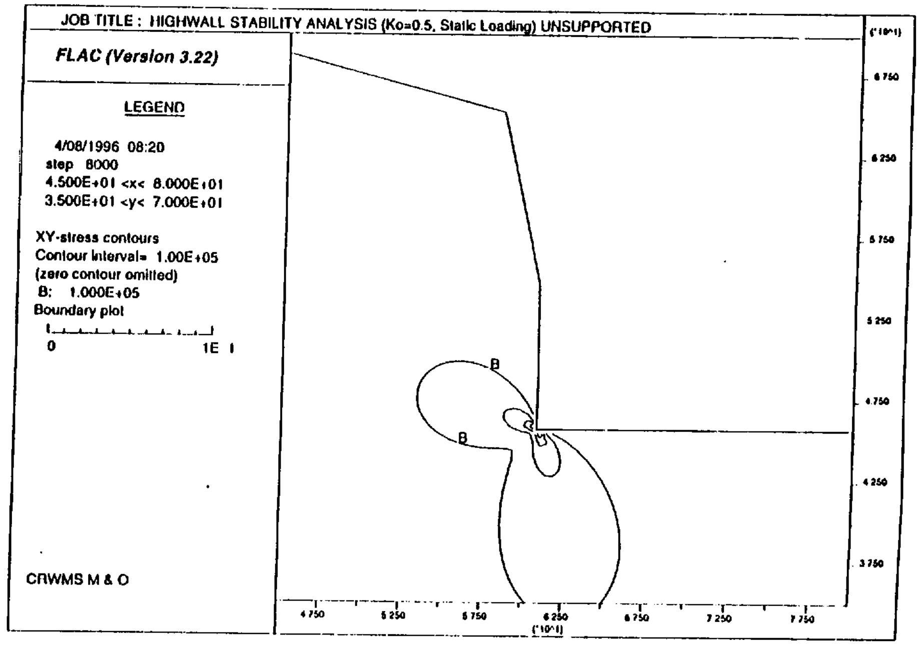


Fig. 5 Principal Stress Vectors Immediately After Box-Cut Excavation at the Highwall, Mohr-Coulomb Plasticity Model, Static Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. Stresses Are in Pa. Grid Dimensions Are in Meters.



a)



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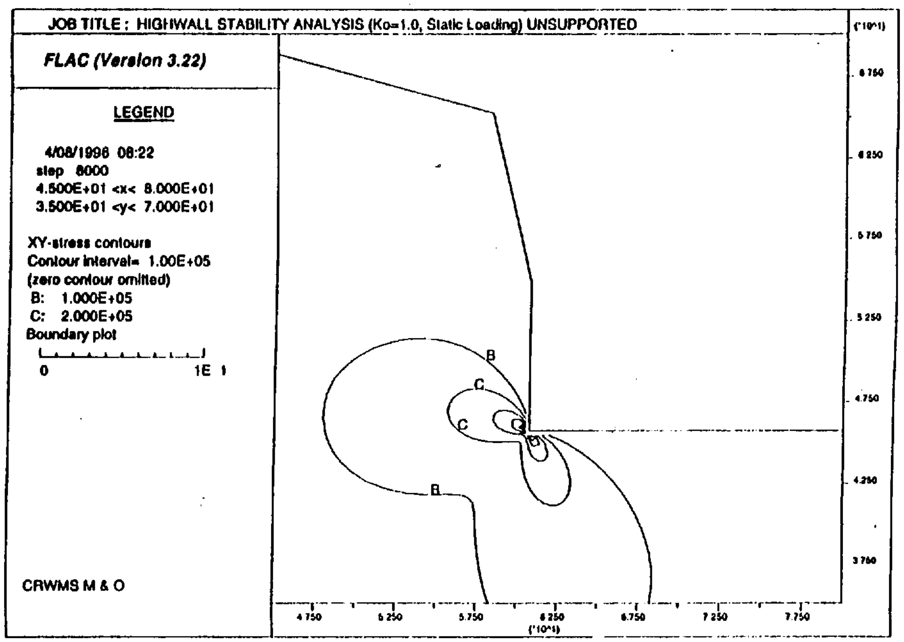
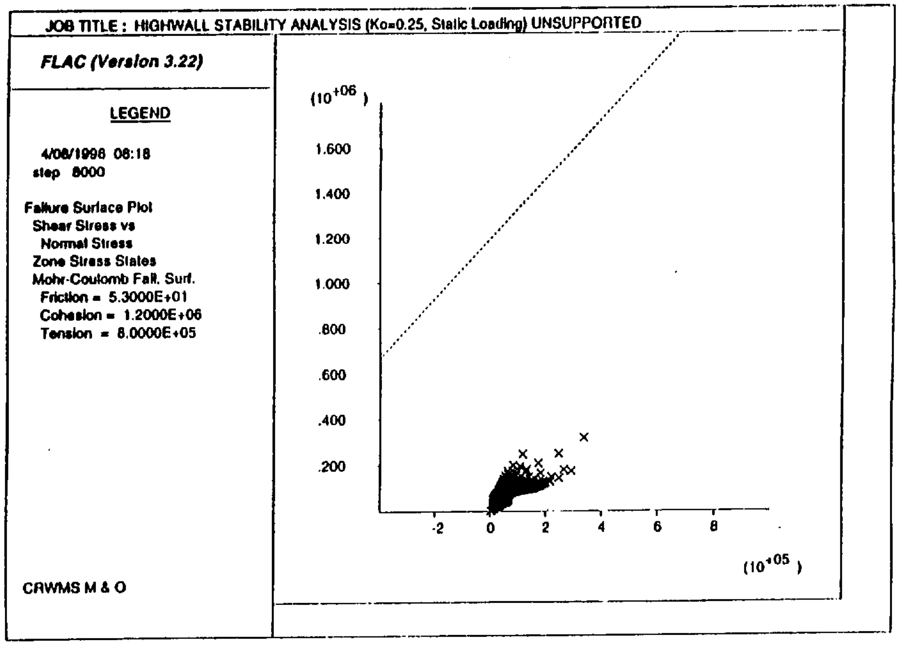


c)

Fig. 6 Shear Stress Contours Immediately After Box-Cut Excavation, Mohr-Coulomb Plasticity Model, Static Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. Stresses Are in Pa. Grid Dimensions Are in Meters.



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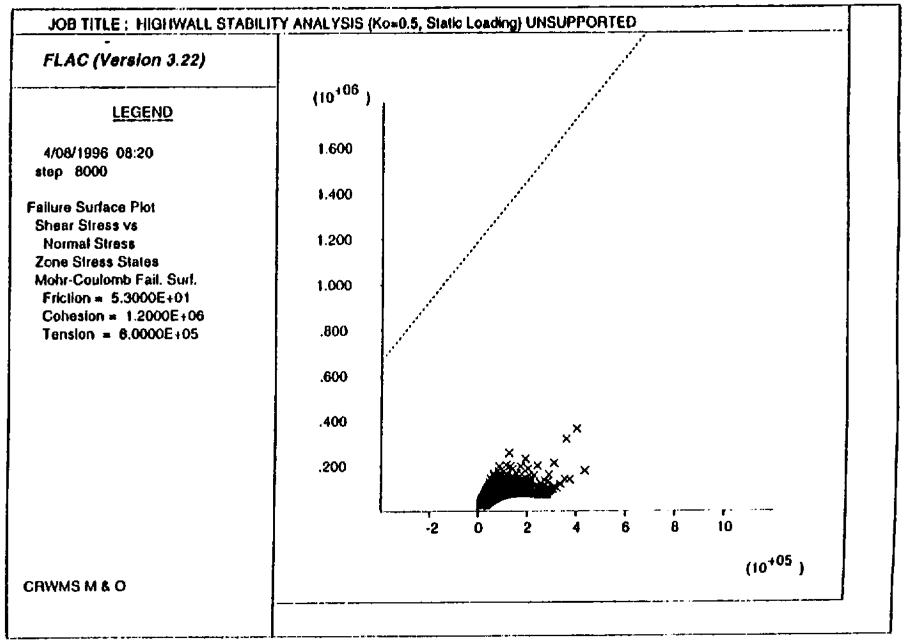

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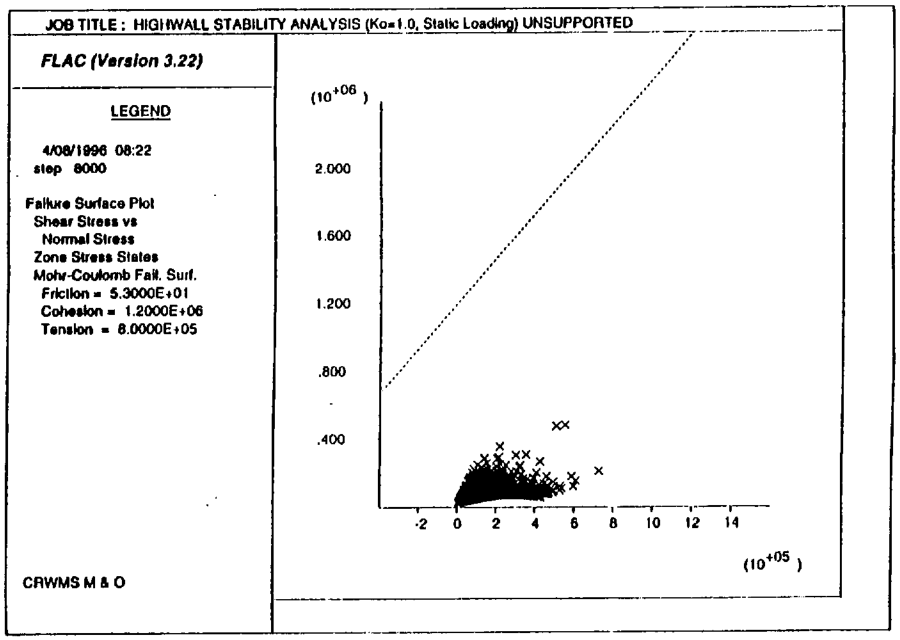
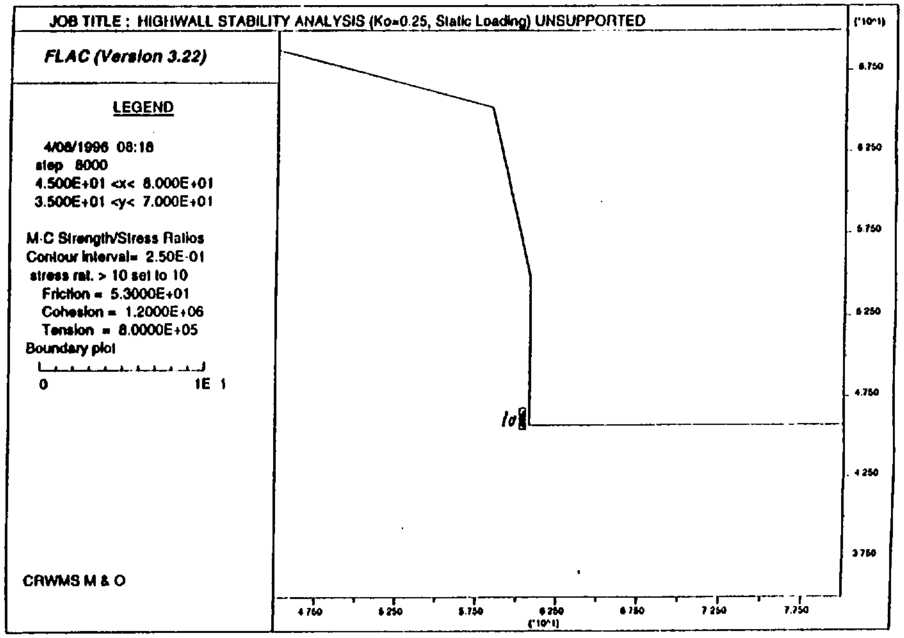


c)

Fig. 7 Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space at the South Portal Highwall, Static Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. The Envelope Is Defined by Cohesion, Friction Angle, and Tension Limit of 1.2 MPa, 53°, and 0.8 MPa Respectively.



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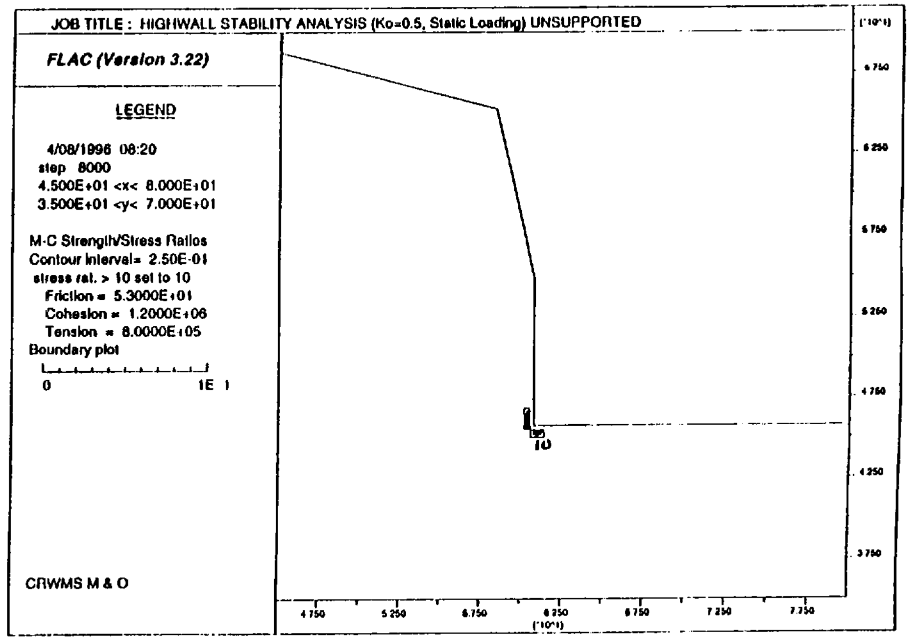

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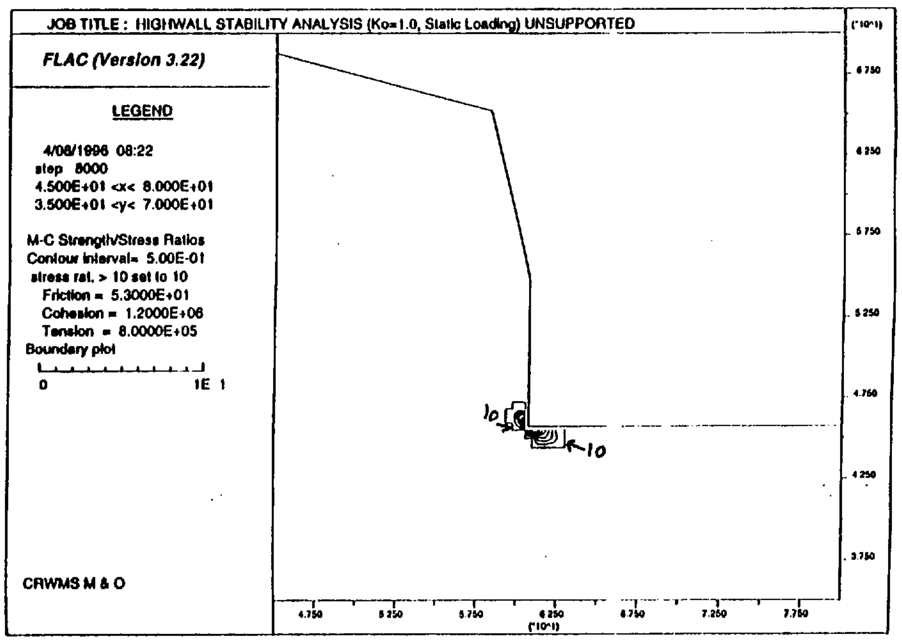


c)

Fig. 8 Strength/Stress Ratio Contours for the Mohr-Coulomb Plasticity Model at the South Portal Highwall, Static Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. The Envelope Is Defined by Cohesion, Friction Angle, and Tension Limit of 1.2 MPa, 53°, and 0.8 MPa Respectively.

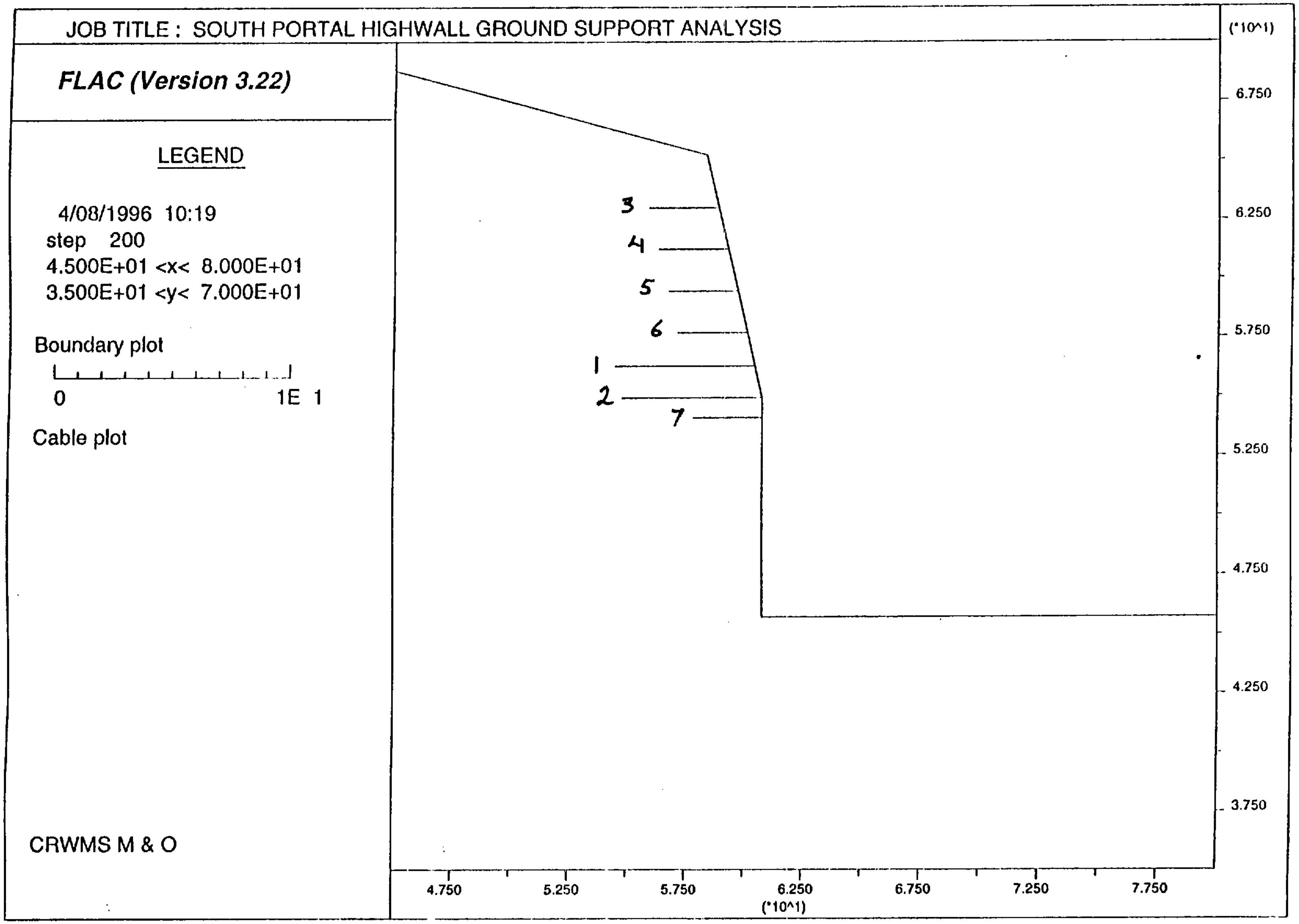
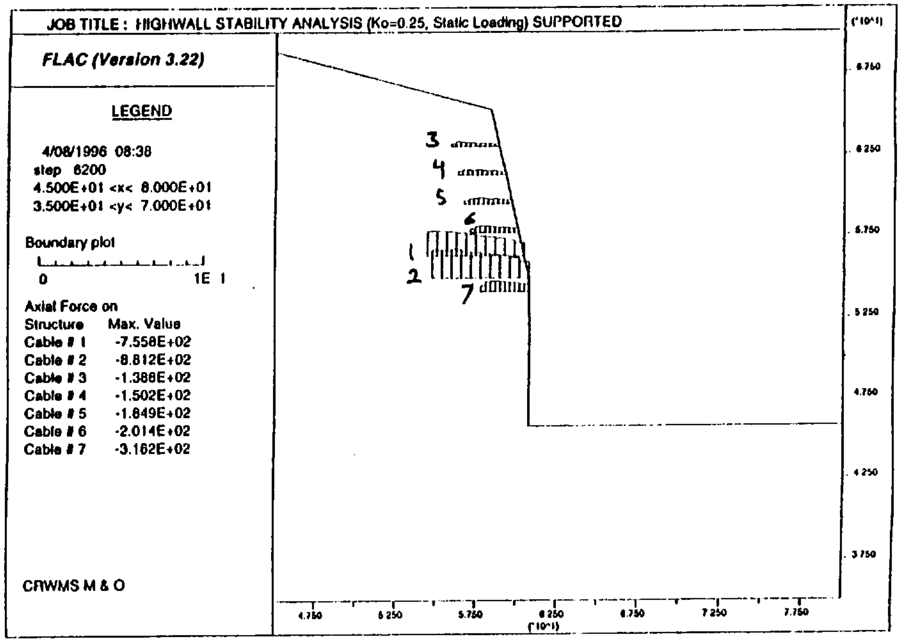
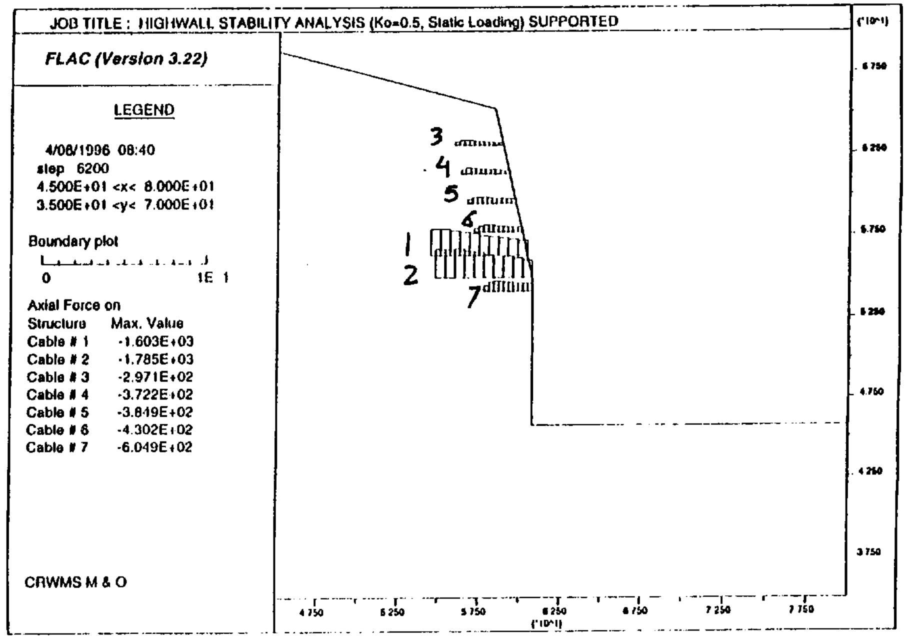


Fig. 9 Rock Bolts Installed at the Highwall Used in the Analyses of the Supported Highwall Which Represents a Typical Pattern Above the Future Portal Opening. Bolts 1 and 2 Represent 6 m Grouted Rock Bolts While Bolts 3 - 7 Represent 3 m Swellex Rock Bolts. Dimensions are in Meters.



a)



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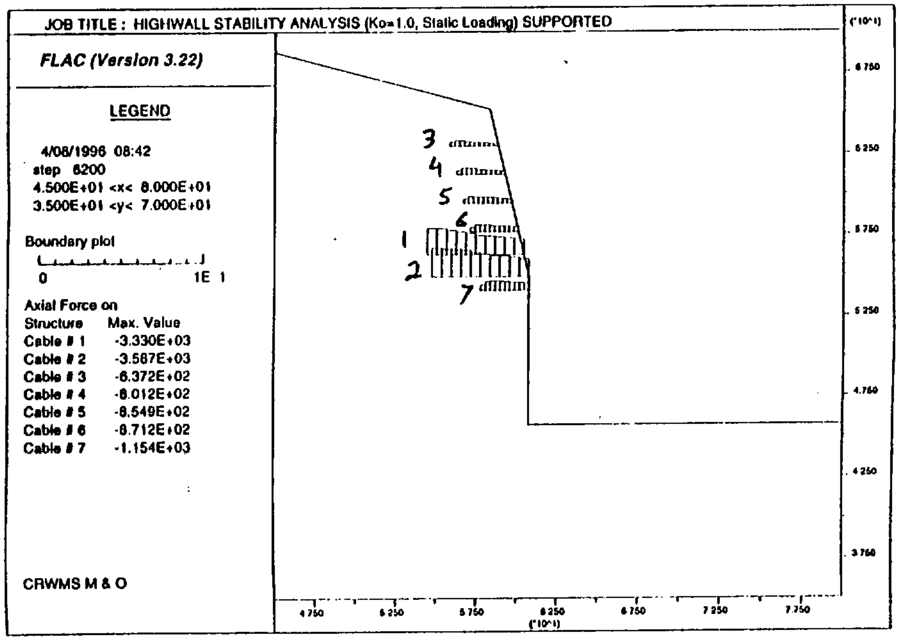
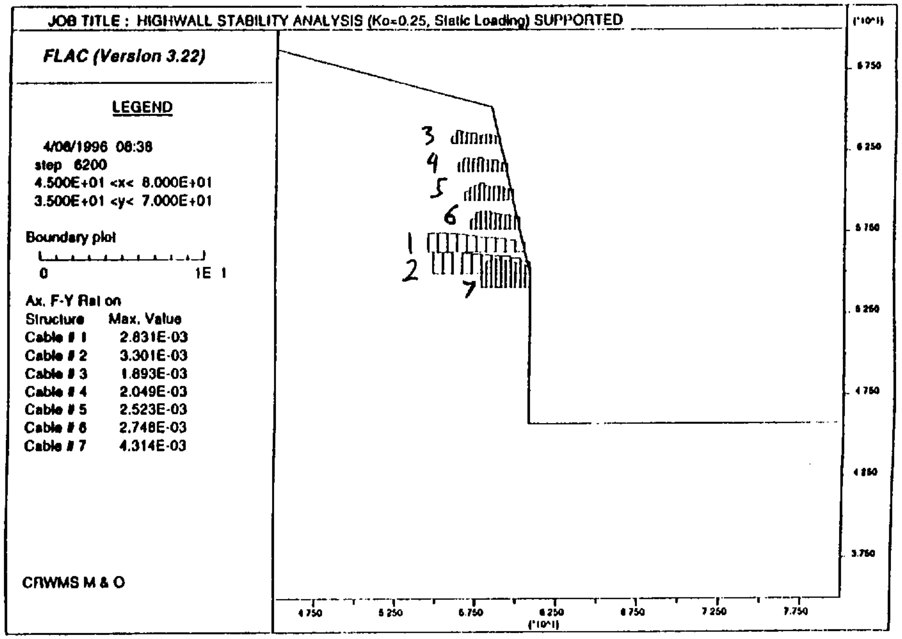


c)

Fig. 10 Axial Loads in Rock Bolts Installed at the Highwall, Static Loading, (a) Case 1, (b) Case 2, (c) Case 3. Grid Dimensions Are in Meters. Forces Are in Newton. Rock Bolts 1 and 2 Represent 6 m Fully Grouted Bolts While Rock Bolts 3 - 7 Depict 3 m Swellex Bolts.



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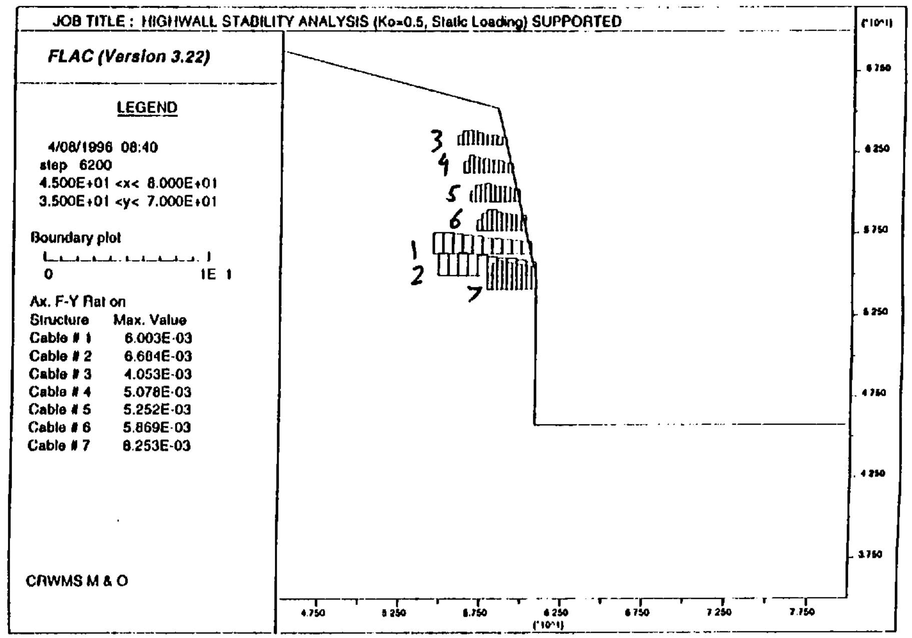

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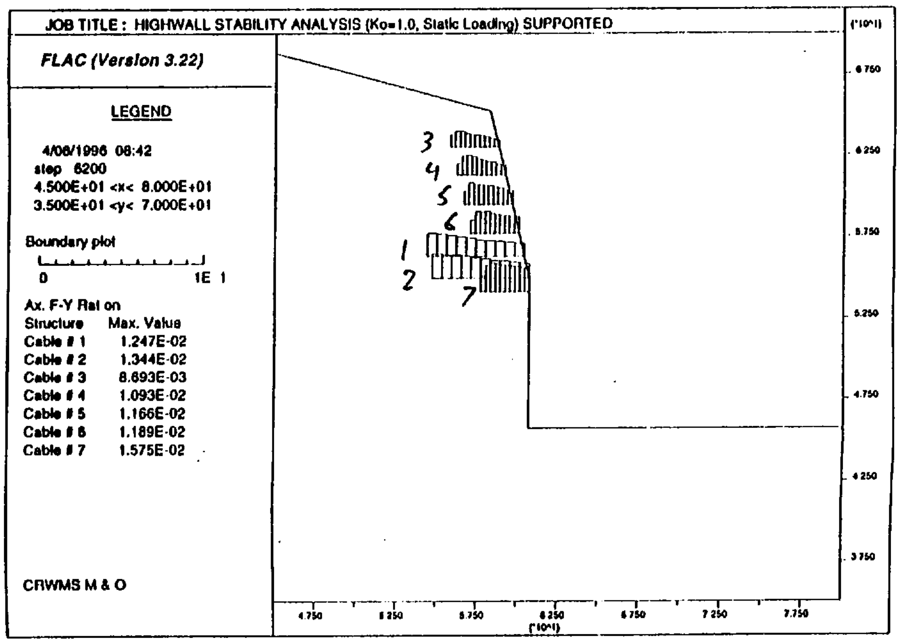
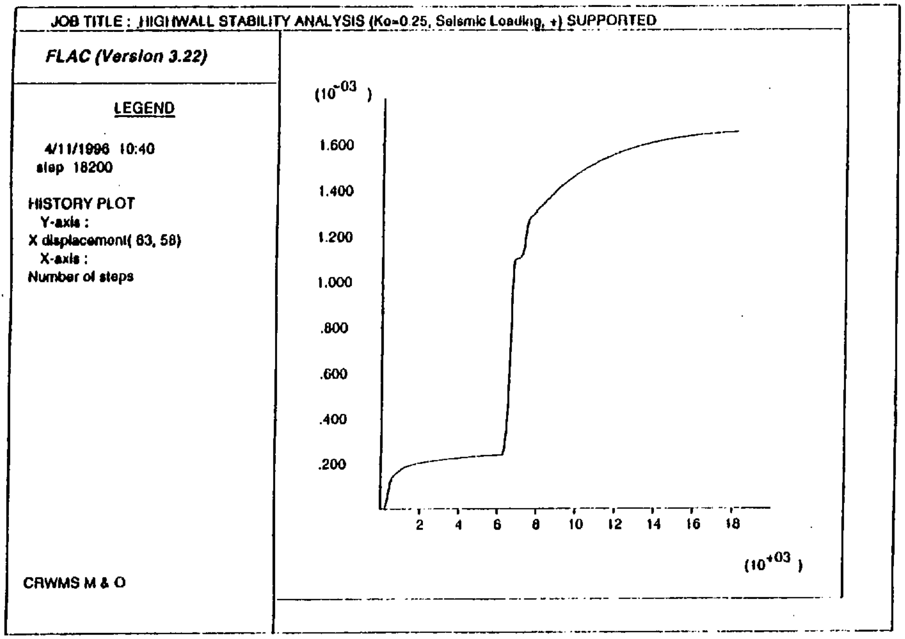
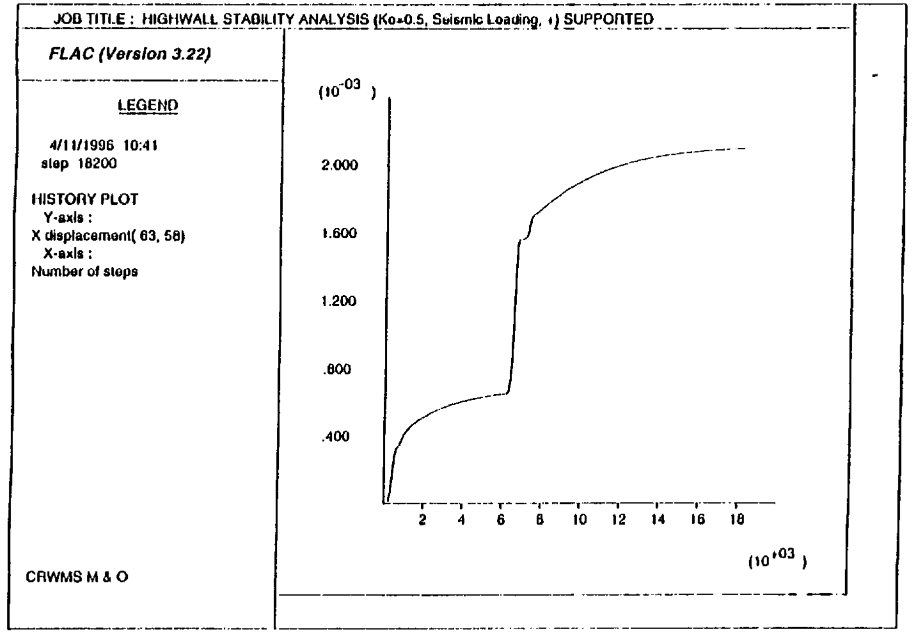


c)

Fig. 11 Ratio of Axial Load to Yield Strength of Bolts Installed at the Highwall, Static Loading, (a) Case 1, (b) Case 2, (c) Case 3. Grid Dimensions Are in Meters. Rock Bolts 1 and 2 Represent 6 m Fully Grouted Bolts While Rock Bolts 3 - 7 Depict 3 m Swellex Bolts.



a)



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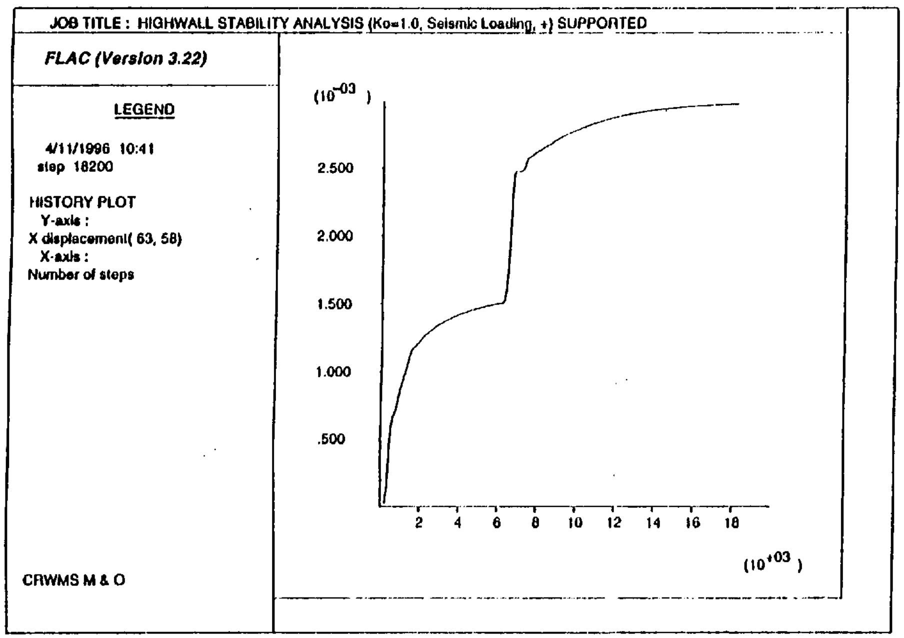
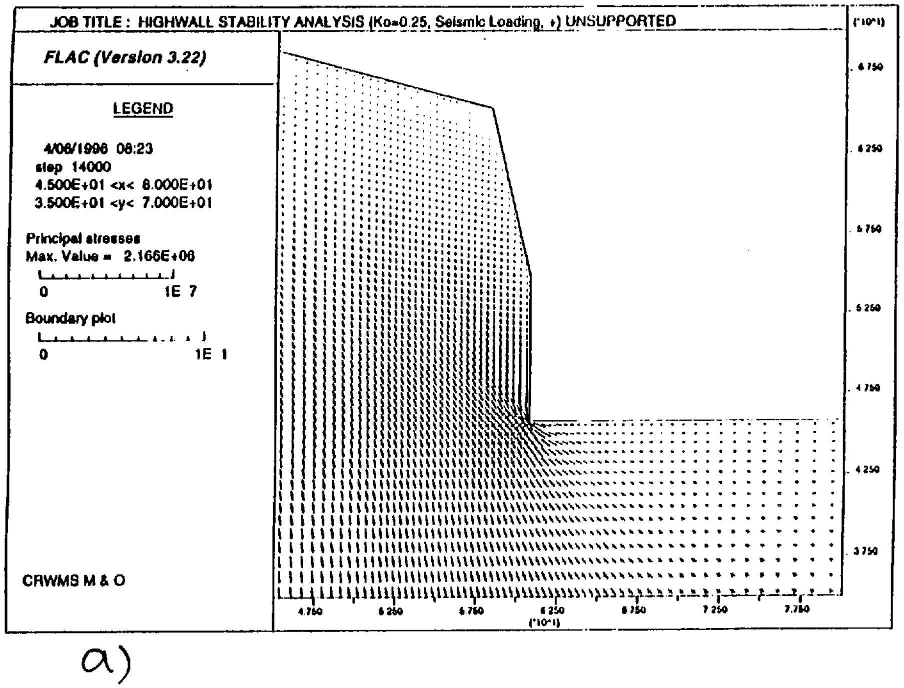
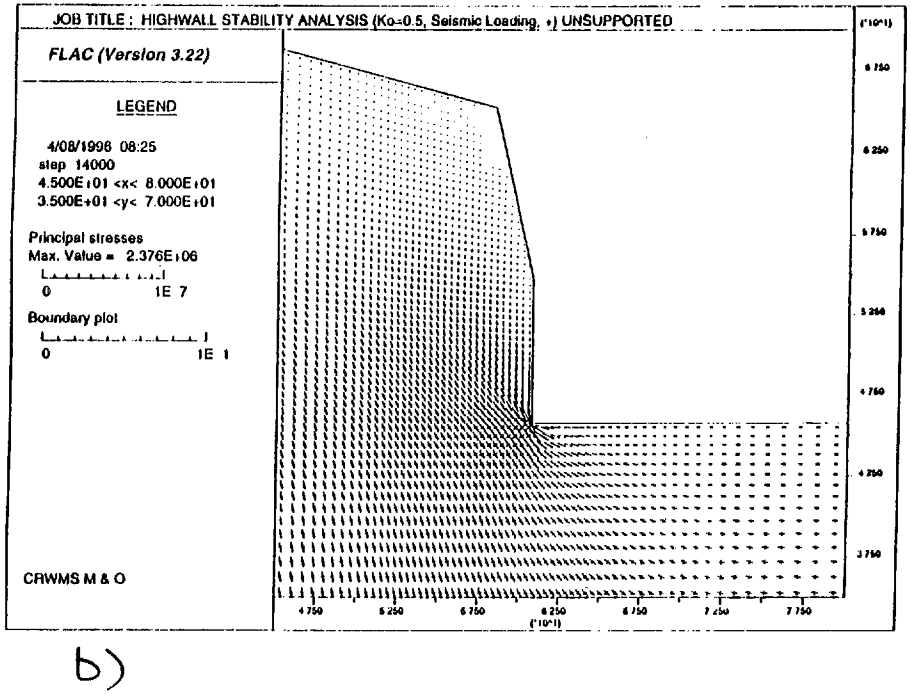


c)

Fig. 12 History Plot of X-Displacements at the South Portal Highwall, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3, (Grid Location: I=63, J=58). Displacements Are in Meters Shown on Y-Axis. X-Axis Represents Number of Iterations.





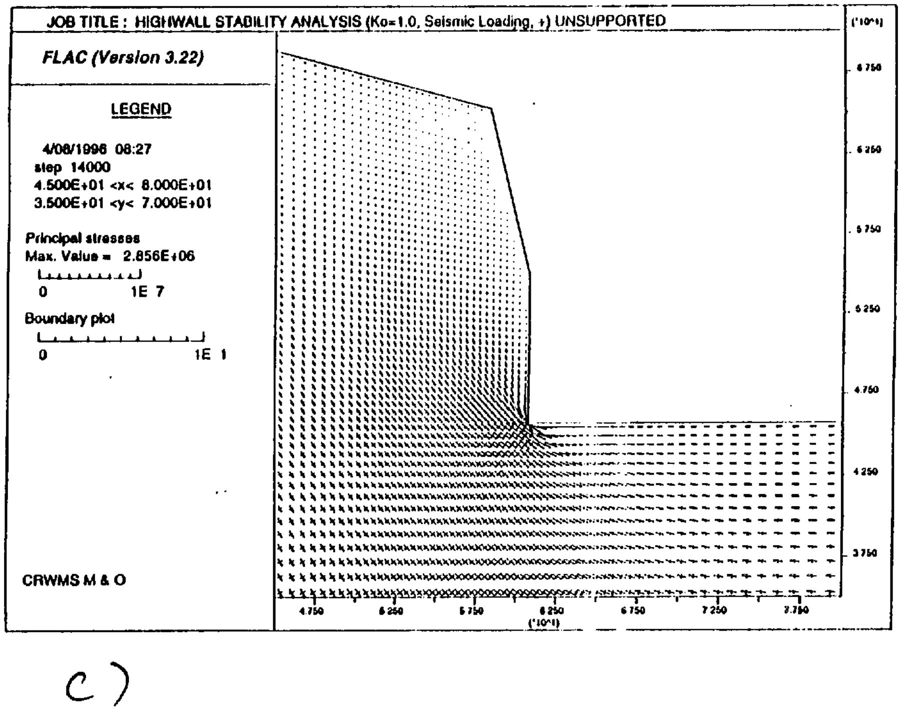
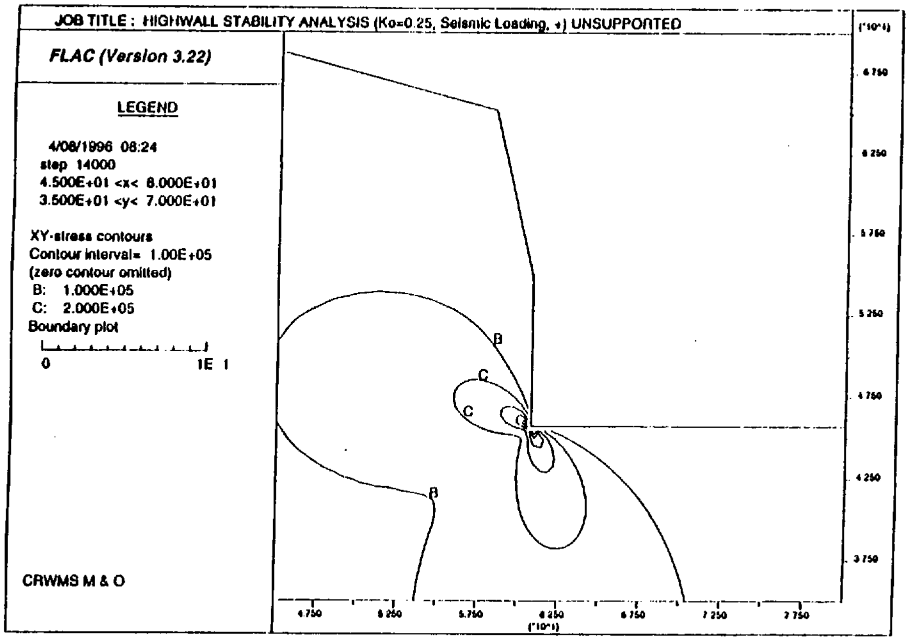
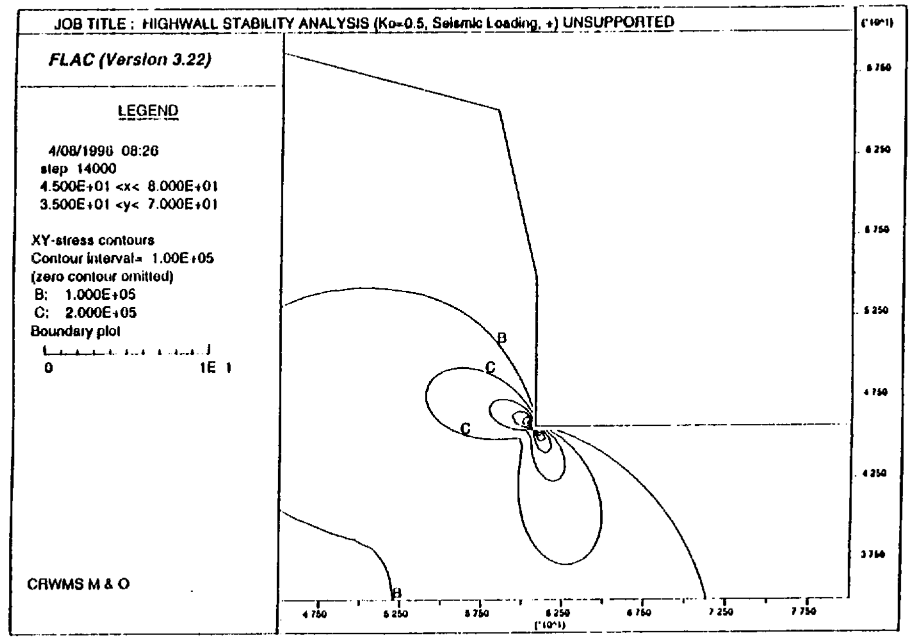


Fig. 13 Principal Stress Vectors Immediately After Box-Cut Excavation at the Highwall, Mohr-Coulomb Plasticity Model, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. Stresses Are in Pa. Grid Dimensions Are in Meters.



a)



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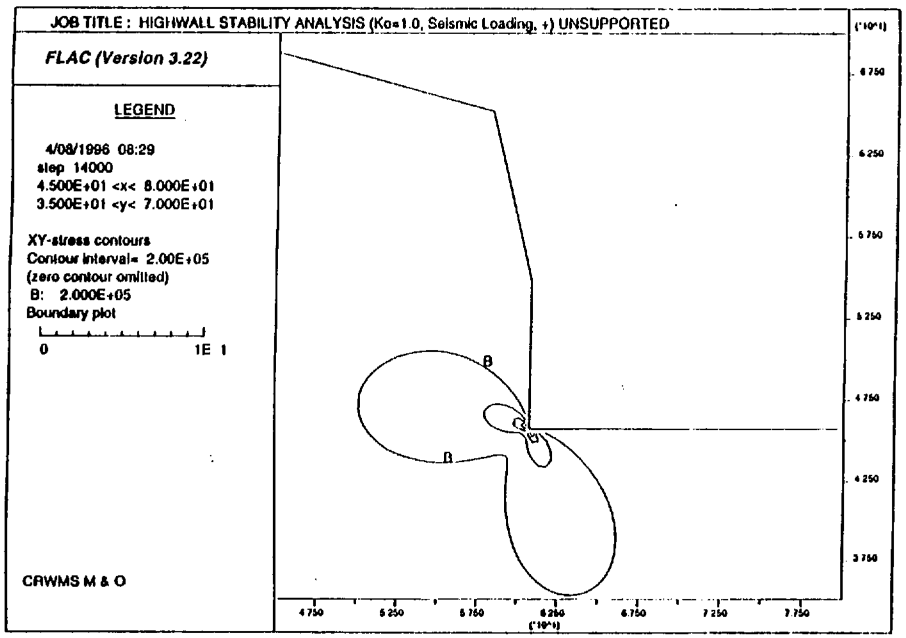
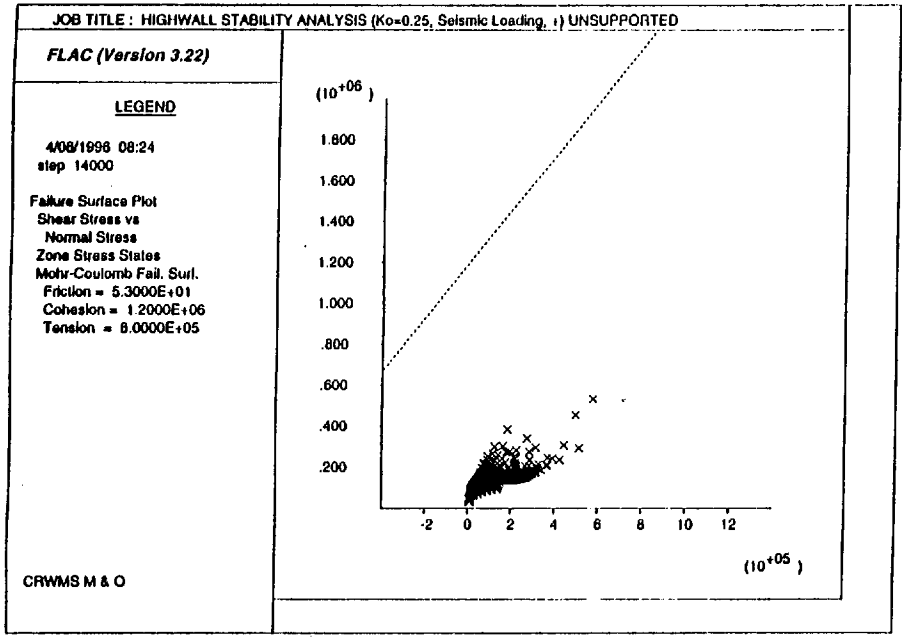
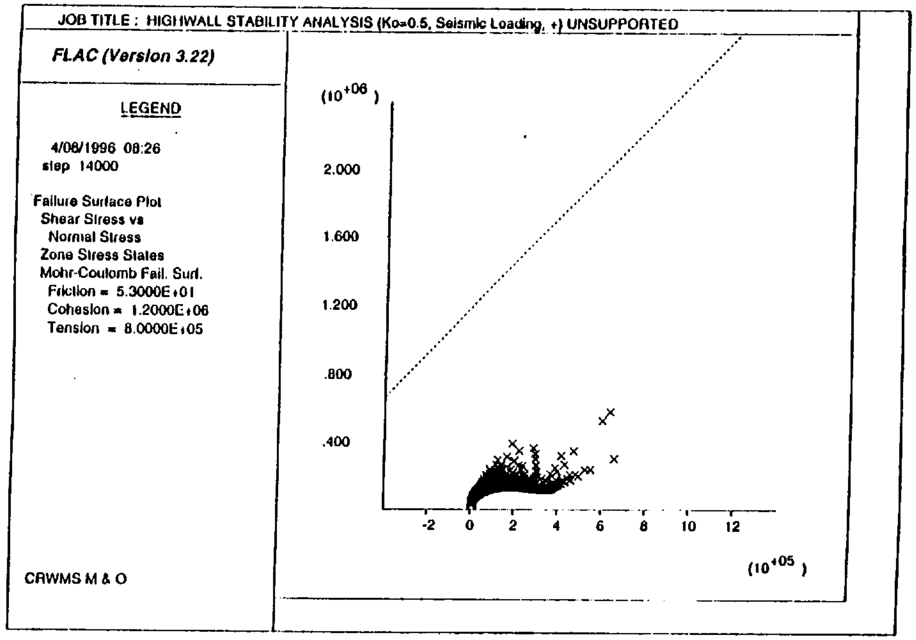


c)

Fig. 14 Shear Stress Contours Immediately After Box-Cut Excavation, Mohr-Coulomb Plasticity Model, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. Stresses Are in Pa. Grid Dimensions Are in Meters.



a)



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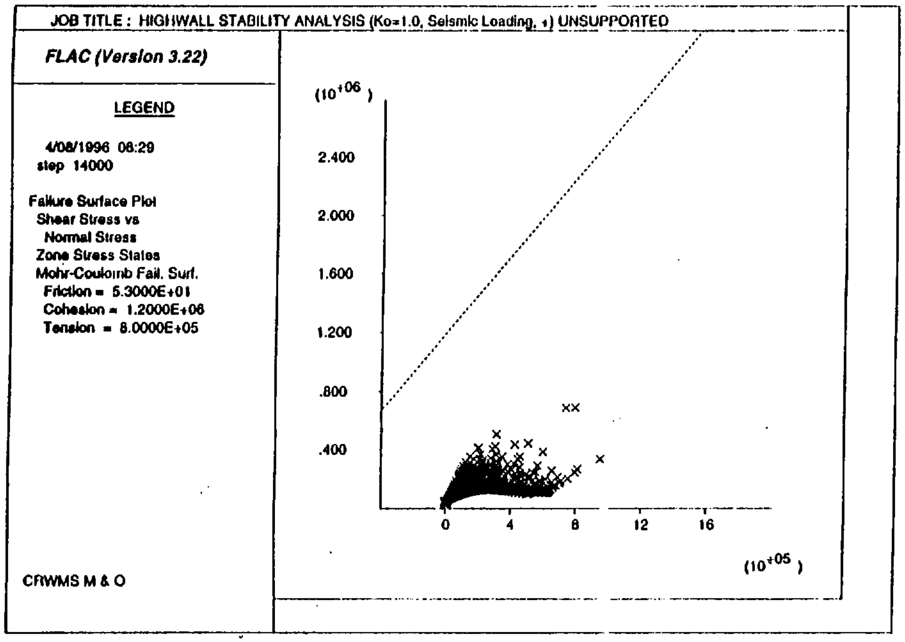
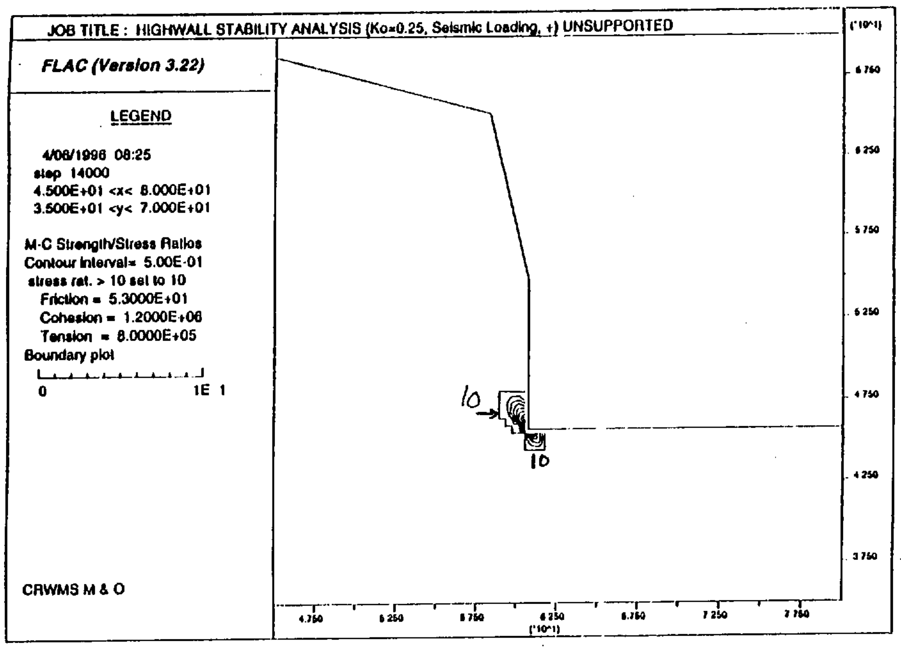
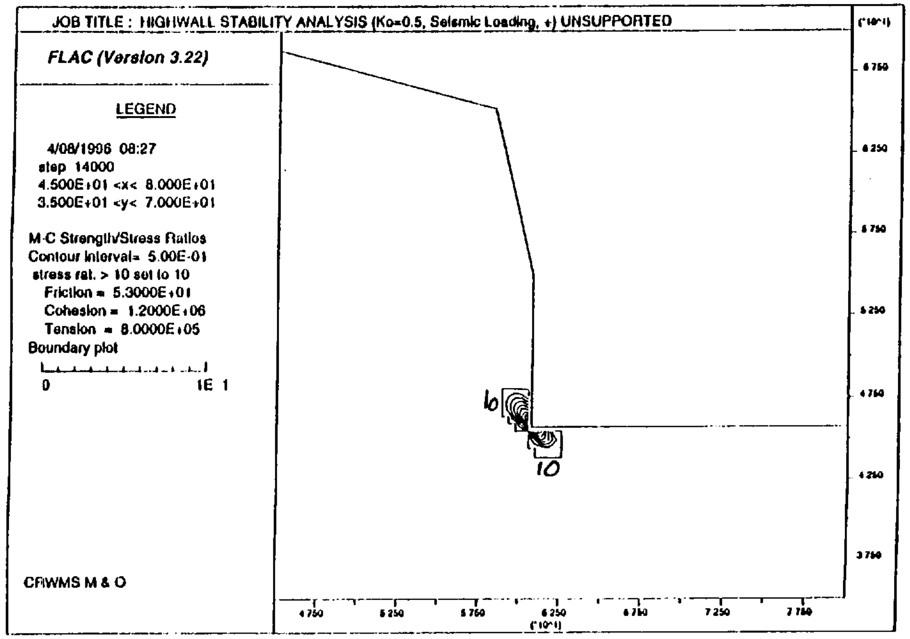


c)

Fig. 15 Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space at the South Portal Highwall, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. The Envelope Is Defined by Cohesion, Friction Angle, and Tension Limit of 1.2 MPa, 53°, and 0.8 MPa Respectively.



a)



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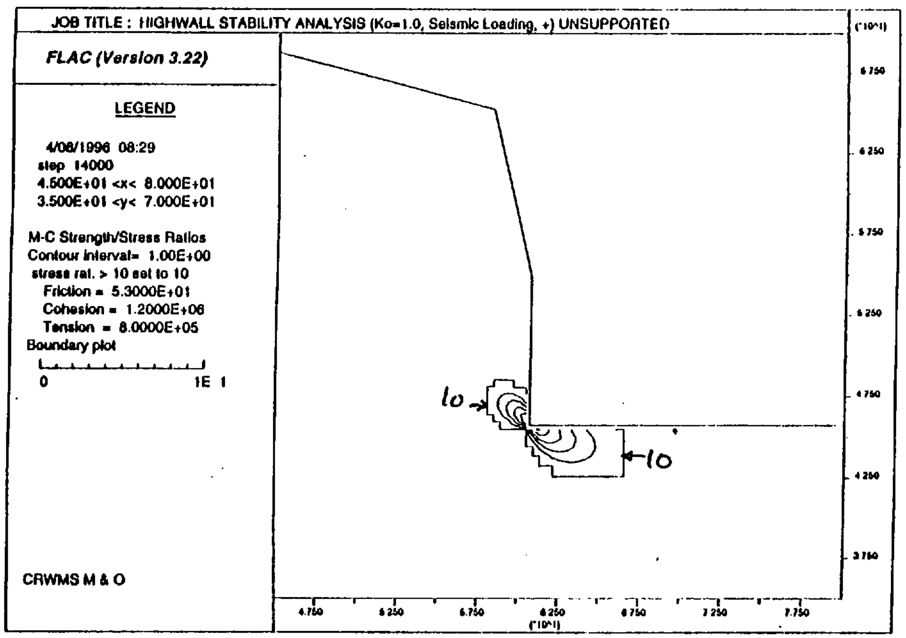
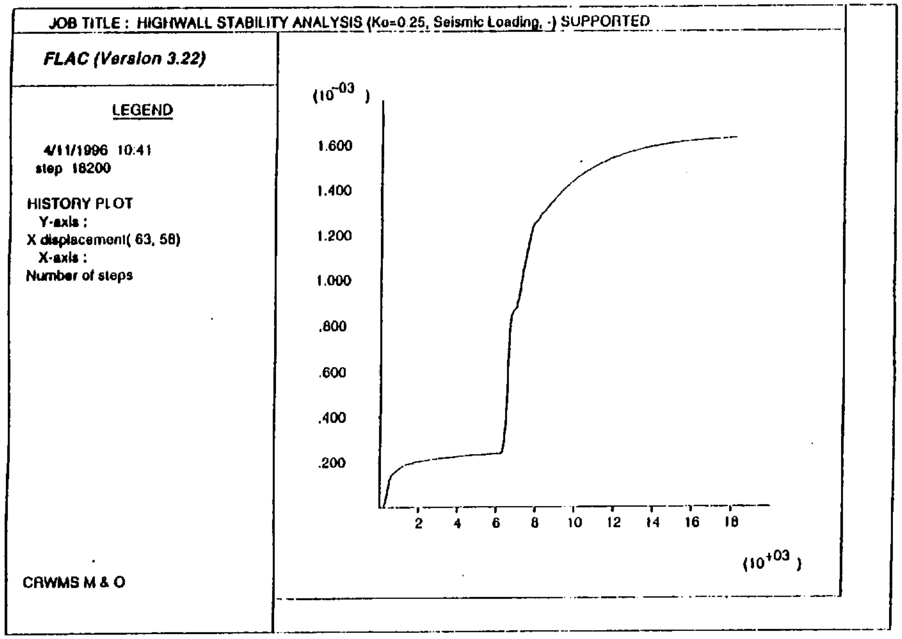
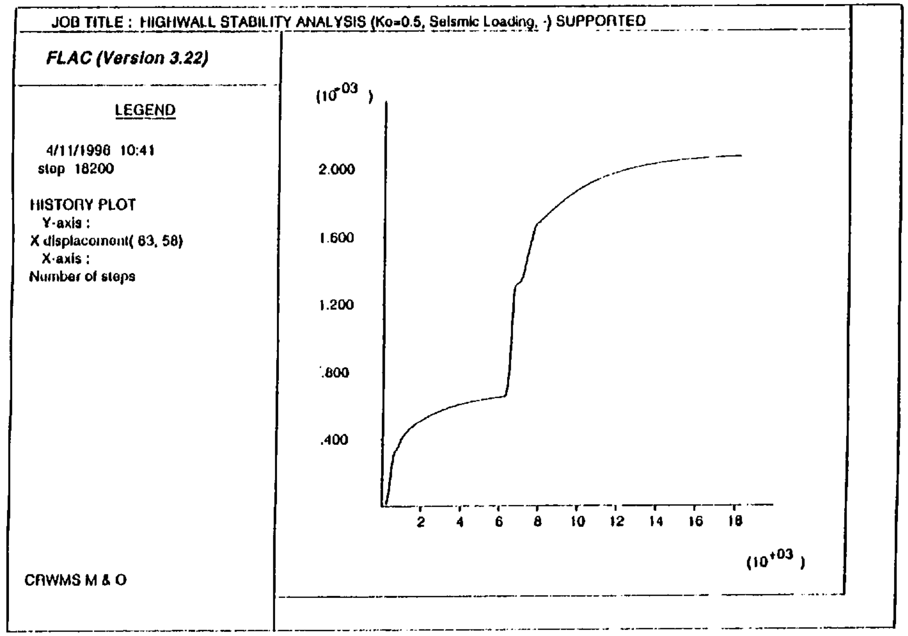


c)

Fig. 16 Strength/Stress Ratio Contours for the Mohr-Coulomb Plasticity Model at the South Portal Highwall, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. The Envelope Is Defined by Cohesion, Friction Angle, and Tension Limit of 1.2 MPa, 53°, and 0.8 MPa Respectively.



a)



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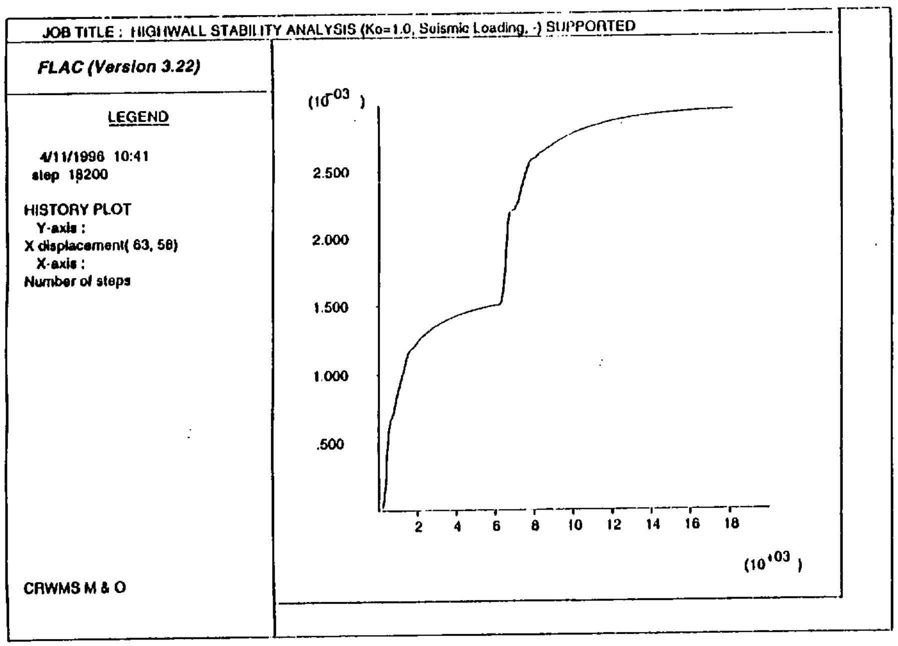


c)

Fig. 17 History Plot of X-Displacements at the South Portal Highwall, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3, (Grid Location: I=63, J=58). Displacements Are in Meters Shown on Y-Axis. X-Axis Represents Number of Iterations.

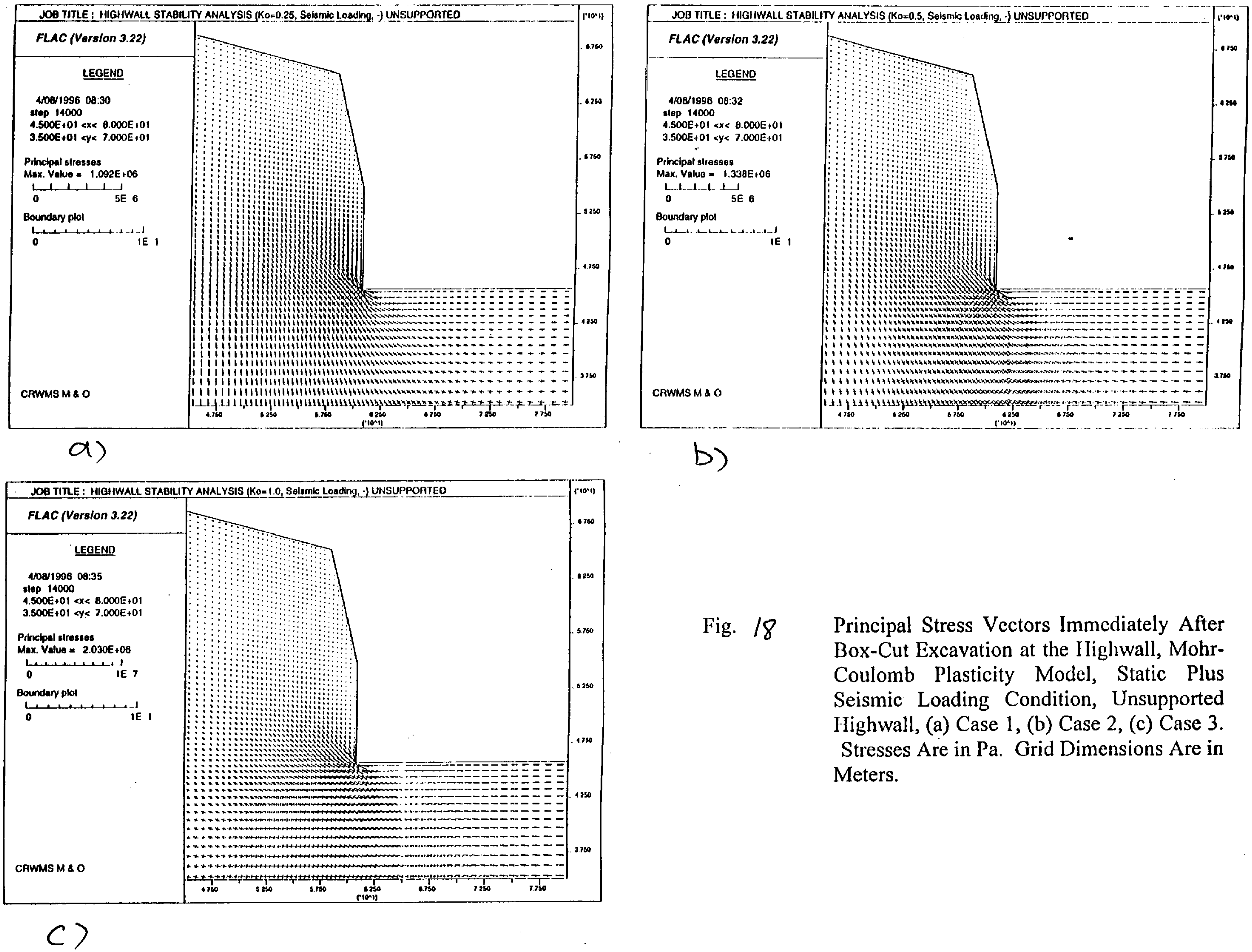
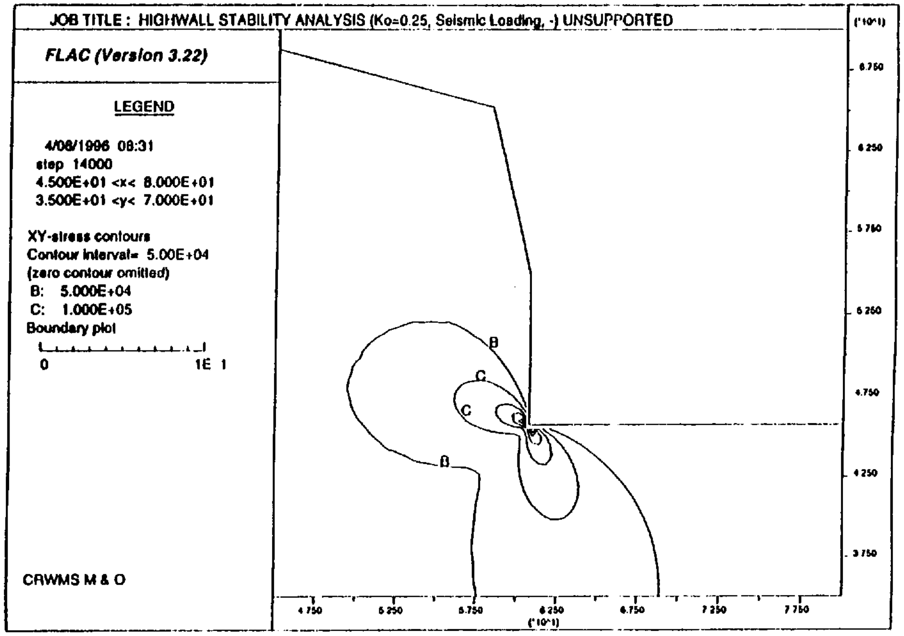
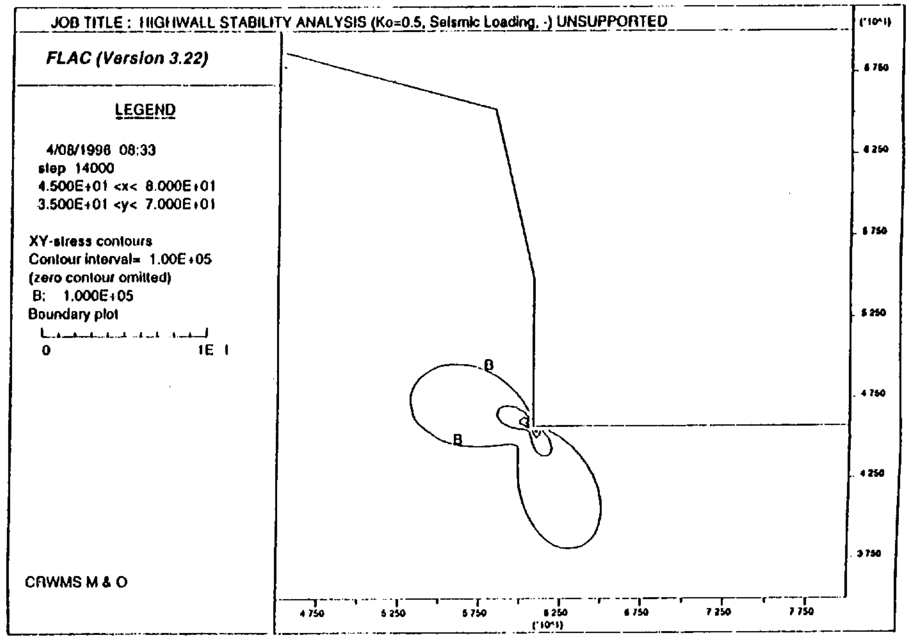


Fig. 18 Principal Stress Vectors Immediately After Box-Cut Excavation at the Highwall, Mohr-Coulomb Plasticity Model, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. Stresses Are in Pa. Grid Dimensions Are in Meters.



a)



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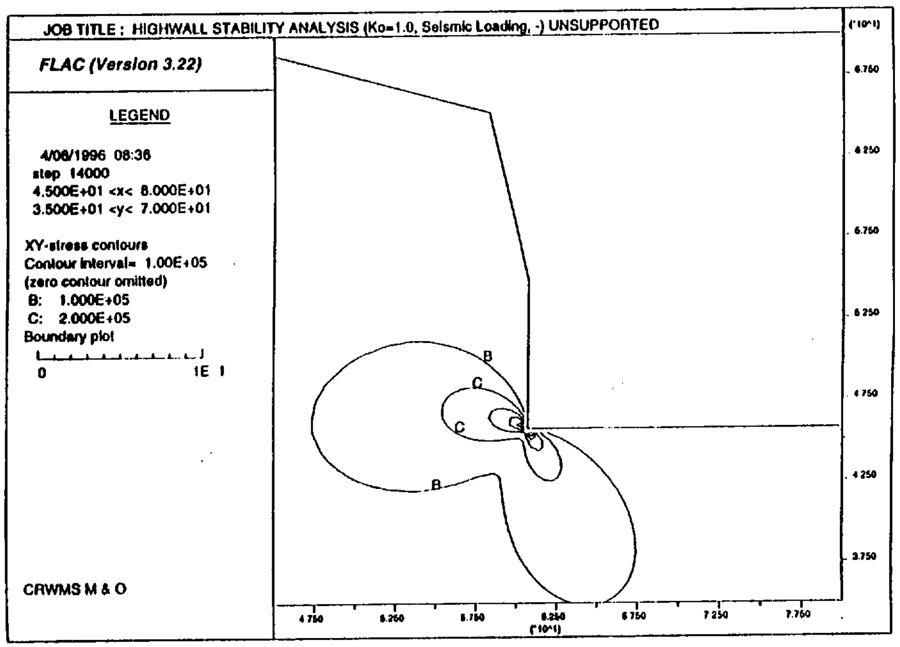
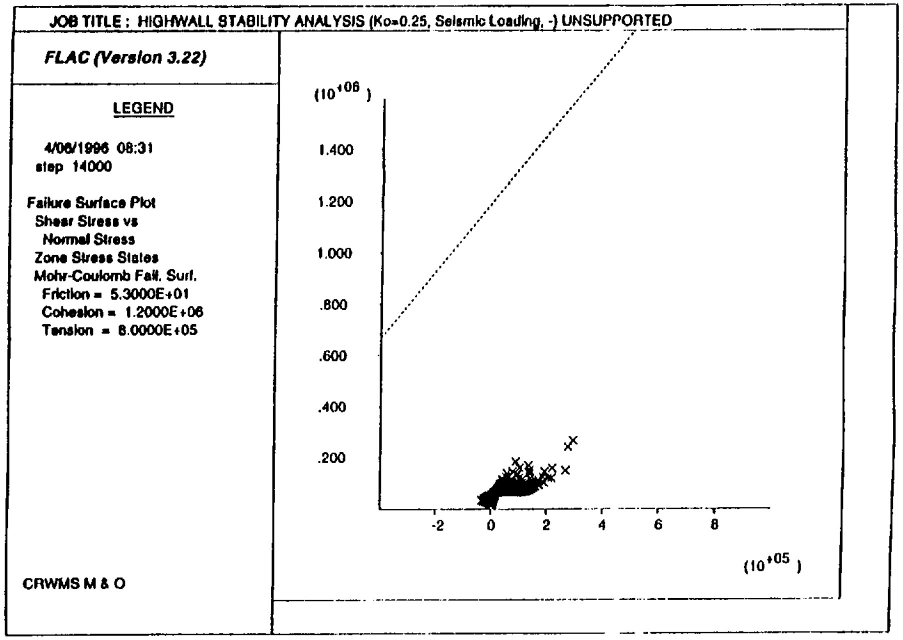


c)

Fig. 19 Shear Stress Contours Immediately After Box-Cut Excavation, Mohr-Coulomb Plasticity Model, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. Stresses Are in Pa. Grid Dimensions Are in Meters.



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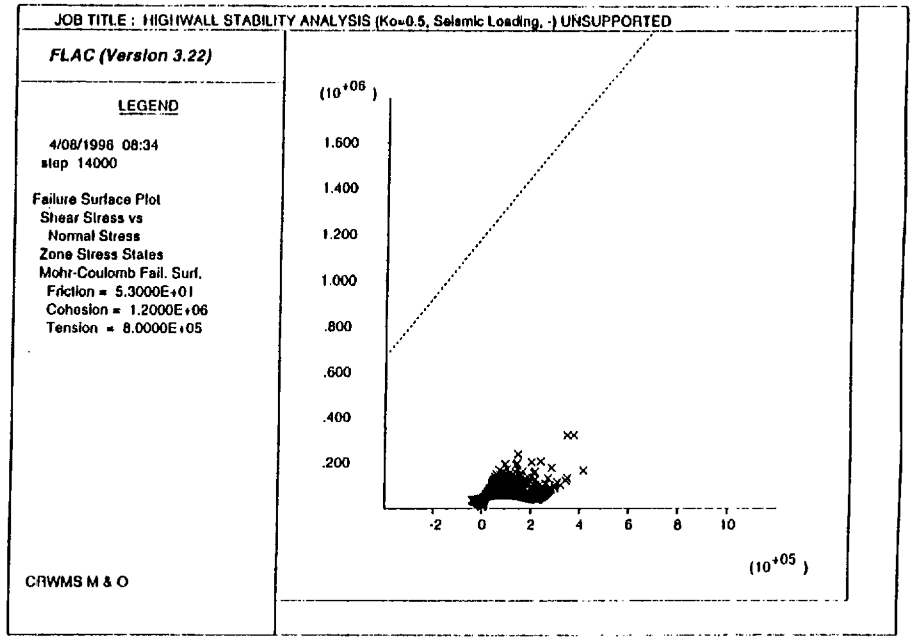

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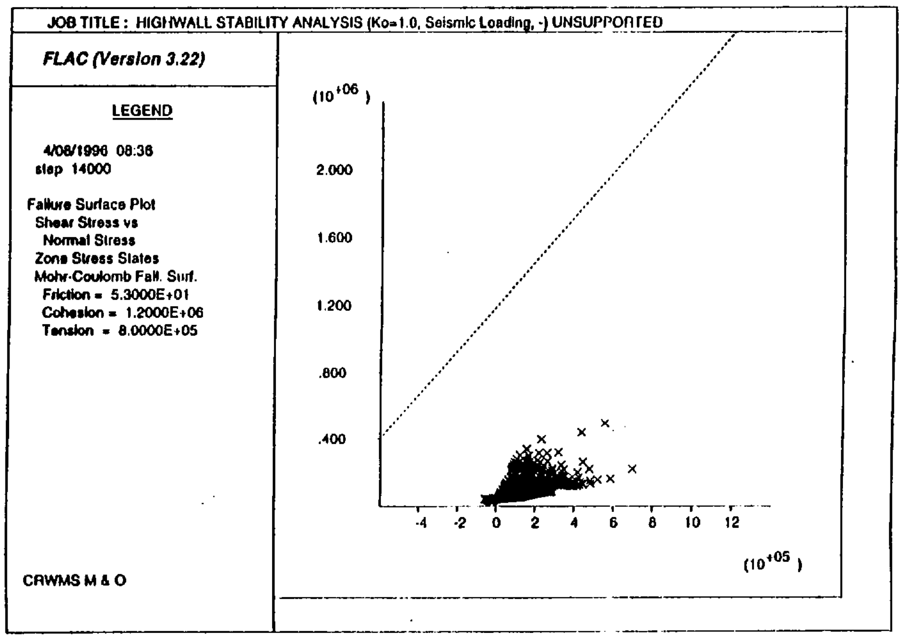
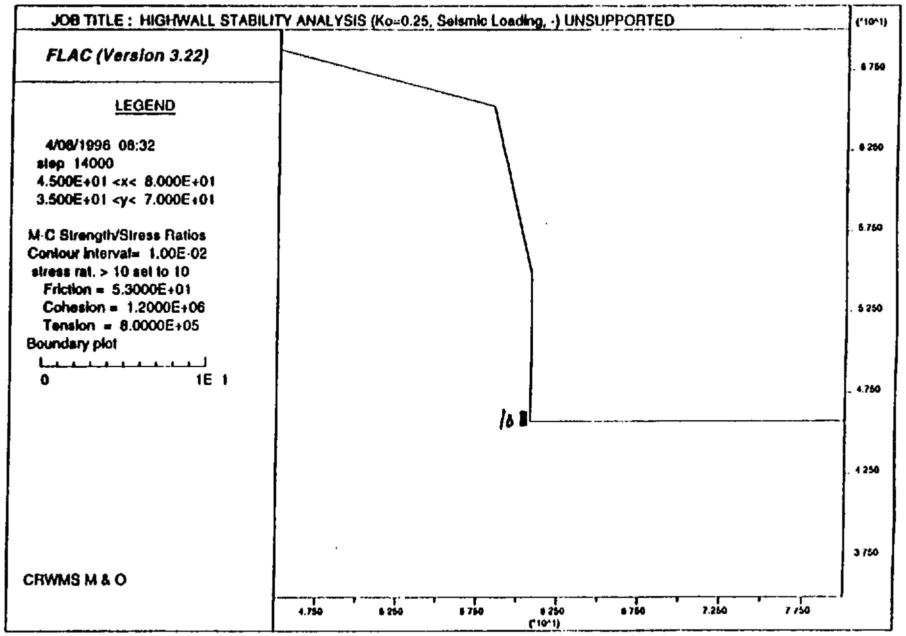
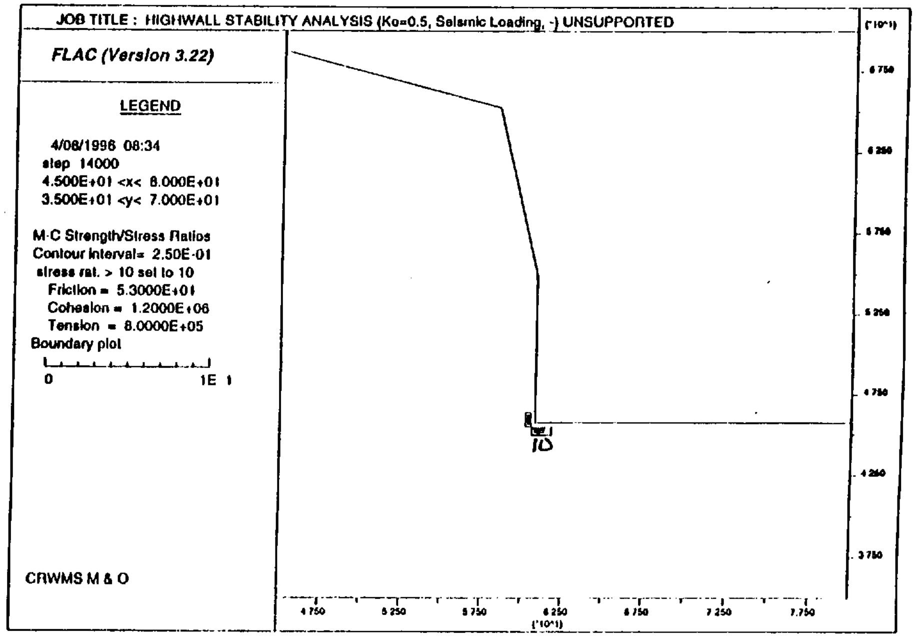


c)

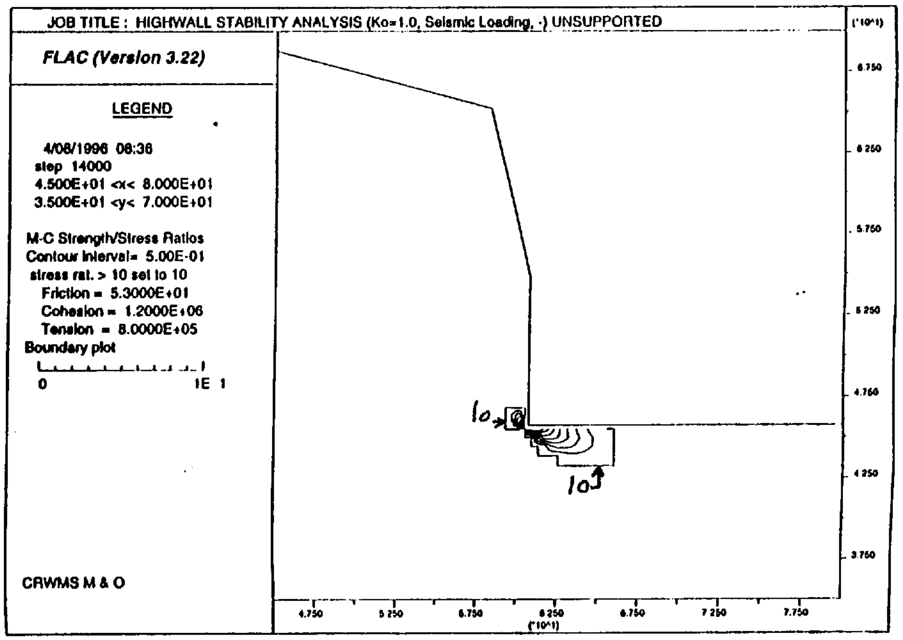
Fig. 20 Mohr-Coulomb Failure Envelope Plot in Shear Stress-Normal Stress Space at the South Portal Highwall, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. The Envelope Is Defined by Cohesion, Friction Angle, and Tension Limit of 1.2 MPa, 53°, and 0.8 MPa Respectively.



a)

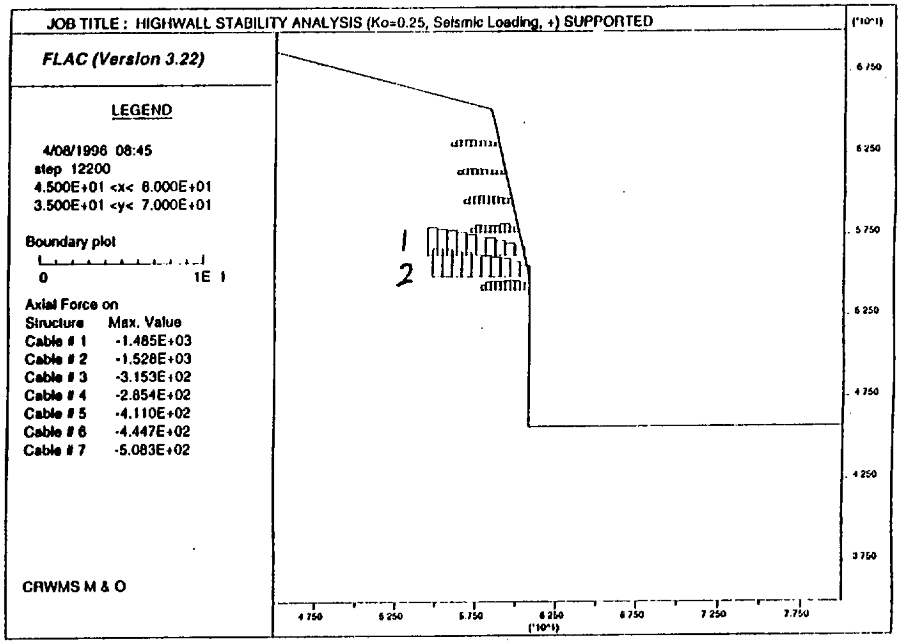


b)

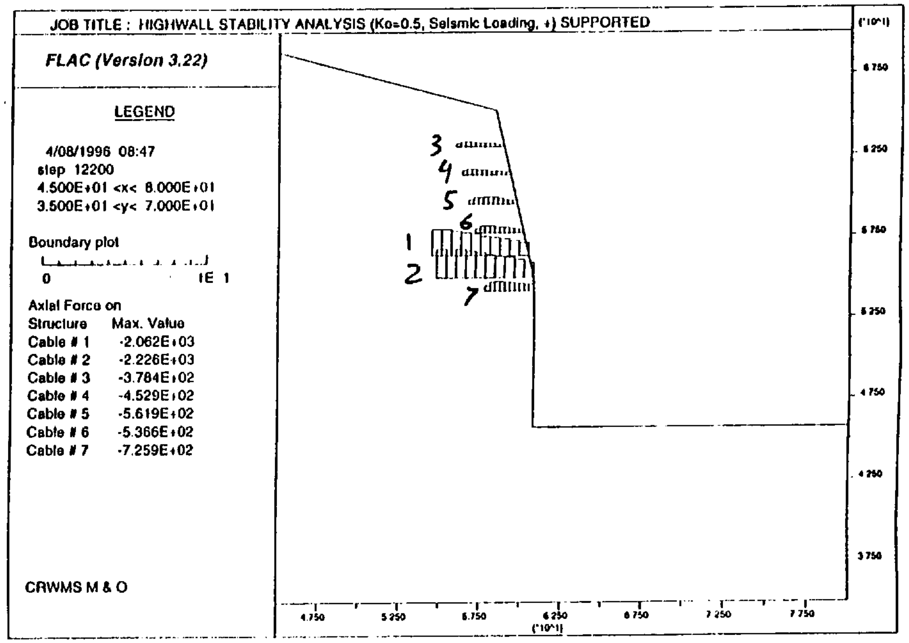


c)

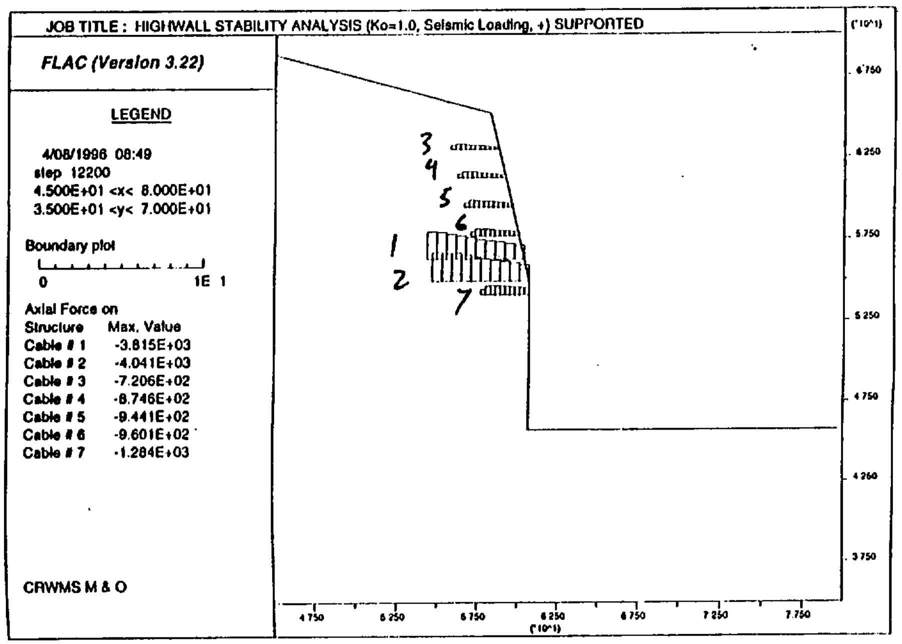
Fig. 21 Strength/Stress Ratio Contours for the Mohr-Coulomb Plasticity Model at the South Portal Highwall, Static Plus Seismic Loading Condition, Unsupported Highwall, (a) Case 1, (b) Case 2, (c) Case 3. The Envelope Is Defined by Cohesion, Friction Angle, and Tension Limit of 1.2 MPa, 53°, and 0.8 MPa Respectively.



a)

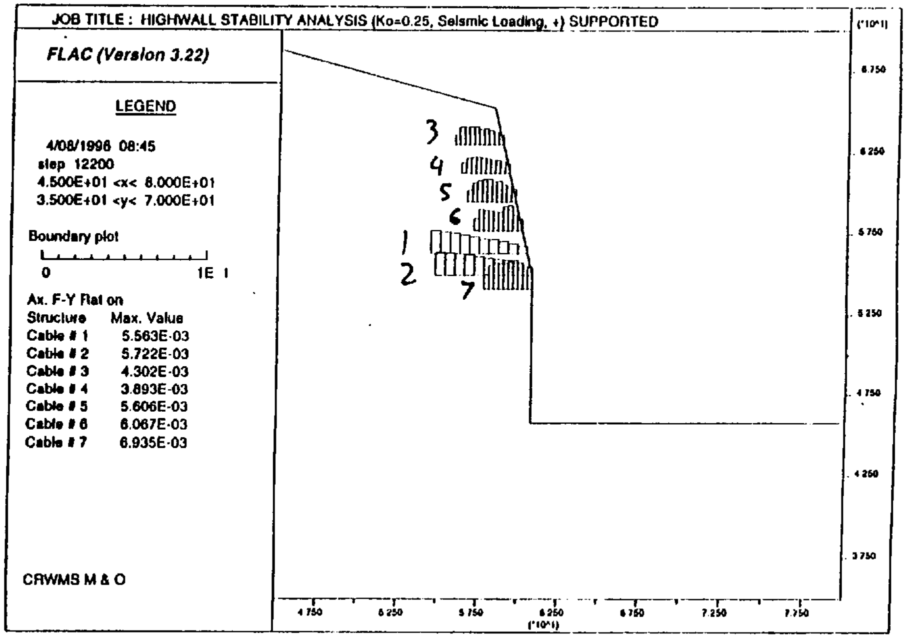


b)

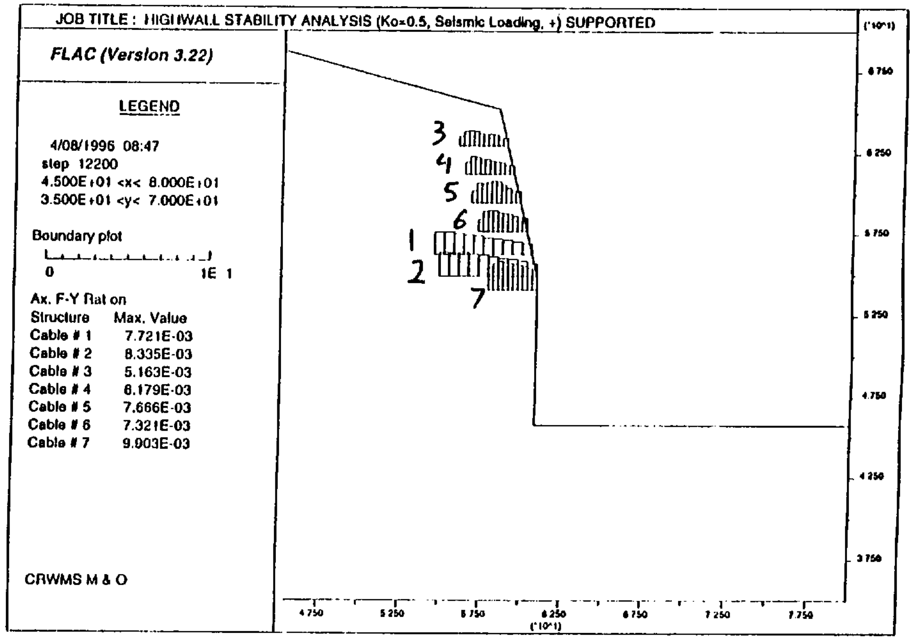


c)

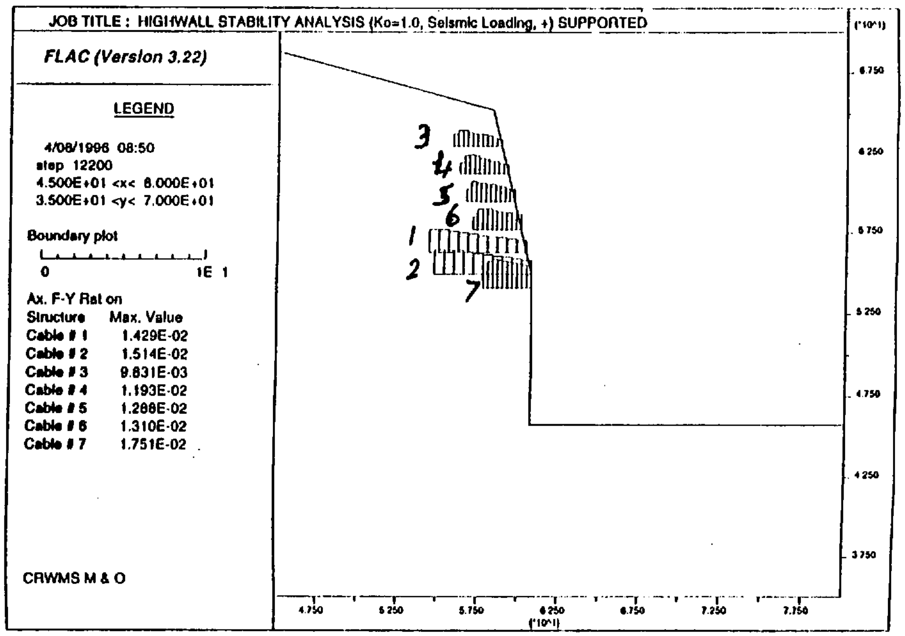
Fig. 22 Axial Loads in Rock Bolts Installed at the Highwall, Static Plus Seismic Loading, (a) Case 1, (b) Case 2, (c) Case 3. Grid Dimensions Are in Meters. Forces Are in Newton. Rock Bolts 1 and 2 Represent 6 m Fully Grouted Bolts While Rock Bolts 3 - 7 Depict 3 m Swellex Bolts.



a)

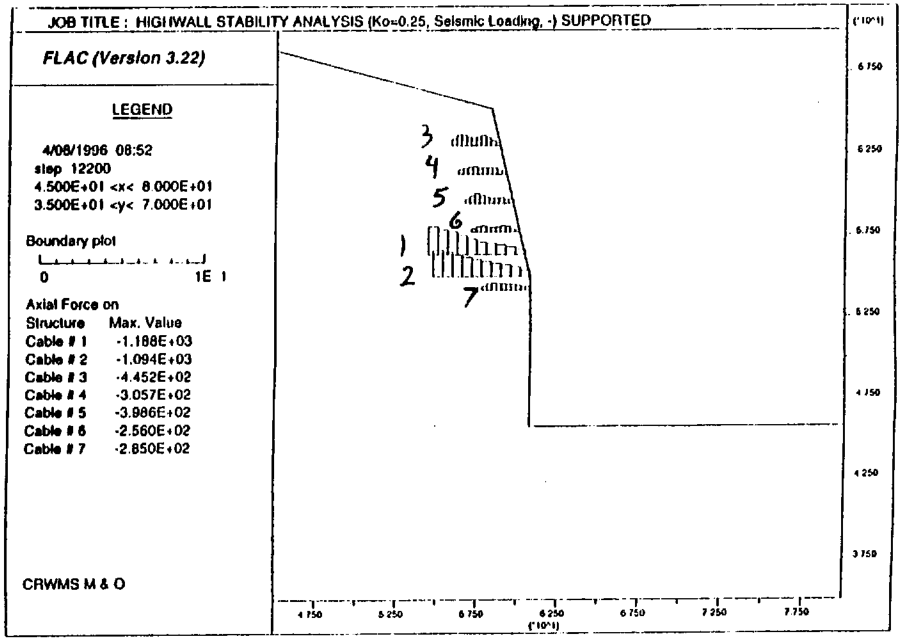


b)

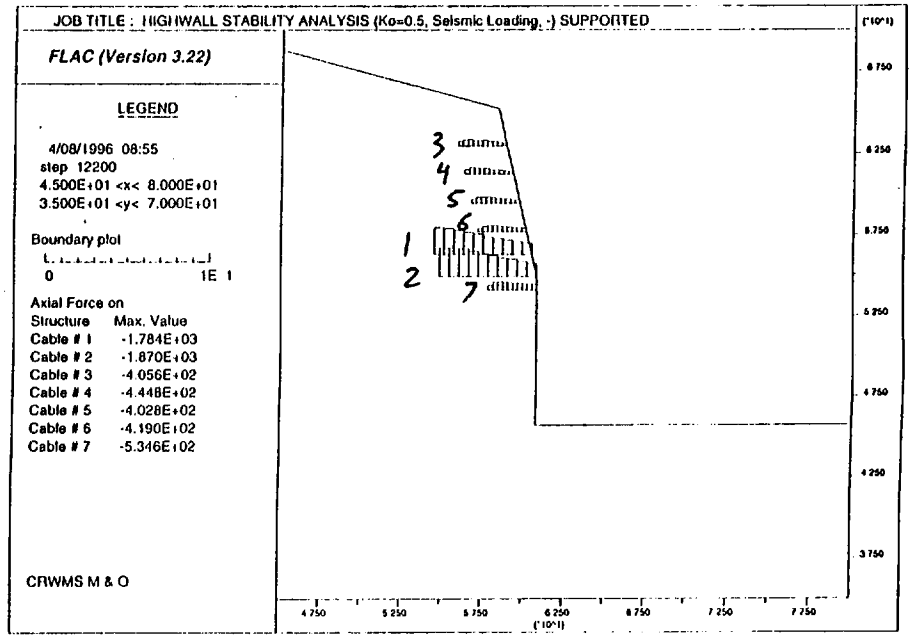


c)

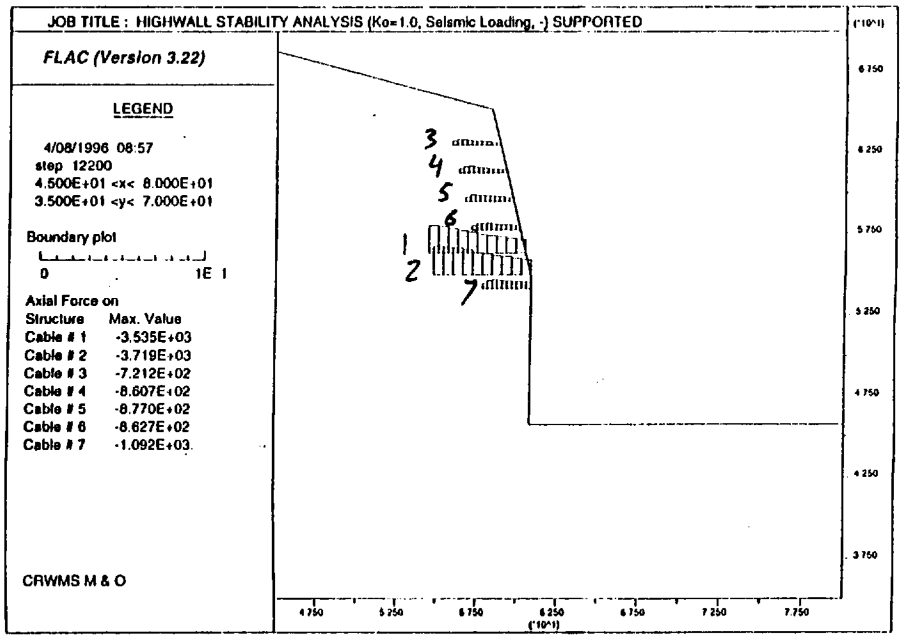
Fig. 23 Ratio of Axial Load to Yield Strength of Bolts Installed at the Highwall, Static Plus Seismic Loading, (a) Case 1, (b) Case 2, (c) Case 3. Grid Dimensions Are in Meters. Rock Bolts 1 and 2 Represent 6 m Fully Grouted Bolts While Rock Bolts 3 - 7 Depict 3 m Swellex Bolts.



a)

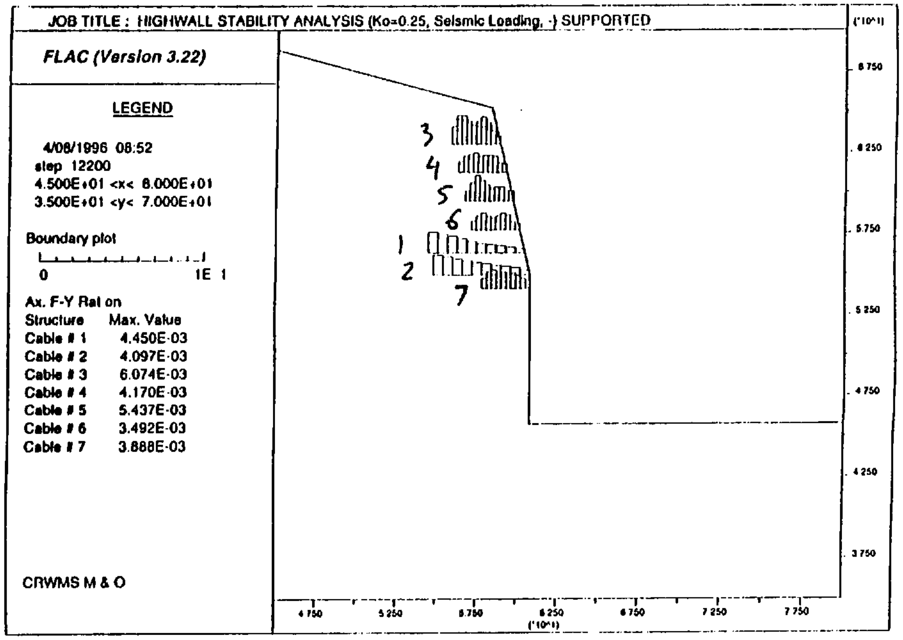


b)

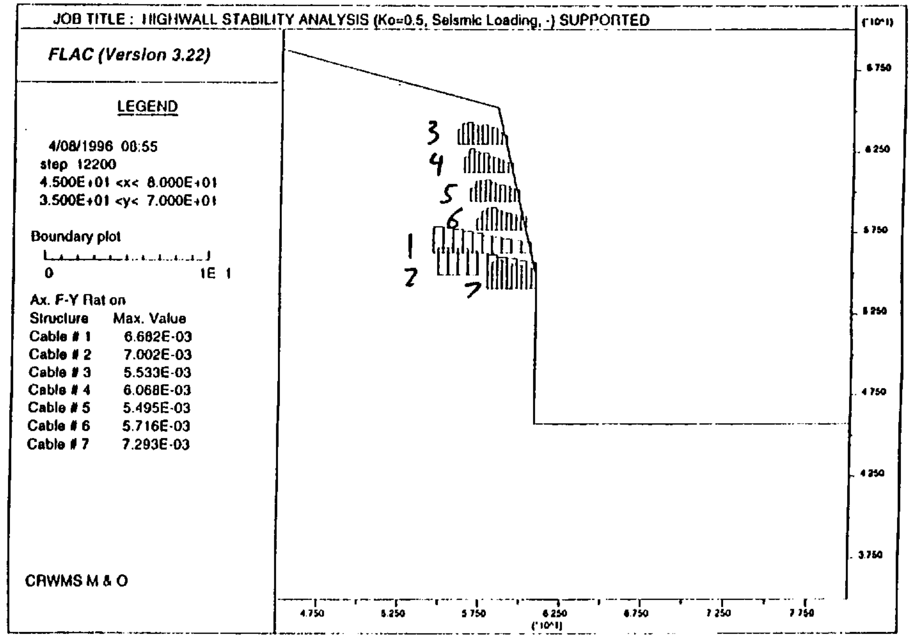


c)

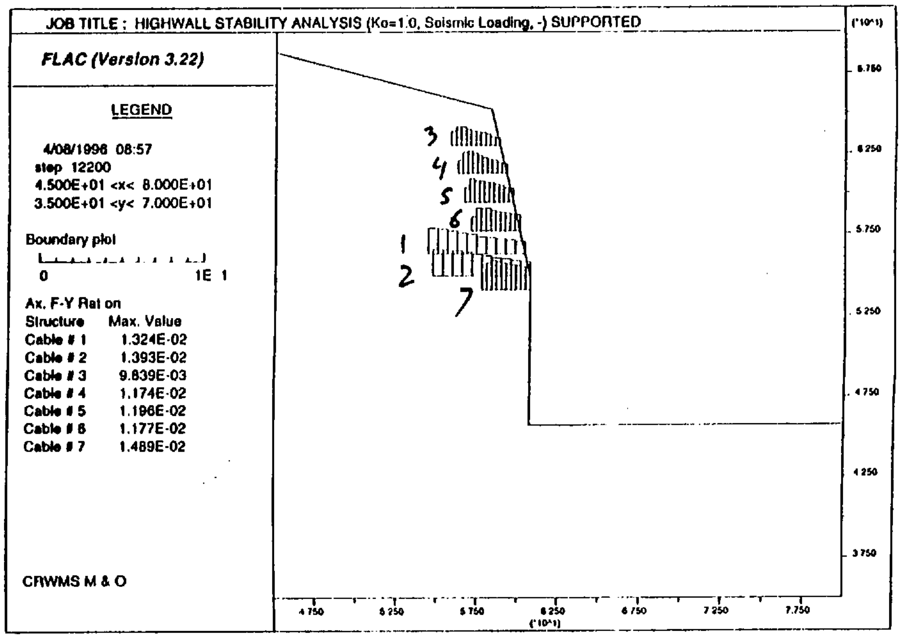
Fig. 24 Axial Loads in Rock Bolts Installed at the Highwall, Static Plus Seismic Loading, (a) Case 1, (b) Case 2, (c) Case 3. Grid Dimensions Are in Meters. Forces Are in Newton. Rock Bolts 1 and 2 Represent 6 m Fully Grouted Bolts While Rock Bolts 3 - 7 Depict 3 m Swellex Bolts.



a)



b)



c)

Fig. 25 Ratio of Axial Load to Yield Strength of Bolts Installed at the Highwall, Static Plus Seismic Loading, (a) Case 1, (b) Case 2, (c) Case 3. Grid Dimensions Are in Meters. Rock Bolts 1 and 2 Represent 6 m Fully Grouted Bolts While Rock Bolts 3 - 7 Depict 3 m Swellex Bolts.

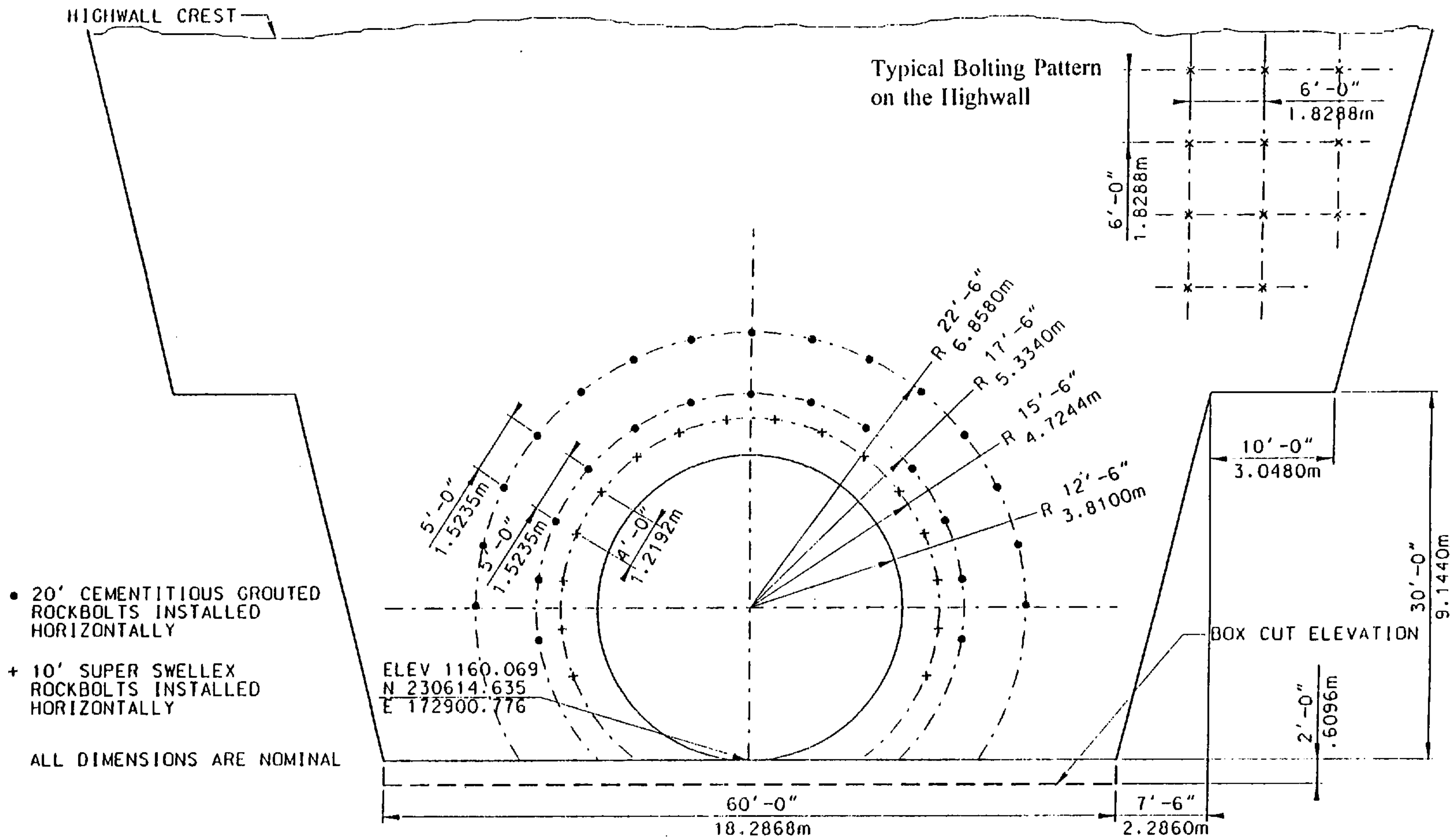
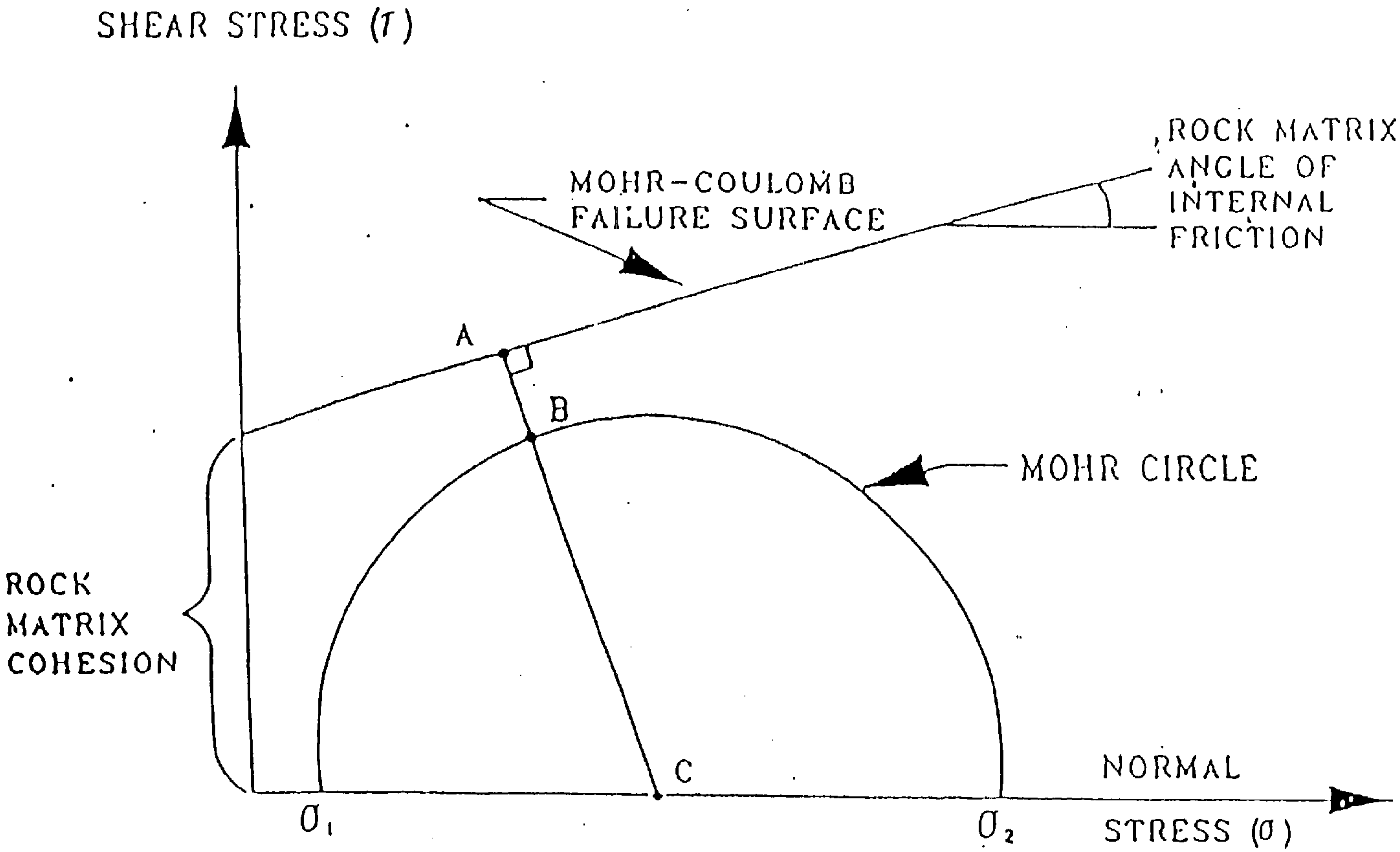


FIG. 26 SOUTH PORTAL HIGHWALL GROUND SUPPORT



MFS = MATRIX FACTOR-OF-SAFETY = $\frac{AC}{BC}$

IF MFS ≥ 1 (NO ROCK FRACTURING)

IF MFS < 1 (POTENTIAL ROCK FRACTURING)

Fig. 27 Mohr-Coulomb Criterion for Rock Matrix in FLAC.

8.0 CONCLUSIONS

A Box-Cut at the South Portal is designed with a Highwall and sidewalls of 1/4:1 slope. The portal location coordinates are determined in Reference 5.3 and with the 1/4:1 slope a Highwall of greater than 2 tunnel diameter (15.24 m) is achieved. The sidewall slopes are recommended to be benched at a nominal 9.14 m (30 ft) height to enhance stability and safety. The bench depth will be nominal 3.048 m (10 ft).

FLAC software was used to perform the analyses of the unsupported and supported Highwall. The unsupported highwall was analyzed under the in situ loading conditions and the results are presented in Figures 4 through 8. Based on the results of the analyses, no failure is expected at the Highwall under the in situ loading conditions. A rock reinforcement system for the South Portal Box-Cut slopes is recommended to enhance safety and provide stability during and after the TBM breakout. The recommended ground support system is presented in Figure 26. A systematic bolting system plus Welded Wire Fabric (WWF), 75 mm x 75 mm, is recommended to enhance stability and eliminate surficial failure due to weathering and jointing. Friction type rock bolts of 3 m in length (Split Sets or Super Swellex) on a nominal 1.83 m (6 ft) square pattern is recommended for the sidewall slopes at the Box-Cut. For the Highwall, 3 meter long Super Swellex rock bolts on a 1.83 m square pattern is recommended (Figure 26). In order to enhance stability during the breakout of the TBM from the Highwall, two rows of fully grouted rock bolts of 6 m in length is recommended as shown in Figure 26. Localized geologic conditions encountered during construction will be addressed by the constructor by installation of additional rock bolts to supplement the design. A layer of fibercrete or shotcrete 50 mm to 75 mm in thickness may be applied to the Highwall face to enhance stability if deemed required by the constructor during the excavation or prior to the TBM breakout. Installation of grouted rock bolts and WWF is not recommended at the face where the TBM will breakout. Fibercrete or shotcrete may be applied to that area if needed for personnel safety at the discretion of the constructor. If during construction it is determined that pressure grouting is required, it must be coordinated with the TCO and applied only after TCO approval.

The supported Highwall was subjected to in situ loading and then the seismic loading was superimposed. The results indicated that the additional loads due to seismic event did not cause any failure at the Highwall. The loads on the ground support components (rock bolts) increase due to seismic loading but were still well below their capacity. There was no failure detected in the rock bolts due to seismic loads (TBV-193-ESF).

The analyses incorporated best available rock mass properties from the ESF drilling for TCw unit. The site specific data from the SPDB will be collected and will be used to confirm the rock mass property values used in the analyses (TBV-224). Discontinuum analyses will be performed if site specific data predict formation of wedges or blocks at the Highwall at the time of removal of TBV-224. A hold on construction will be placed on the South Portal Box-Cut construction drawing(s) and will be removed upon receipt and review of the preliminary borehole data by the

A/E.

In order to control the irregularities and damage to the rock at the surfaces of the slopes, it is recommended that the Box-Cut perimeter along the Highwall and for a minimum distance of 20 meters out from the Highwall along the sidewalls shall be presplit using standard presplitting techniques. The presplitting drill and blast techniques are not only used to reduce blast damage to rock and achieve stable rock slopes, they are also used to allow for steeper rock slopes to be designed. The excavation of steeper rock slopes reduce cut volumes and improve project economy.

The remainder of the Box-Cut could be ripped or excavated by drill and blast methods. If blasting is used elsewhere along the perimeter in the Box-Cut, techniques shall be used to limit blast damage along the Box-Cut sidewalls.

The standard blasting techniques will be performed in construction of South Portal Box-Cut as indicated in Section 7.3. The constructor is required to submit a blast plan to the A/E prior to blasting at the South Portal Box-Cut to obtain its approval. The manufacturer selected to provide explosives shall be licensed under 27 CFR Part 55 Chapter 1, Subpart D and shall have a recognized technical product support program.

9.0 ATTACHMENTS

Attachment I: FLAC Input files for computer runs — Pages: I-1 to I-14

ATTACHMENT I

```
TITLE
SOUTH PORTAL HIGHWALL STABILITY ANALYSIS CATEGORY 1 (KO=0.25)
SUPPORTED
gr 100 80
m m
def xy_grad
r1=1.05
r2=1./r1
end
xy_grad
*
gen   0   0   0 265 300 265 300   0
gen   0   0   0 150 170 150 170   0 r=r2, r2 i=1,41  j=1,36
gen   0 150   0 265 170 265 170 150 r=r2, 1. i=1,41  j=36,81
gen 170   0 170 150 210 150 210   0 r=1., r2 i=41,71 j=1,36
gen 170 150 170 265 210 265 210 150 r=1., 1. i=41,71 j=36,81
gen 210   0 210 150 300 150 300   0 r=r1, r2 i=71,101 j=1,36
gen 210 150 210 265 300 265 300 150 r=r1, 1. i=71,101 j=36,81
*
*
def max_min
  xmax=0.
  xmin=10e5
  ymax=0.
  ymin=10e5
  loop i (1,igp)
    loop j (1,jgp)
      if x(i,j) > xmax then
        xmax=x(i,j)
      end_if
      if x(i,j) < xmin then
        xmin=x(i,j)
      end_if
      if y(i,j) > ymax then
        ymax=y(i,j)
      end_if
      if y(i,j) < ymin then
        ymin=y(i,j)
      end_if
    end_loop
```

```
  end_loop
end
max_min
*
def slope
  delta_y=-80.
  yminr=y(1,36)
  loop i (1, igp)
    loop j (36, jgp)
      x_scale=(x(i,j)-xmin)/(xmax-xmin)
      y_scale=(y(i,j)-yminr)/(ymax-yminr)
      y(i,j)=y(i,j)+x_scale*y_scale*delta_y
    end_loop
  end_loop
end
slope
*
gen line 199.34 150 305 150
gen line 199.34 150 199.34 180
gen line 199.34 180 185 241

* Covert to SI units
ini x mul 0.3048
ini y mul 0.3048
*
prop sh=2.79e9 bu=3.72e9 density=2169 coh=1.2e6 fric=53 ten=0.8e6
set gravity=9.81
*
def geostres
ko=0.25
den_tcw=2169
grav_si=9.81
delta_y=delta_y*0.3048
ymax=ymax*0.3048
xmax=xmax*0.3048
ymin=ymin*0.3048
xmin=xmin*0.3048
       loop i (1, izones)
         loop j (1,jzones)
           yc=(y(i,j)+y(i,j+1)+y(i+1,j)+y(i+1,j+1))/4
           yimax=ymax+delta_y*((x(i,j)-xmin)/(xmax-xmin))
           hc=yimax-yc
```

```
      syy(i,j)=-grav_si*den_tcw*hc
      sxx(i,j)=ko*syy(i,j)
      szz(i,j)=sxx(i,j)
    end_loop
  end_loop
end
geostres
*
fix x i=1
fix x i=101
fix y j=1
*
his unbal
step 200
sav mc1k1N_o.sav
ini xdisp 0 ydisp 0
his xdisp i 57 j 81
his xdisp i 63 j 58
his xdisp i 63 j 36
his ydisp i 63 j 36
his ydisp i 101 j 36
m n reg 99 79
ca bolting.dat
step 6000
sav mc1k1N_s.sav
**********************************************************
*SEISMIC LOADING
*case 1:
*horizontal acceleration component=0.37g
*vertical acceleration component=gravitational acceleration + seismic acceleration
*    = g + 0.37g = 1.37g
* resultant acceleration = sqrt(0.37^2 + 1.37^2)g = 1.42g
*inclination angle with respect to vertical = tan^-1(0.37/1.37)=15.11°
*case 2:
*horizontal acceleration component=0.37g
*vertical acceleration component=gravitational acceleration - seismic acceleration
*    = g - 0.37g = 0.63g
* resultant acceleration = sqrt(0.37^2 + 0.63^2)g = 0.73g
*inclination angle with respect to vertical = tan^-1(0.37/0.63)=30.42°
**********************************************************
set gravity 13.92 15.11
step 6000
```

```
sav mc1k1N_d.sav
*
set gravity 9.81 0
step 6000
sav mc1k1ndr.sav
*
res mc1k1n_s.sav
set gravity 7.16 30.42
step 6000
sav mc1k1n_u.sav
*
set gravity 9.81 0
step 6000
sav mc1k1nur.sav
new
TITLE
SOUTH PORTAL HIGHWALL STABILITY ANALYSIS CATEGORY 1 (KO=0.50)
SUPPORTED
gr 100 80
m m
def xy_grad
r1=1.05
r2=1./r1
end
xy_grad
*
gen   0   0   0 265 300 265 300   0
gen   0   0   0 150 170 150 170   0 r=r2, r2 i=1,41  j=1,36
gen   0 150   0 265 170 265 170 150 r=r2, 1. i=1,41  j=36,81
gen 170   0 170 150 210 150 210   0 r=1., r2 i=41,71 j=1,36
gen 170 150 170 265 210 265 210 150 r=1., 1. i=41,71 j=36,81
gen 210   0 210 150 300 150 300   0 r=r1, r2 i=71,101 j=1,36
gen 210 150 210 265 300 265 300 150 r=r1, 1. i=71,101 j=36,81
*
*
def max_min
  xmax=0.
  xmin=10e5
  ymax=0.
  ymin=10e5
  loop i (1,igp)
    loop j (1,jgp)
```

```
      if x(i,j) > xmax then
        xmax=x(i,j)
      end_if
      if x(i,j) < xmin then
        xmin=x(i,j)
      end_if
      if y(i,j) > ymax then
        ymax=y(i,j)
      end_if
      if y(i,j) < ymin then
        ymin=y(i,j)
      end_if
    end_loop
  end_loop
end
max_min
*
def slope
  delta_y=-80.
  yminr=y(1,36)
  loop i (1, igp)
    loop j (36, jgp)
      x_scale=(x(i,j)-xmin)/(xmax-xmin)
      y_scale=(y(i,j)-yminr)/(ymax-yminr)
      y(i,j)=y(i,j)+x_scale*y_scale*delta_y
    end_loop
  end_loop
end
slope
*
gen line 199.34 150 305 150
gen line 199.34 150 199.34 180
gen line 199.34 180 185 241

* Covert to SI units
ini x mul 0.3048
ini y mul 0.3048
*
prop sh=2.79e9 bu=3.72e9 density=2169 coh=1.2e6 fric=53 ten=0.8e6
set gravity=9.81
*
def geostres
```

```
ko=0.50
den_tcw=2169
grav_si=9.81
delta_y=delta_y*0.3048
ymax=ymax*0.3048
xmax=xmax*0.3048
ymin=ymin*0.3048
xmin=xmin*0.3048
    loop i (1, izones)
      loop j (1,jzones)
        yc=(y(i,j)+y(i,j+1)+y(i+1,j)+y(i+1,j+1))/4
        yimax=ymax+delta_y*((x(i,j)-xmin)/(xmax-xmin))
        hc=yimax-yc
        syy(i,j)=-grav_si*den_tcw*hc
        sxx(i,j)=ko*syy(i,j)
        szz(i,j)=sxx(i,j)
      end_loop
    end_loop
end
geostres
*
fix x i=1
fix x i=101
fix y j=1
*
his unbal
step 200
sav mc1k2n_o.sav
ini xdisp 0 ydisp 0
his xdisp i 57 j 81
his xdisp i 63 j 58
his xdisp i 63 j 36
his ydisp i 63 j 36
his ydisp i 101 j 36
m n reg 99 79
CA BOLTING.DAT
step 6000
sav mc1k2n_s.sav
*
set gravity 13.92 15.11
step 6000
sav mc1k2n_d.sav
```

```
*
set gravity 9.81 0
step 6000
sav mc1k2ndr.sav
*
res mc1k2n_s.sav
set gravity 7.16 30.42
step 6000
sav mc1k2n_u.sav
*
set gravity 9.81 0
step 6000
sav mc1k2nur.sav
*
new
TITLE
SOUTH PORTAL HIGHWALL STABILITY ANALYSIS CATEGORY 1 (KO=1.00)
SUPPORTED
gr 100 80
m m
def xy_grad
r1=1.05
r2=1./r1
end
xy_grad
*
gen   0   0   0 265 300 265 300   0
gen   0   0   0 150 170 150 170   0 r=r2, r2 i=1,41  j=1,36
gen   0 150   0 265 170 265 170 150 r=r2, 1. i=1,41  j=36,81
gen 170   0 170 150 210 150 210   0 r=1., r2 i=41,71 j=1,36
gen 170 150 170 265 210 265 210 150 r=1., 1. i=41,71 j=36,81
gen 210   0 210 150 300 150 300   0 r=r1, r2 i=71,101 j=1,36
gen 210 150 210 265 300 265 300 150 r=r1, 1. i=71,101 j=36,81
*
*
def max_min
  xmax=0.
  xmin=10e5
  ymax=0.
  ymin=10e5
  loop i (1,igp)
    loop j (1,jgp)
```

```
      if x(i,j) > xmax then
        xmax=x(i,j)
      end_if
      if x(i,j) < xmin then
        xmin=x(i,j)
      end_if
      if y(i,j) > ymax then
        ymax=y(i,j)
      end_if
      if y(i,j) < ymin then
        ymin=y(i,j)
      end_if
    end_loop
  end_loop
end
max_min
*
def slope
  delta_y=-80.
  yminr=y(1,36)
  loop i (1, igp)
    loop j (36, jgp)
      x_scale=(x(i,j)-xmin)/(xmax-xmin)
      y_scale=(y(i,j)-yminr)/(ymax-yminr)
      y(i,j)=y(i,j)+x_scale*y_scale*delta_y
    end_loop
  end_loop
end
slope
*
gen line 199.34 150 305 150
gen line 199.34 150 199.34 180
gen line 199.34 180 185 241

* Covert to SI units
ini x mul 0.3048
ini y mul 0.3048
*
prop sh=2.79e9 bu=3.72e9 density=2169 coh=1.2e6 fric=53 ten=0.8e6
set gravity=9.81
*
def geostres
```

```
ko=1.00
den_tcw=2169
grav_si=9.81
delta_y=delta_y*0.3048
ymax=ymax*0.3048
xmax=xmax*0.3048
ymin=ymin*0.3048
xmin=xmin*0.3048
      loop i (1, izones)
        loop j (1,jzones)
          yc=(y(i,j)+y(i,j+1)+y(i+1,j)+y(i+1,j+1))/4
          yimax=ymax+delta_y*((x(i,j)-xmin)/(xmax-xmin))
          hc=yimax-yc
          syy(i,j)=-grav_si*den_tcw*hc
          sxx(i,j)=ko*syy(i,j)
          szz(i,j)=sxx(i,j)
         end_loop
       end_loop
 end
 geostres
 *
 fix x i=1
 fix x i=101
 fix y j=1
 *
 his unbal
 step 200
 sav mc1k3n_o.sav
 ini xdisp 0 ydisp 0
 his xdisp i 57 j 81
 his xdisp i 63 j 58
 his xdisp i 63 j 36
 his ydisp i 63 j 36
 his ydisp i 101 j 36
 m n reg 99 79
 CA BOLTING.DAT
 step 6000
 sav mc1k3n_s.sav
 *
 set gravity 13.92 15.11
 step 6000
 sav mc1k3n_d.sav
```

```
*
set gravity 9.81 0
step 6000
sav mc1k3ndr.sav
*
res mc1k3n_s.sav
set gravity 7.16 30.42
step 6000
sav mc1k3n_u.sav
*
set gravity 9.81 0
step 6000
sav mc1k3nur.sav
ret
```

```
************
*BOLT_2.FIS *
************

def bolt_2
  ib=ibb
  jb=jbb
  pn=prop_id
  ang=alph_b*2*pi/360
  xe=x(ib,jb) - blength*cos(ang)
  ye=y(ib,jb) - blength*sin(ang)
  command
    stru cable beg gr ib, jb end xe, ye seg 10 prop pn
  end_command
end
```

```
********************
*tcw_blt2.fis
********************
def tcw_blt2
grn_inst=int(grn_typ)
pn=prop_id
;
case_of grn_inst
;
```

```
case 1
;Williams Bolts on 1.5 m spacing
command
  stru prop pn a=0.439e-3 e=133.33e9 sbo=0.383e6 kbo=10.9e9 yield=178e3
end_command
;
case 2
; Williams Bolts on 1 m spacing
command
  stru prop pn a=0.439e-3 e=200.00e9 sbo=0.575e6 kbo=16.34e9 yield=267e3
end_command
;
case 3
; Williams Bolts on 1 m spacing + 100 mm shotcrete
command
  stru pn a=0.439e-3 e=200.00e9 sbo=0.575e6 kbo=16.34e9 yield=267e3
  stru beam beg gr 42 36 end gr 42 37 seg 1 prop 2
  stru beam beg gr 42 37 end gr 42 38 seg 1 prop 2
  stru beam beg gr 42 38 end gr 42 39 seg 1 prop 2
  stru beam beg gr 42 39 end gr 41 39 seg 1 prop 2
  stru beam beg gr 41 39 end gr 41 40 seg 1 prop 2
  stru beam beg gr 41 40 end gr 40 40 seg 1 prop 2
  stru beam beg gr 40 40 end gr 40 41 seg 1 prop 2
  stru beam beg gr 40 41 end gr 39 41 seg 1 prop 2
  stru beam beg gr 39 41 end gr 39 42 seg 1 prop 2
  stru beam beg gr 39 42 end gr 38 42 seg 1 prop 2
  stru beam beg gr 38 42 end gr 37 42 seg 1 prop 2
  stru beam beg gr 37 42 end gr 36 42 seg 1 prop 2
  stru beam beg gr 36 42 end gr 35 42 seg 1 prop 2
  stru beam beg gr 35 42 end gr 34 42 seg 1 prop 2
  stru beam beg gr 34 42 end gr 33 42 seg 1 prop 2
  stru beam beg gr 33 42 end gr 33 41 seg 1 prop 2
  stru beam beg gr 33 41 end gr 32 41 seg 1 prop 2
  stru beam beg gr 32 41 end gr 32 40 seg 1 prop 2
  stru beam beg gr 32 40 end gr 31 40 seg 1 prop 2
  stru beam beg gr 31 40 end gr 31 39 seg 1 prop 2
  stru beam beg gr 31 39 end gr 30 39 seg 1 prop 2
  stru beam beg gr 30 39 end gr 30 38 seg 1 prop 2
  stru beam beg gr 30 38 end gr 30 37 seg 1 prop 2
  stru beam beg gr 30 37 end gr 30 36 seg 1 prop 2
  stru beam beg gr 30 36 end gr 30 35 seg 1 prop 2
  stru beam beg gr 30 35 end gr 30 34 seg 1 prop 2
```

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  stru beam beg gr 30 34 end gr 30 33 seg 1 prop 2
  stru beam beg gr 30 33 end gr 31 33 seg 1 prop 2
  stru beam beg gr 31 33 end gr 31 32 seg 1 prop 2
  stru beam beg gr 31 32 end gr 32 32 seg 1 prop 2
  stru beam beg gr 32 32 end gr 32 31 seg 1 prop 2
  stru beam beg gr 32 31 end gr 33 31 seg 1 prop 2
  stru beam beg gr 33 31 end gr 33 30 seg 1 prop 2
  stru beam beg gr 33 30 end gr 34 30 seg 1 prop 2
  stru beam beg gr 34 30 end gr 35 30 seg 1 prop 2
  stru beam beg gr 35 30 end gr 36 30 seg 1 prop 2
  stru beam beg gr 36 30 end gr 37 30 seg 1 prop 2
  stru beam beg gr 37 30 end gr 38 30 seg 1 prop 2
  stru beam beg gr 38 30 end gr 39 30 seg 1 prop 2
  stru beam beg gr 39 30 end gr 39 31 seg 1 prop 2
  stru beam beg gr 39 31 end gr 40 31 seg 1 prop 2
  stru beam beg gr 40 31 end gr 40 32 seg 1 prop 2
  stru beam beg gr 40 32 end gr 41 32 seg 1 prop 2
  stru beam beg gr 41 32 end gr 41 33 seg 1 prop 2
  stru beam beg gr 41 33 end gr 42 33 seg 1 prop 2
  stru beam beg gr 42 33 end gr 42 34 seg 1 prop 2
  stru beam beg gr 42 34 end gr 42 35 seg 1 prop 2
  stru beam beg gr 42 35 end gr 42 36 seg 1 prop 2
  stru prop 3 a=0.10  e=27.58e9 i=8.3333e-5
end_command
;
case 4
; Williams Bolts on 1 m spacing + 50 mm shotcrete
command
  stru prop pn a=0.439e-3 e=200.00e9 sbo=0.575e6 kbo=16.34e9 yield=267e3
  stru beam beg gr 42 36 end gr 42 37 seg 1 prop 2
  stru beam beg gr 42 37 end gr 42 38 seg 1 prop 2
  stru beam beg gr 42 38 end gr 42 39 seg 1 prop 2
  stru beam beg gr 42 39 end gr 41 39 seg 1 prop 2
  stru beam beg gr 41 39 end gr 41 40 seg 1 prop 2
  stru beam beg gr 41 40 end gr 40 40 seg 1 prop 2
  stru beam beg gr 40 40 end gr 40 41 seg 1 prop 2
  stru beam beg gr 40 41 end gr 39 41 seg 1 prop 2
  stru beam beg gr 39 41 end gr 39 42 seg 1 prop 2
  stru beam beg gr 39 42 end gr 38 42 seg 1 prop 2
  stru beam beg gr 38 42 end gr 37 42 seg 1 prop 2
  stru beam beg gr 37 42 end gr 36 42 seg 1 prop 2
  stru beam beg gr 36 42 end gr 35 42 seg 1 prop 2
```

```
  stru beam beg gr 35 42 end gr 34 42 seg 1 prop 2
  stru beam beg gr 34 42 end gr 33 42 seg 1 prop 2
  stru beam beg gr 33 42 end gr 33 41 seg 1 prop 2
  stru beam beg gr 33 41 end gr 32 41 seg 1 prop 2
  stru beam beg gr 32 41 end gr 32 40 seg 1 prop 2
  stru beam beg gr 32 40 end gr 31 40 seg 1 prop 2
  stru beam beg gr 31 40 end gr 31 39 seg 1 prop 2
  stru beam beg gr 31 39 end gr 30 39 seg 1 prop 2
  stru beam beg gr 30 39 end gr 30 38 seg 1 prop 2
  stru beam beg gr 30 38 end gr 30 37 seg 1 prop 2
  stru beam beg gr 30 37 end gr 30 36 seg 1 prop 2
  stru beam beg gr 30 36 end gr 30 35 seg 1 prop 2
  stru beam beg gr 30 35 end gr 30 34 seg 1 prop 2
  stru beam beg gr 30 34 end gr 30 33 seg 1 prop 2
  stru beam beg gr 30 33 end gr 31 33 seg 1 prop 2
  stru beam beg gr 31 33 end gr 31 32 seg 1 prop 2
  stru beam beg gr 31 32 end gr 32 32 seg 1 prop 2
  stru beam beg gr 32 32 end gr 32 31 seg 1 prop 2
  stru beam beg gr 32 31 end gr 33 31 seg 1 prop 2
  stru beam beg gr 33 31 end gr 33 30 seg 1 prop 2
  stru beam beg gr 33 30 end gr 34 30 seg 1 prop 2
  stru beam beg gr 34 30 end gr 35 30 seg 1 prop 2
  stru beam beg gr 35 30 end gr 36 30 seg 1 prop 2
  stru beam beg gr 36 30 end gr 37 30 seg 1 prop 2
  stru beam beg gr 37 30 end gr 38 30 seg 1 prop 2
  stru beam beg gr 38 30 end gr 39 30 seg 1 prop 2
  stru beam beg gr 39 30 end gr 39 31 seg 1 prop 2
  stru beam beg gr 39 31 end gr 40 31 seg 1 prop 2
  stru beam beg gr 40 31 end gr 40 32 seg 1 prop 2
  stru beam beg gr 40 32 end gr 41 32 seg 1 prop 2
  stru beam beg gr 41 32 end gr 41 33 seg 1 prop 2
  stru beam beg gr 41 33 end gr 42 33 seg 1 prop 2
  stru beam beg gr 42 33 end gr 42 34 seg 1 prop 2
  stru beam beg gr 42 34 end gr 42 35 seg 1 prop 2
  stru beam beg gr 42 35 end gr 42 36 seg 1 prop 2
  stru prop 3 a=0.05  e=27.58e9 i=1.042e-5
end_command
;
case 5
; Swellex Bolt on 1 m spacing
command
  struc prop pn e 200e9 yield 110e3 a 2.58e-4  sbond 7.33e4 kbond 7.33e8
```

```
end_command
;
case 6
; Swellex Bolts on 1.5 m spacing
command
  struc prop pn e 133e9 yield 73.3e3 a 2.58e-4  sbond 4.87e4 kbond 4.87e8
end_command
end_case
end
```

```
****************
* "BOLTING.DAT"*
****************
call bolt_2.fis
call tcw_blt2.fis
* The following three lines install one bolt.
set grn_typ=6 prop_id=1 ibb=63 jbb=56 alph_b=0 blength=3
bolt_2
tcw_blt2
set grn_typ=6 prop_id=1 ibb=61 jbb=64 alph_b=0 blength=3
bolt_2
tcw_blt2
set grn_typ=6 prop_id=1 ibb=60 jbb=68 alph_b=0 blength=3
bolt_2
tcw_blt2
set grn_typ=6 prop_id=1 ibb=59 jbb=72 alph_b=0 blength=3
bolt_2
tcw_blt2
set grn_typ=6 prop_id=1 ibb=58 jbb=76 alph_b=0 blength=3
bolt_2
tcw_blt2
set grn_typ=2 prop_id=2 ibb=63 jbb=58 alph_b=0 blength=6
bolt_2
tcw_blt2
set grn_typ=2 prop_id=2 ibb=62 jbb=61 alph_b=0 blength=6
bolt_2
tcw_blt2
```