0039

United States Department of the Interior

BUREAU OF MINES

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DENVER, COLORADO 80225

May 15, 1989

David R. Smaldone
Director Permitting, Compliance & Services
Mining Division
Utah Power & Light Company
41 North Redwood Road
Salt Lake City, UT 84140

Dear Dave:

Enclosed is a draft copy of a description of the work conducted by the Bureau of Mines, Denver Research Center relative to the escarpment stability study.

Please note that the results of this investigation are preliminary, and are subject to further review. Additional research is needed before any valid conclusions on the behavior of escarpments subjected to underground coal mining can be drawn.

If you have any questions about the report, please do not hesitate to call me at (303) 236-0720.

Sincerely,

Frederick K. Allgaier

Frederick K. Allgaier

Enclosure
cc: R. DeCesare, WO

CASTLEGATE ESCARPMENT STABILITY STUDY

INTRODUCTION

This status report discusses preliminary numerical modeling results conducted by the Bureau of Mines, Denver Research Center (DRC) as part of the Castlegate escarpment stability study. The specific study area in question is the south lease of the Cottonwood Mine near Huntington, Utah. The mine is owned and operated by the Utah Power & Light Company.

The objective of this status report is to illustrate the capabilities of two unique numerical modeling techniques, namely the boundary element and discrete element methods, in predicting, comparing, and assessing the effects of mining beneath the Castlegate sandstone escarpments.

A series of two dimensional cross sections were modeled using the BESOL/P5005 boundary element computer code to compute the stresses and displacements induced near the escarpments as a result of mining the underlying Hiawatha coal seam. Initial work has also begun using the MUDEC discrete element code. The main distinction between these two methods of analysis is that the boundary element method assumes the rock mass acts as a continuum while the discrete element method treats the rock mass as a highly jointed and fractured discontinuum. The discrete element method can also simulate large displacements and rotations of individual blocks of rock created as a result of failure along the escarpments caused by mining the underlying coal seam. It must be emphasized that the results of this analysis are preliminary, as approximate material parameters were used for the rock mass and the Mohr-Coulomb failure criterion. Drilling and laboratory testing were still being conducted at the time of the analysis. In addition, no comparisons have yet been made between the numerical modeling results and actual field observations and measurements.

BACKGROUND

In general terms, escarpments are simply the outcropping of massive sedimentary layers. These "cliffs" are usually well weathered sandstones, such as the massive Castlegate Sandstone found in south-central Utah.

The environmental impacts of mining under escarpments is rapidly becoming a major concern in the western United States. As an escarpment is undermined, the resulting subsidence induced by the mining causes large blocks of material to fail along existing joint planes and slide or topple down to the talus slope below. This can result in damage to wildlife nesting and breeding sites, destruction of vegetation, and poses a threat to any proximal man-made structures such as power lines, water lines, bridges, buildings, and roads.

As a result of this potential damage, increasingly strict stipulations are forcing western coal mine operators to assess the effects of mining beneath escarpments and develop mining practices to minimize the environmental damage. This status report introduces two numerical procedures that can be used as tools towards accomplishing this goal.

BOUNDARY ELEMENT ANALYSIS

The boundary element method is similar to that of the finite element method in that the region of interest being modeled, i.e. a rock mass, is treated as a continuum. The two methods differ in that the boundary element approach requires discretization only along the boundary of the problem, for example the surface of an excavation. The two-dimensional computer program BESOL/P5005 was used for this analysis. This program computes the stresses, strains, and displacements induced within a rock mass as a result of mining.

The particular geologic region that can be modeled with the program consists of two isotropic, linearly elastic half-planes bonded together along an inclined interface. In the case of the escarpment analysis, this interface was taken to lie between the Castlegate Sandstone and the Blackhawk Formation, and is assumed to be horizontal. No boundary elements are needed along this boundary, since the continuity conditions between the two materials is satisfied automatically within the program.

Figure 1 shows the physical escarpment problem being analyzed along with the corresponding boundary element model. Displacement discontinuity boundary elements were placed along the slope and escarpment regions and prescribed zero normal and shear stresses. Displacement discontinuity elements were also placed along the top surface of the Castlegate Sandstone and prescribed varying normal stresses equivalent to the overburden pressure supplied by the Price River Formation. The reason for this is that BESOL/P5005 can only model two distinct rock mass materials, one on either side of the horizontal interface. Since the analysis was primarily focused on the stablity of the Castlegate Sandstone as a result of undermining, the Price River Formation could be treated as a varying dead weight load.

Finally, displacement discontinuity elements were placed along the Hiawatha coal seam. These elements were given a thickness of 10 feet and normal and shear stiffnesses of 2.0E4 and 7.69E3 psi/ft, respectively, to represent the coal seam. Figure 1 shows the remaining rock mass properties used for this analysis. In situ stresses were generated by gravity loading alone.

Figures 2-5 show the results of a boundary element analysis of cross section A located in the south lease area (Newberry Canyon) of the Cottonwood Mine. Figures 2 and 3 show plots of principal stress vectors and failure indices as a result of mining the 6th East longwall panel. One can see from Figure 2, high tensile stresses immediately above and below the mined panel. Since rock is very weak in tension, this would indicate a large amount of fracturing perpendicular to the tensile stress directions and subsequent caving. A compression arch is formed well above the coal seam beyond which no tensile stresses or caving exists, even in the vicinity of the escarpment. One would not expect rock fracturing in this area. However, this analysis did not take into account joints, common in the vicinity of the escarpment. A small amount of subsidence could affect the stability of blocks formed by joints in this area. Figures 4 and 5 again show plots of principal stress vectors and failure indices as a result of mining the adjacent 7th East longwall panel. It is evident that the zone of tensile stress now extends all the way up through the Castlegate Sandstone. If these tensile stresses were to exceed the rock strength, subvertical fractures would form and most likely extend to the surface. The escarpment itself is also subjected to tensile stresses as a result of mining this 7th East panel, indicating potential instability.

Similar boundary element analyses were conducted for cross sections C, E, and F, and plots are shown in Appendix A. No attempt was made to predict the escarpment behavior from future mining of the 8th and 9th East longwall panels, represented by cross sections E and F. There are a number of reasons for this. First, adequate rock and joint material properties were not yet available at the time of this analysis. Observations have also not yet been performed of the escarpments and the effects of mining. Finally, it must be established how accurately the boundary element results from cross sections A and C represent actual field conditions as a result of mining the 6th and 7th East panels before predictions on future mining can be made.

DISCRETE ELEMENT ANALYSIS

Rock masses in nature are associated with joints and cracks, which greatly influence the behavior of rock masses. In some cases the joint properties govern the physical properties of rock masses.

The distinct (discrete) element method, in recent years, has been widely used for simulating behavior of jointed rock masses. For this approach, the rock mass is considered as an assemblage of blocks, and discontinuities are regarded as boundary interactions between these blocks. This type of modeling is especially effective for simulating mine subsidence and rock slope stability.

The discrete element method is a proper technique for the escarpment stability study, because the nature of the study involves both subsidence and slope stability problems.

Two distinct element programs are currently available at DRC. One of them is the two dimensional micro-computer code (MUDEC), and the other is the two and three dimensional computer code (DECICE). For the preliminary study both programs were utilized, and some encouraging results were produced.

The discrete element models were constructed based on the reports by Utah Power & Light Co. (UP&L) and Seegmiller (1987). As shown in Figure 6, the model is composed of four layers. Above the coal seam, the Blackhawk Formation, Castlegate Sandstone, and Price River Formation are overlain in sequence. This model was made for simulating the worst possible condition.

In this case, the slope angle of the Castlegate Sandstone layer is 90 degrees, and the layer is composed of frequent vertical joints with varying joint intervals of 10 to 50 feet. In the middle of the layer, there is a mudstone (shale) layer, which plays an important role in the stability of the cliff at the study area. The Blackhawk Formation has vertical and horizontal cracks creating two dimensional rectangular blocks. A portion of the coal seam underlying this formation in mined out.

Figures 7 - 9 show the sequential movement of the sandstone blocks along the vertical slope and the subsidence movement above the excavated coal seam in the overburden layers. This agrees with the failure mode of the cliff (Figure 10) suggested by UP&L (1987).

The results seem to be realistic, but it has to be noted that the physical properties of the material and joints were only assumed because they were not yet available. Also, joint patterns and slope conditions are not clearly known. Therefore the results of this preliminary study are not definitive. One important result is that the capability of the discrete element method for this type of analysis is clearly demonstrated.

CONCLUSIONS AND RECOMMENDATIONS

The Bureau of Mines, Denver Research Center, conducted a preliminary study to demonstrate the use of numerical modeling procedures in assessing the effects of slope instability resulting from mining beneath escarpments. This represents a problem of great interest and importance to many western coal operators seeking to attain mining permits and satisfy increasingly strict state and federal environmental regulations.

The boundary element method is limited to continuum analysis; however, it can still provide useful qualitative information on the trends of expected principal stress magnitudes and direction associated with various stages of seam extraction. The discrete element method is capable of simulating the actual rock movement and large-scale displacement associated with escarpment failure. Quantitative values for predicted stresses and displacements are only limited by the input data, such as material properties and joint conditions.

At this stage of the project, it is extremely risky to predict the behavior of the escarpment or interpret the failures that have been occurred without further analysis and study. In order to achieve the goal of this study, the following recommendations are provided:

1. No single numerical method will solve all the problems associated with this project. The Bureau of Mines, Denver Research Center, has begun applying the boundary element and discrete element methods in the escarpment study, while the University of Utah is utilizing the finite element method. Further escarpment stability analyses should continue using these three numerical techniques, along with an effort to correlate results between them.

2. The model study must be accompanied by field monitoring for refinement and verification. A careful field monitoring

program of subsidence and slope movement is urgently needed.

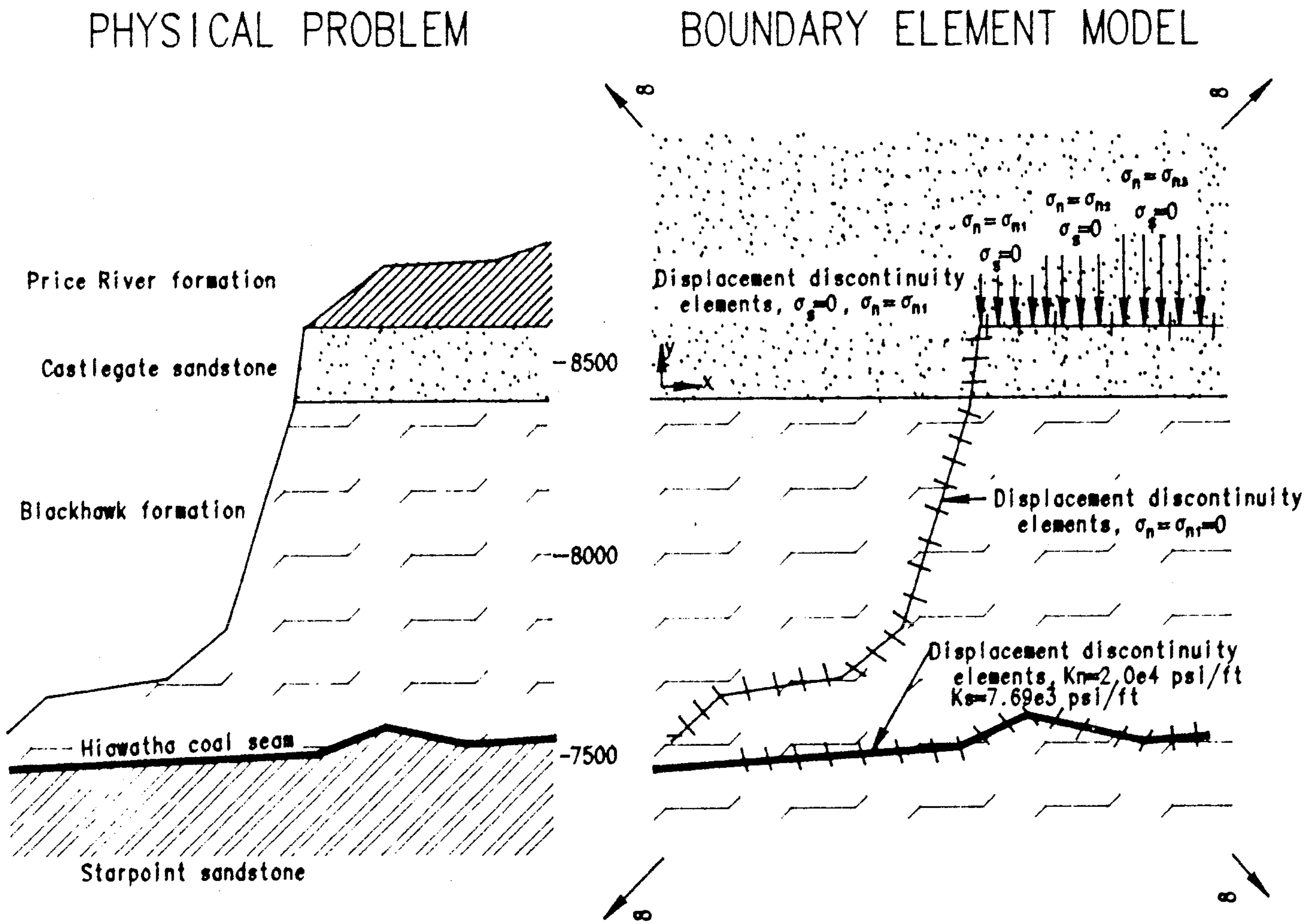
3. Detailed geologic investigations should continue at the site of modeling to provide accurate input geometries for the numerical models.

4. A thorough rock and rock joint property testing program is recommended to provide accurate geomechanical parameters for input into the numerical models.

REFERENCES

1. Utah Power & Light Co., Mining Division, 1987, "Castlegate Sandstone Cliff Stability," November.

2. Seegmiller, B. L., 1987, "Surface Stability Evaluation, 6E/7E and 9E/10E Panels, Cottonwood Mine," submitted to UP&L, November.



	Rock properties		Mohr-Coulomb failure parameters		
Formation	E(psi)	ν	To(psi)	Co(psi)	θ
Castlegate sandstone	7.2E6	0.22	500.0	1500.0	30°
Blackhawk formation	3.5E6	0.25	500.0	1500.0	30°
Hiawatha coal seam	2.0E6	0.30	—	—	

E Young's modulus

ν Poisson's ratio

To Uniaxial tensile strength

Co Cohesion

θ Angle of interial friction

9-300

Figure 1 Boundary Element Model

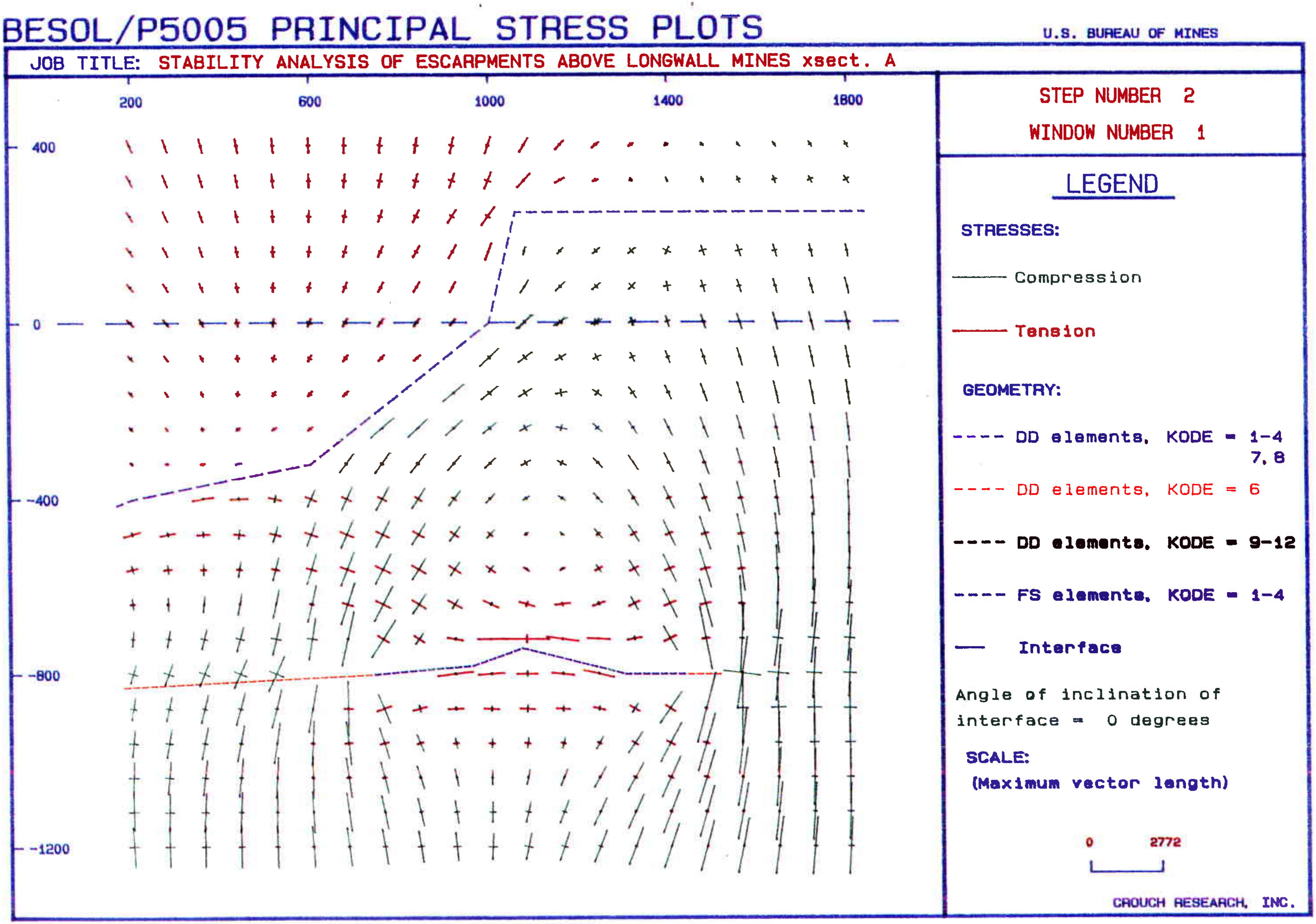


Figure 2 Principal Stress Plot (Step 2)

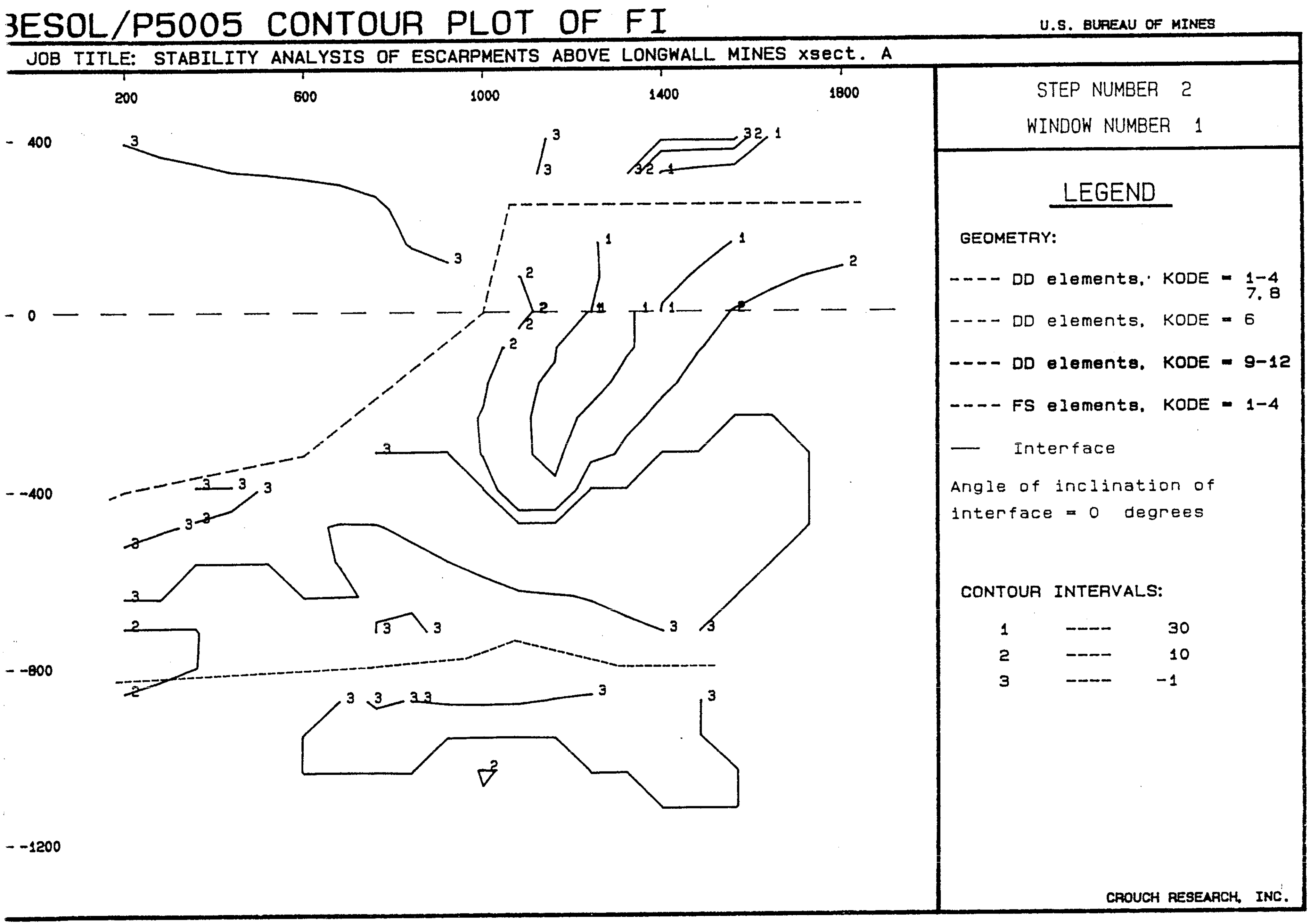
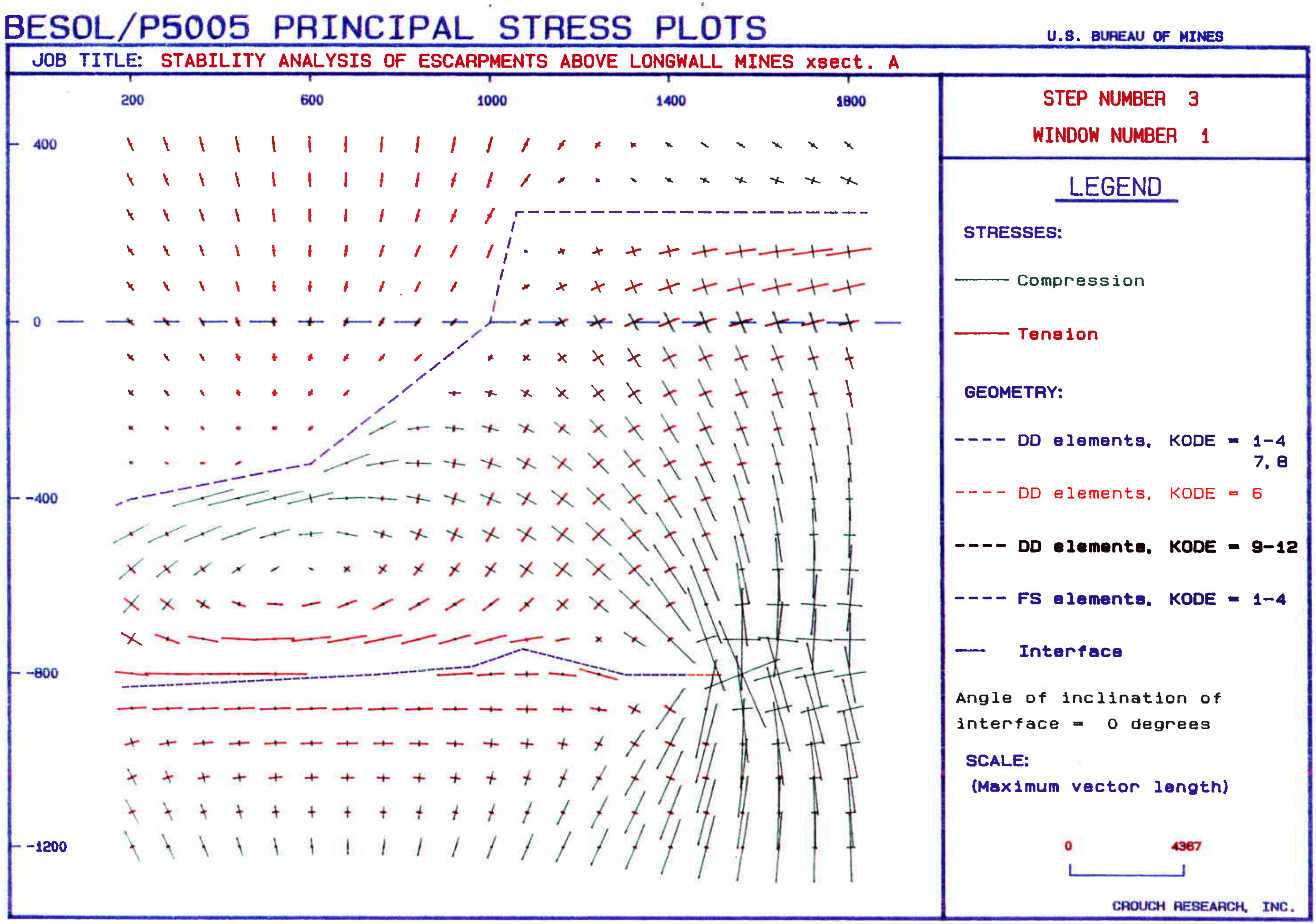


Figure 3 Failure Index Plot (Step 2)



2

Figure 4 Principal Stress Plot (Step 3)

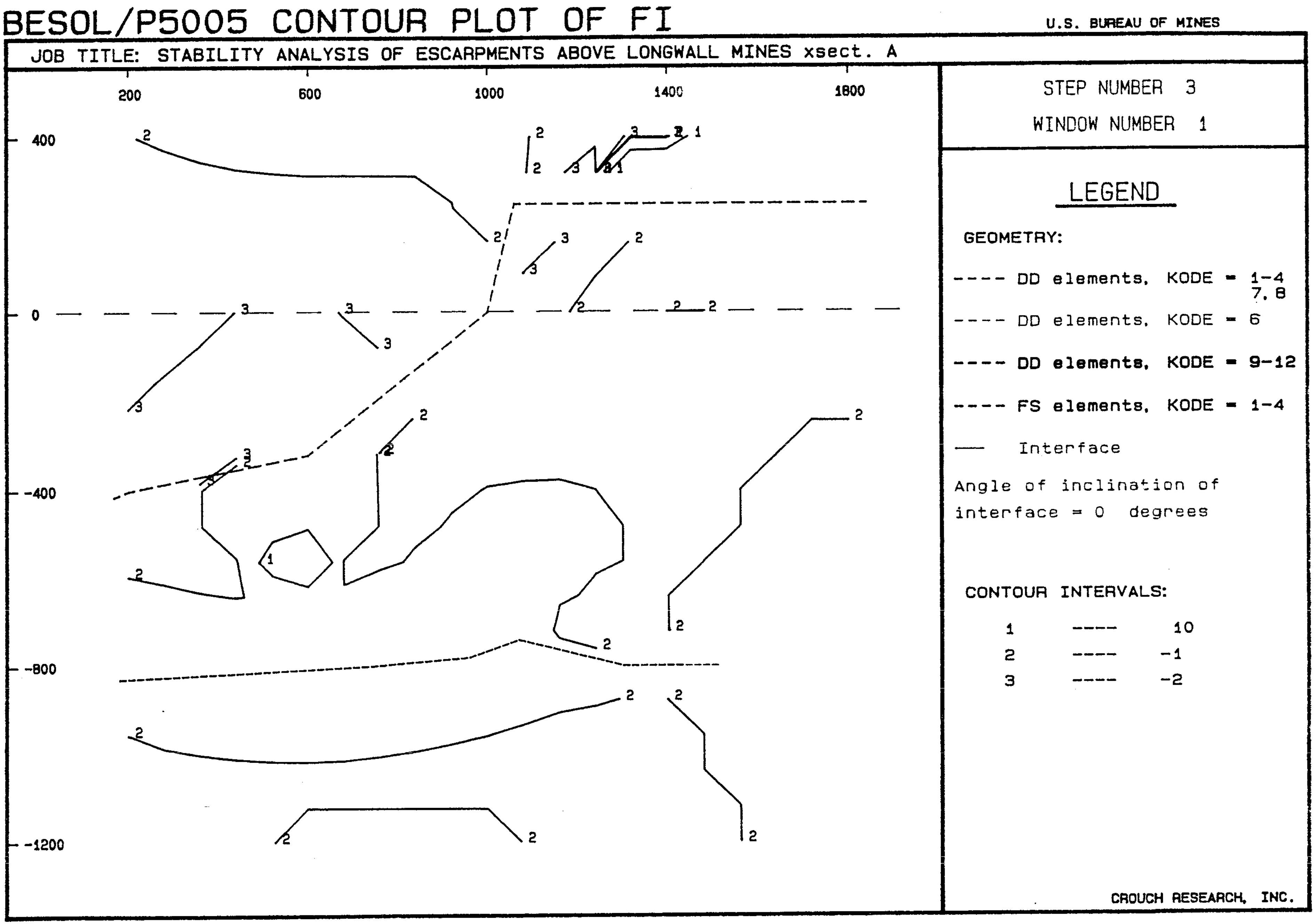


Figure 5 Failure Index Plot (Step 3)

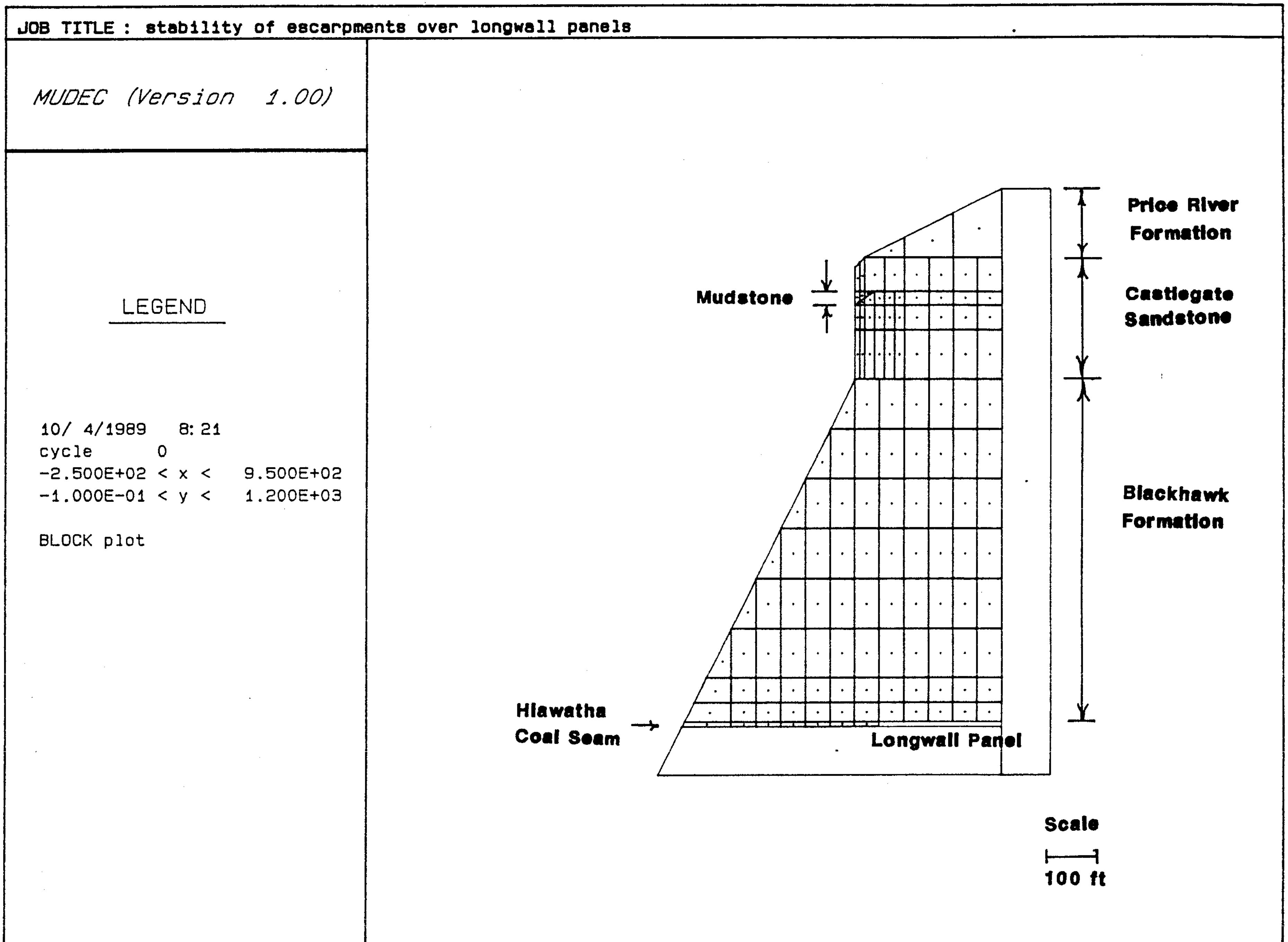


Figure 6 Discrete Element Model

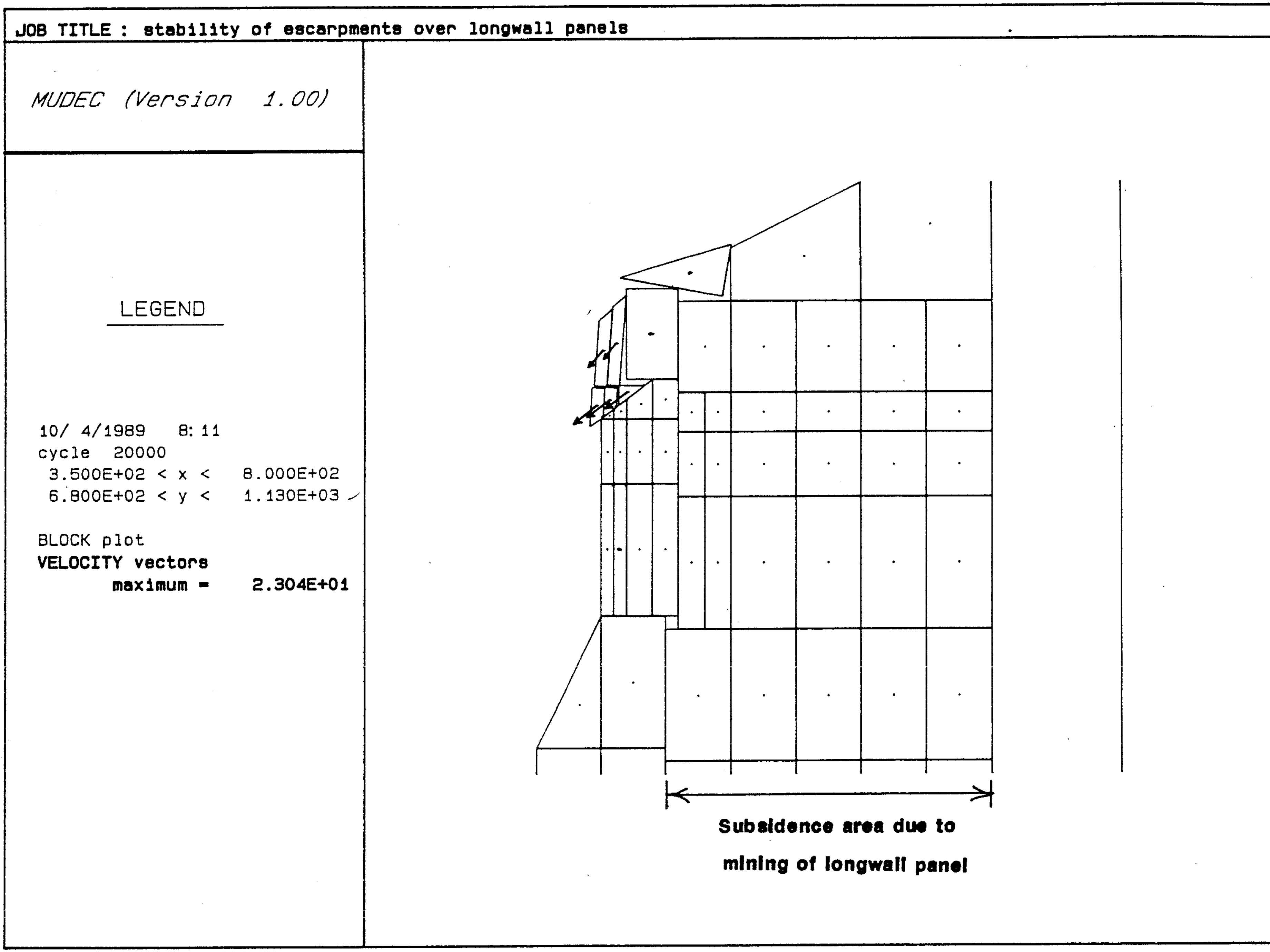


Figure 7 Sequential Slope Failure – Step 1

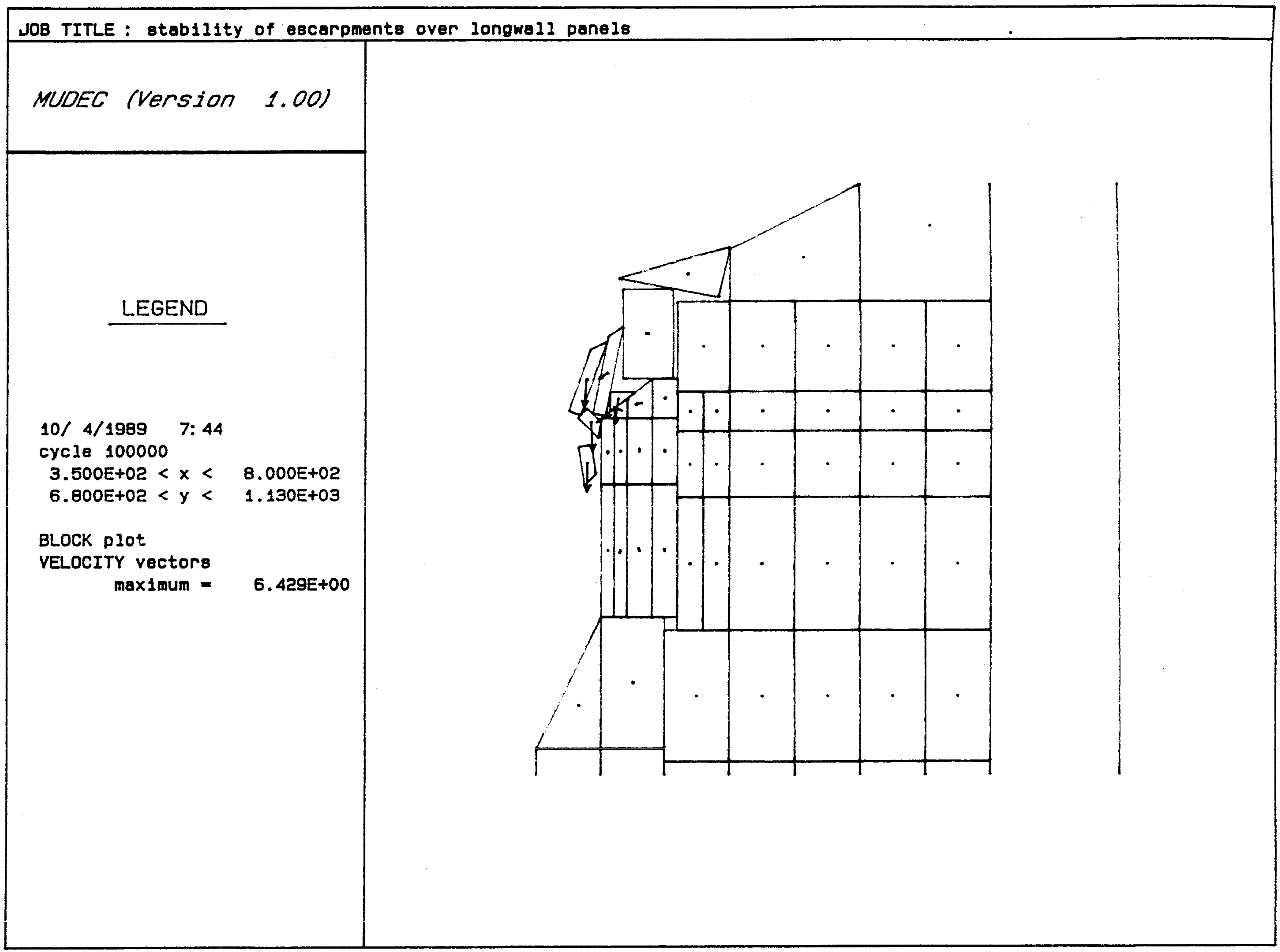


Figure 8 Sequential Slope Failure - Step 2

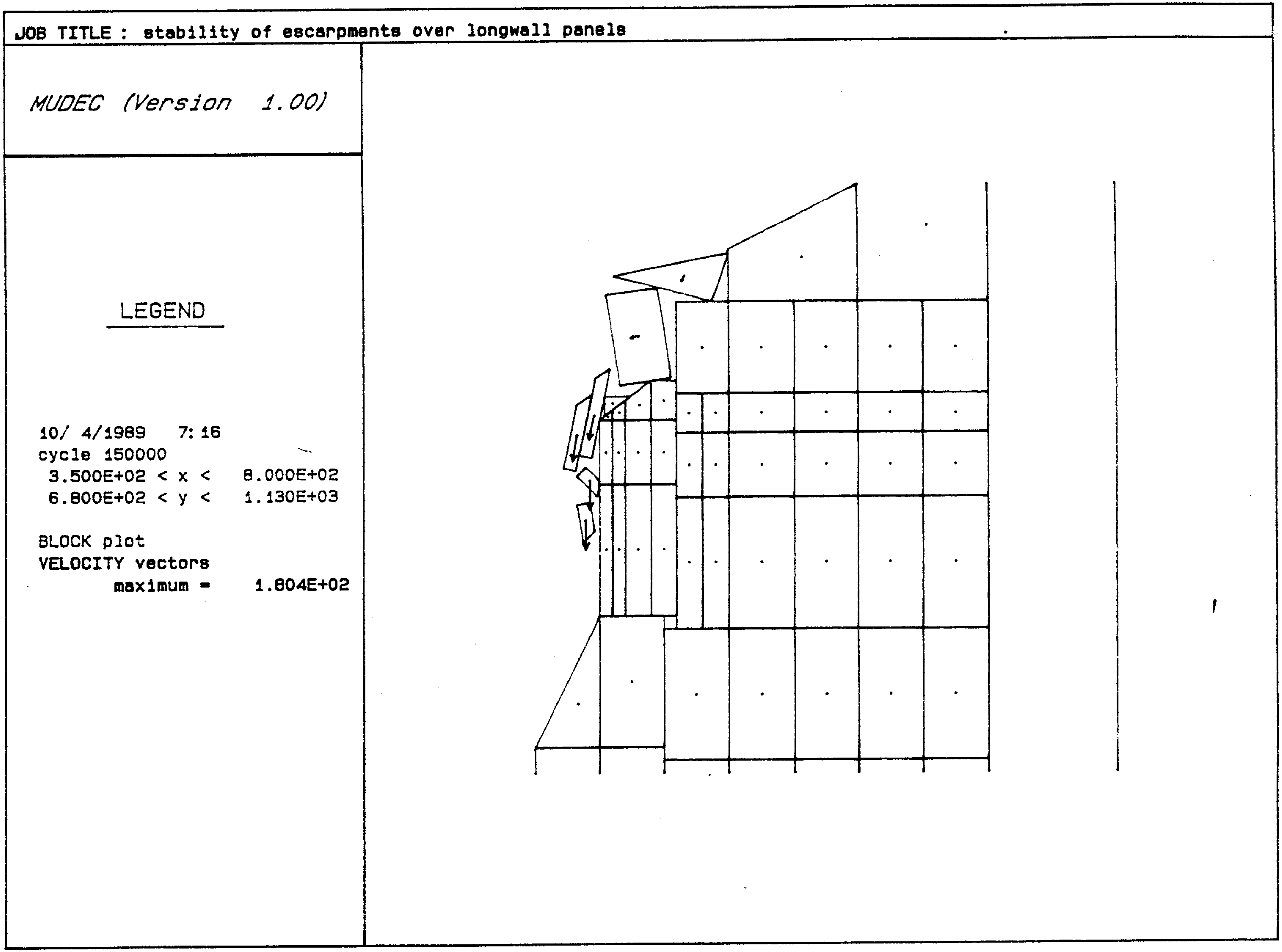
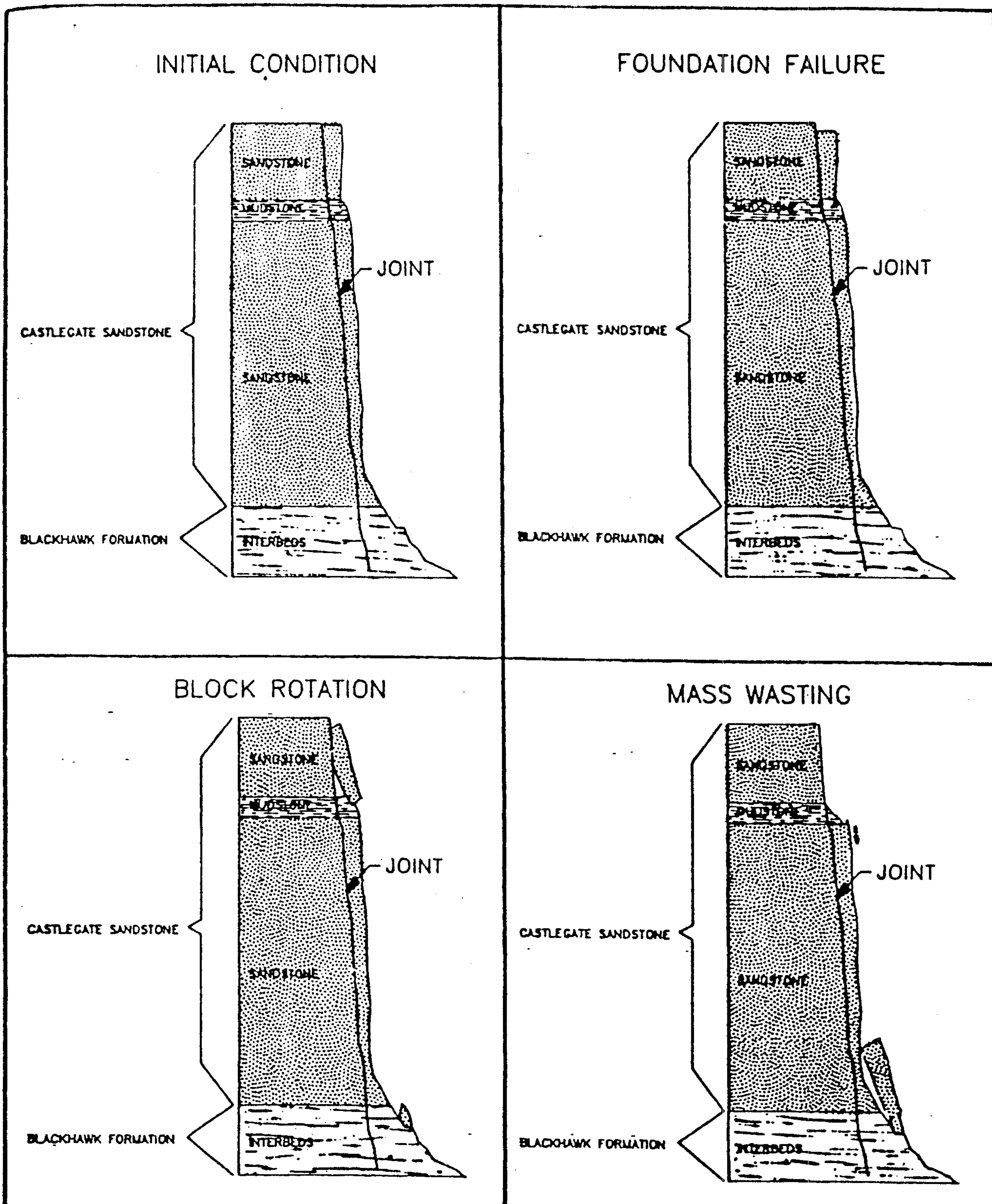


Figure 9 Sequential Slope Failure – Step 3

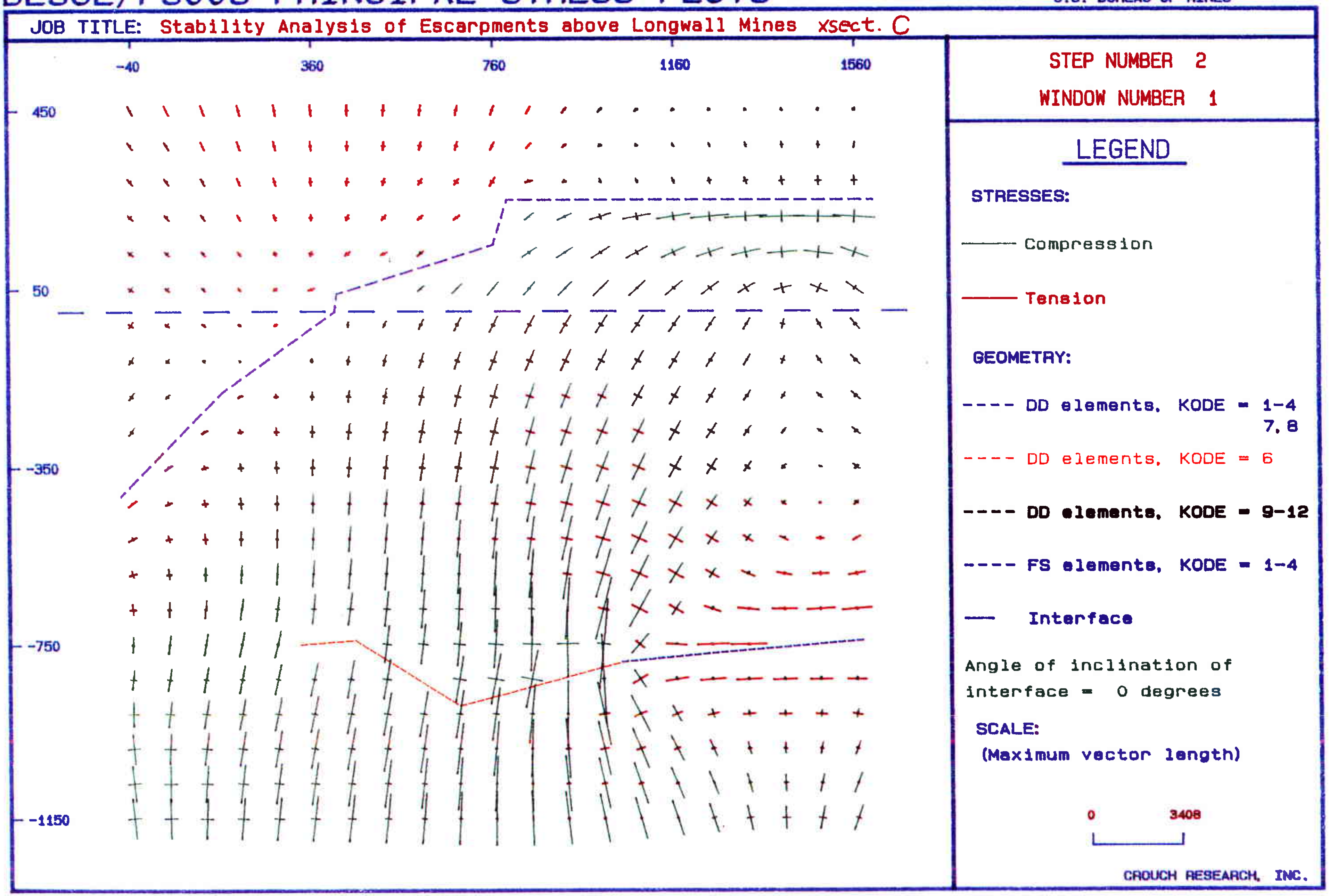


CASTLEGATE SANDSTONE CLIFF FAILURE

Fig. 10 (UP&L, 1987)

APPENDIX A

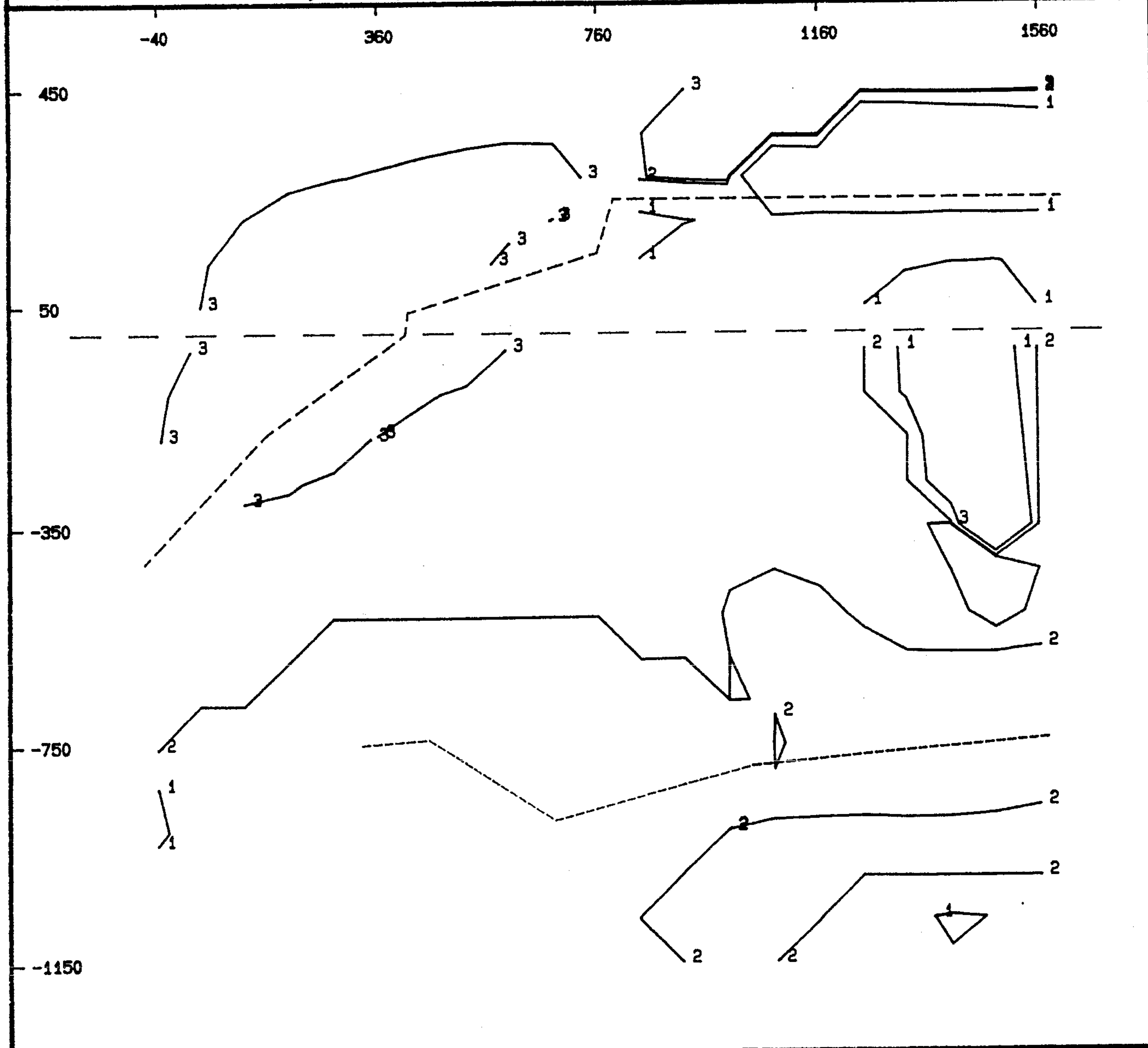
BESOL/P5005 PRINCIPAL STRESS PLOTS



BESOL/P5005 CONTOUR PLOT OF FI

U.S. BUREAU OF MINES

JOB TITLE: Stability Analysis of Escarpments above Longwall Mines xsect. C



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4, 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	10
2	----	-1
3	----	-2

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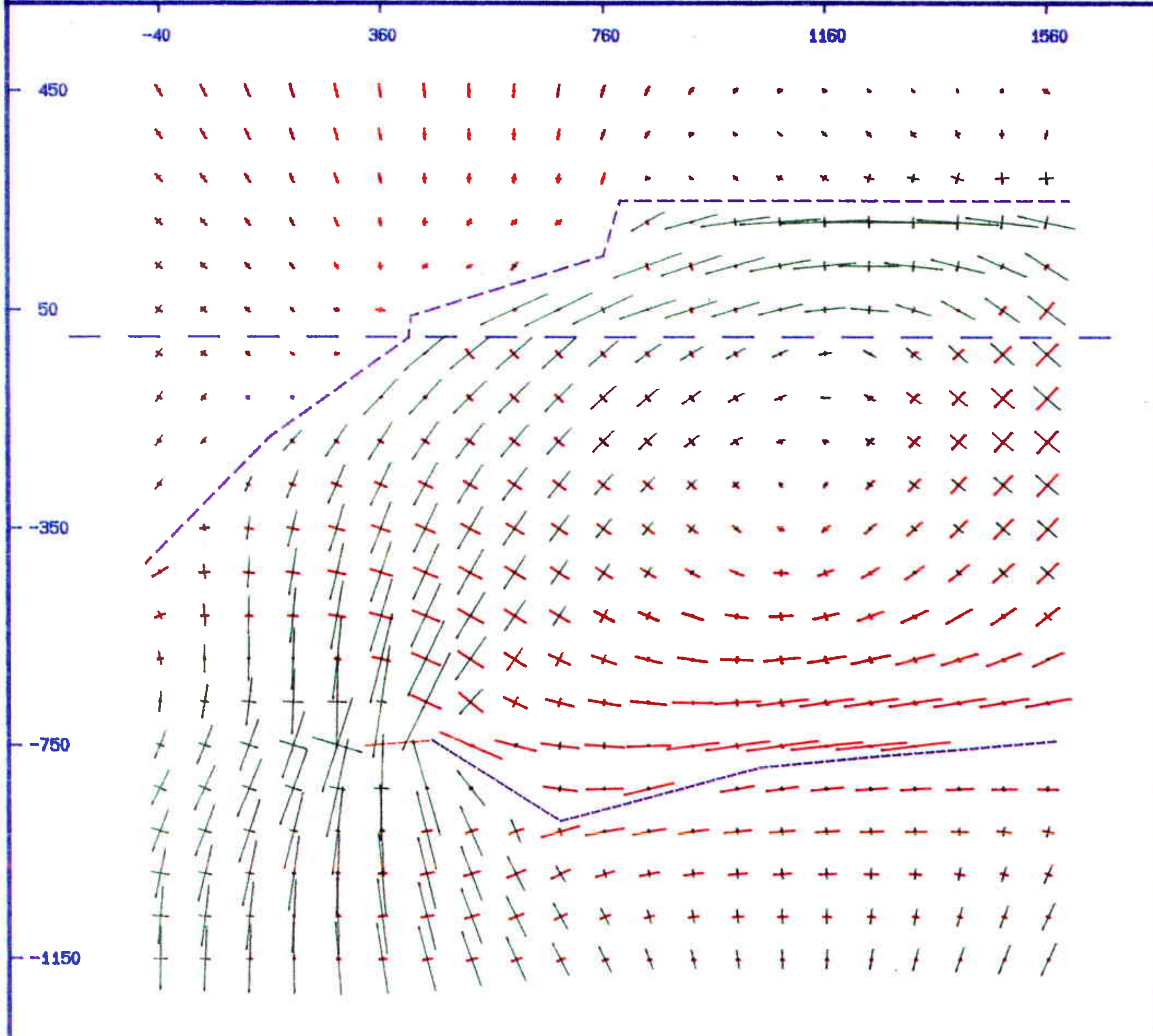
BESOL/P5005 PRINCIPAL STRESS PLOTS

U.S. BUREAU OF MINES

JOB TITLE: Stability Analysis of Escarpments above Longwall Mines xSect. C



STEP NUMBER 3

WINDOW NUMBER 1

LEGEND

STRESSES:

Compression

Tension

GEOMETRY:

---- DD elements, KODE = 1-4 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

— Interface

Angle of inclination of interface = 0 degrees

SCALE:
(Maximum vector length)

0 3459

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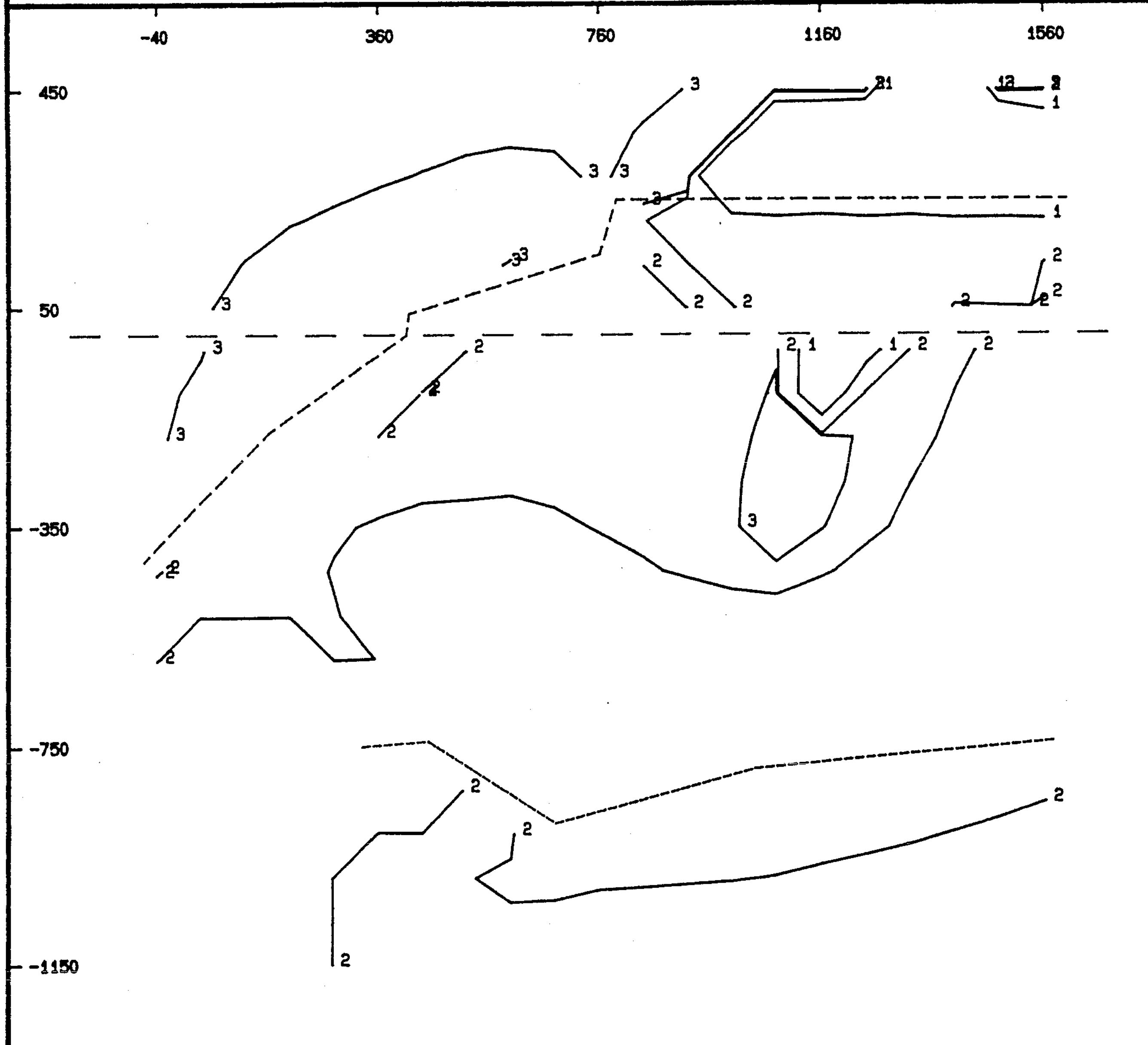
4

BESOL/P5005 CONTOUR PLOT OF FI

U.S. BUREAU OF MINES

JOB TITLE: Stability Analysis of Escarpments above Longwall Mines xsect. C



STEP NUMBER 3

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4
7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	10
2	----	-1
3	----	-2

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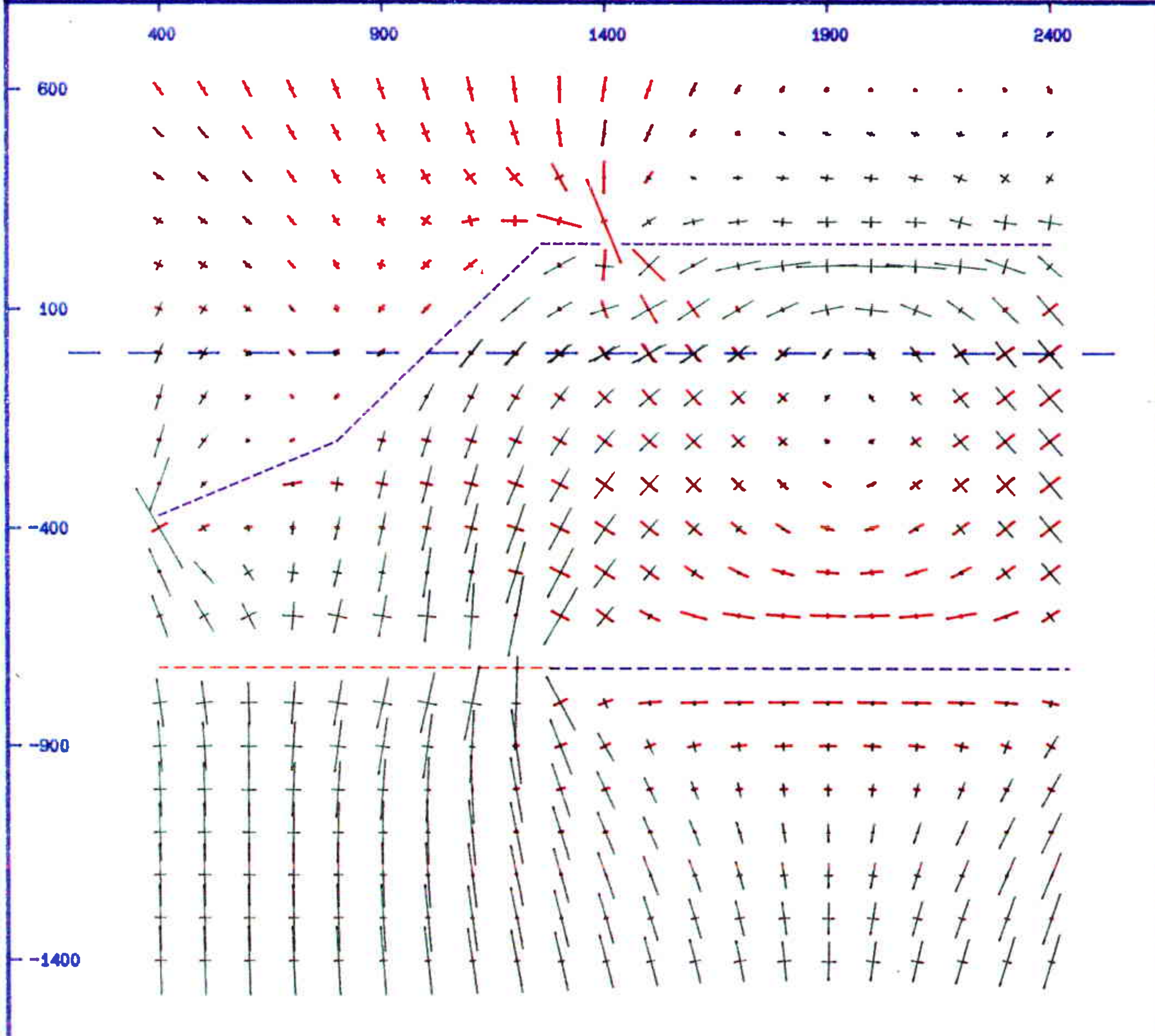
4

BESOL/P5005 PRINCIPAL STRESS PLOTS

U.S. BUREAU OF MINES

JOB TITLE: Stability Analysis of Escarpments above Longwall Mines   Xsect. E



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

STRESSES:

——— Compression

——— Tension

GEOMETRY:

---- DD elements, KODE = 1-4, 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

—— Interface

Angle of inclination of interface = 0 degrees

SCALE: (Maximum vector length)

0 3073

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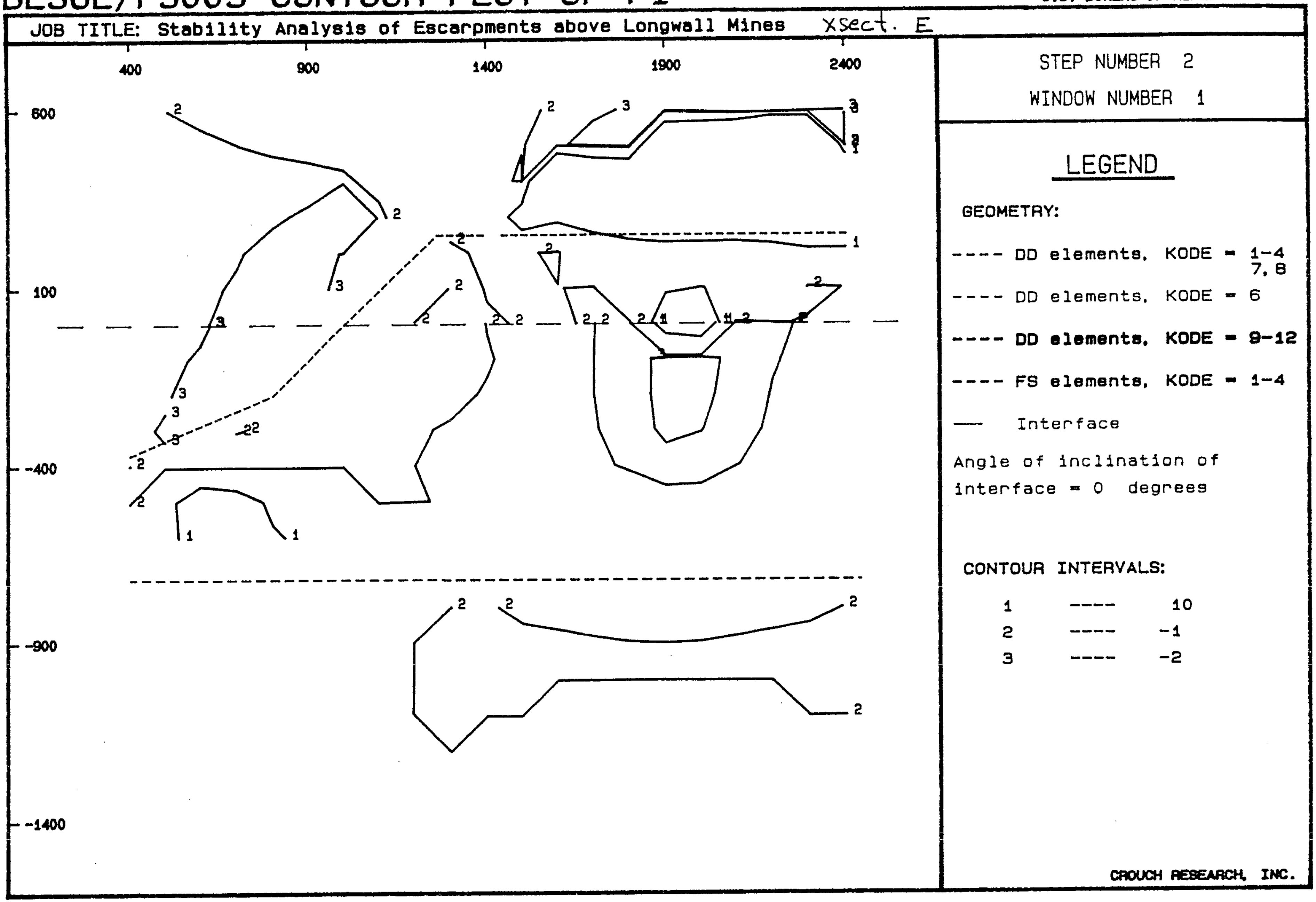
5

BESOL/P5005 CONTOUR PLOT OF FI

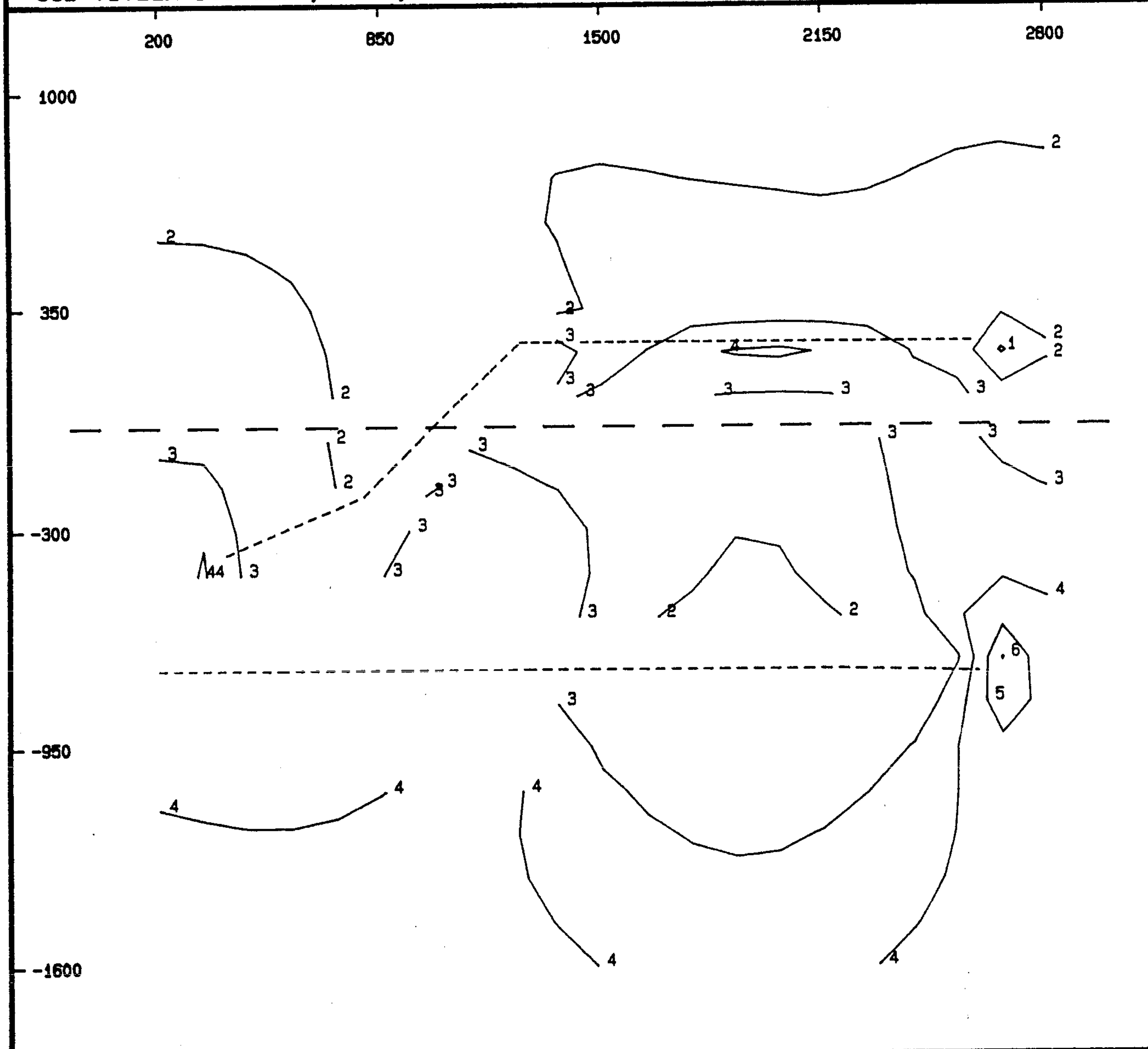
U.S. BUREAU OF MINES



BESOL/P5005 CONTOUR PLOT OF S1

U.S. BUREAU OF MINES

JOB TITLE: Stability Analysis of Escarpments above Longwall Mines   Xsect. E



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	-1000
2	----	0
3	----	1000
4	----	2000
5	----	3000
6	----	4000

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BESOL/P5005 CONTOUR PLOT OF S2

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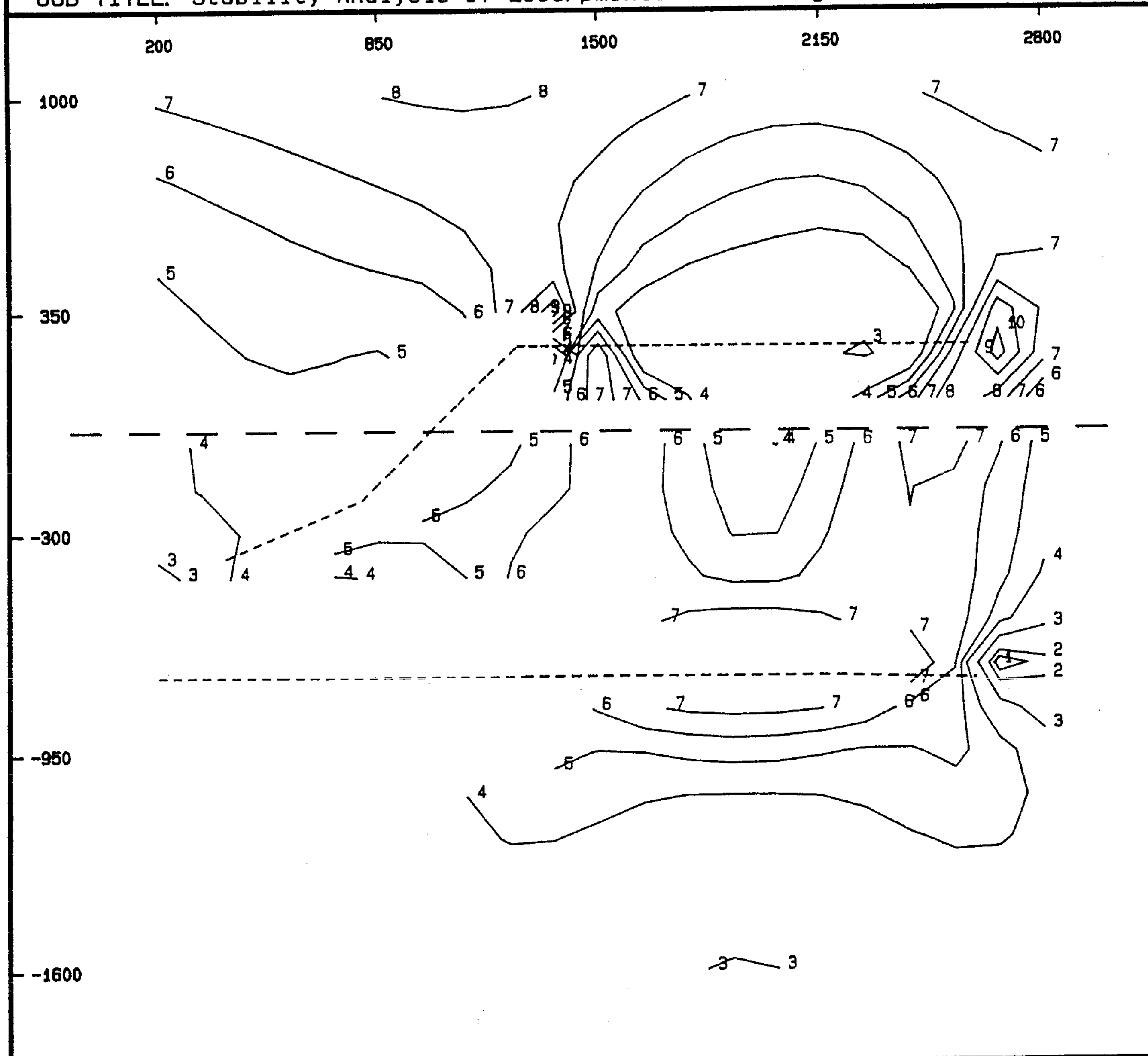
JOB TITLE: Stability Analysis of Escarpments above Longwall Mines xsect. E



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4, 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	1250
2	----	1000
3	----	500
4	----	0
5	----	-250
6	----	-500
7	----	-750
8	----	-1000
9	----	-1250
10	----	-1500

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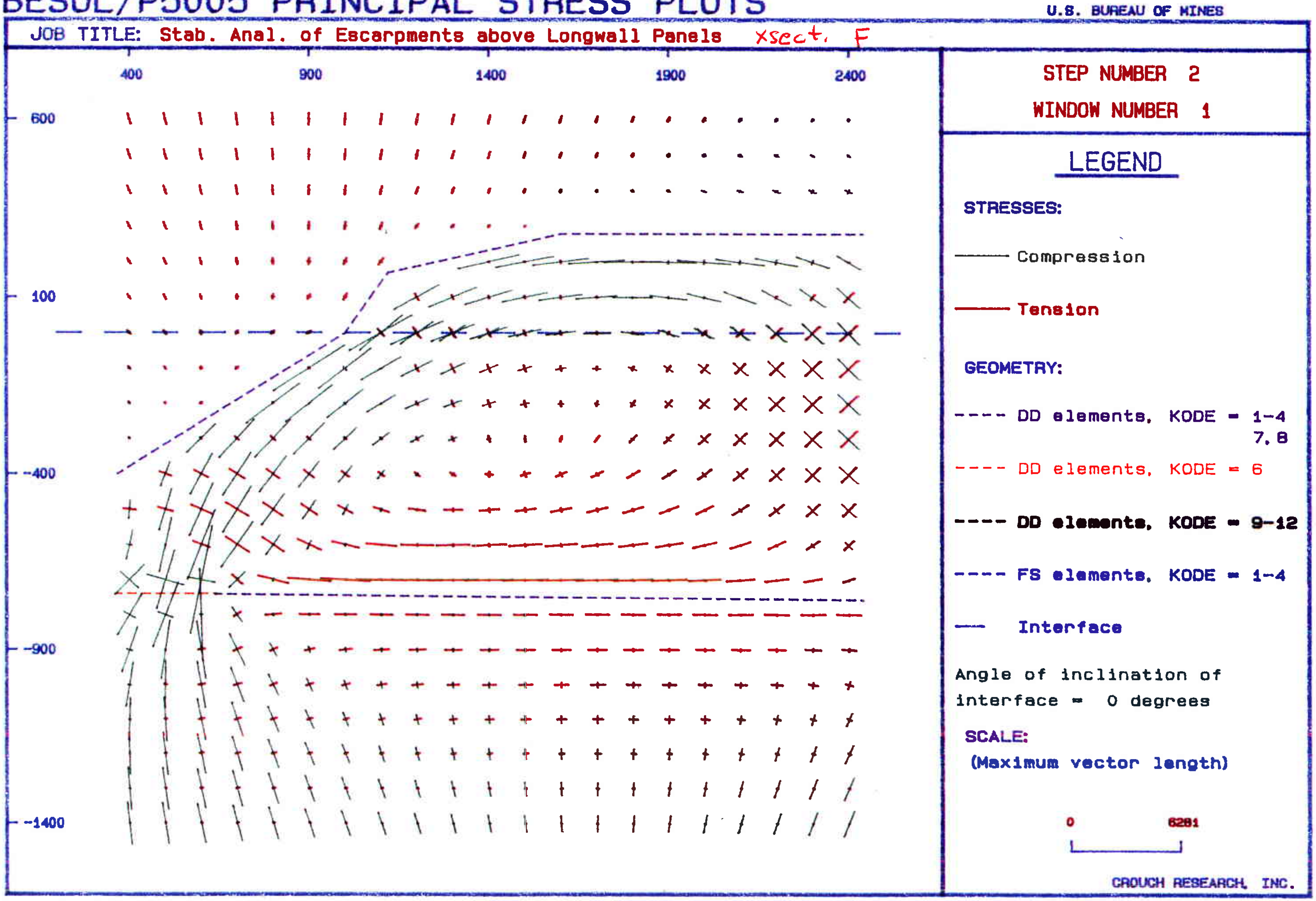
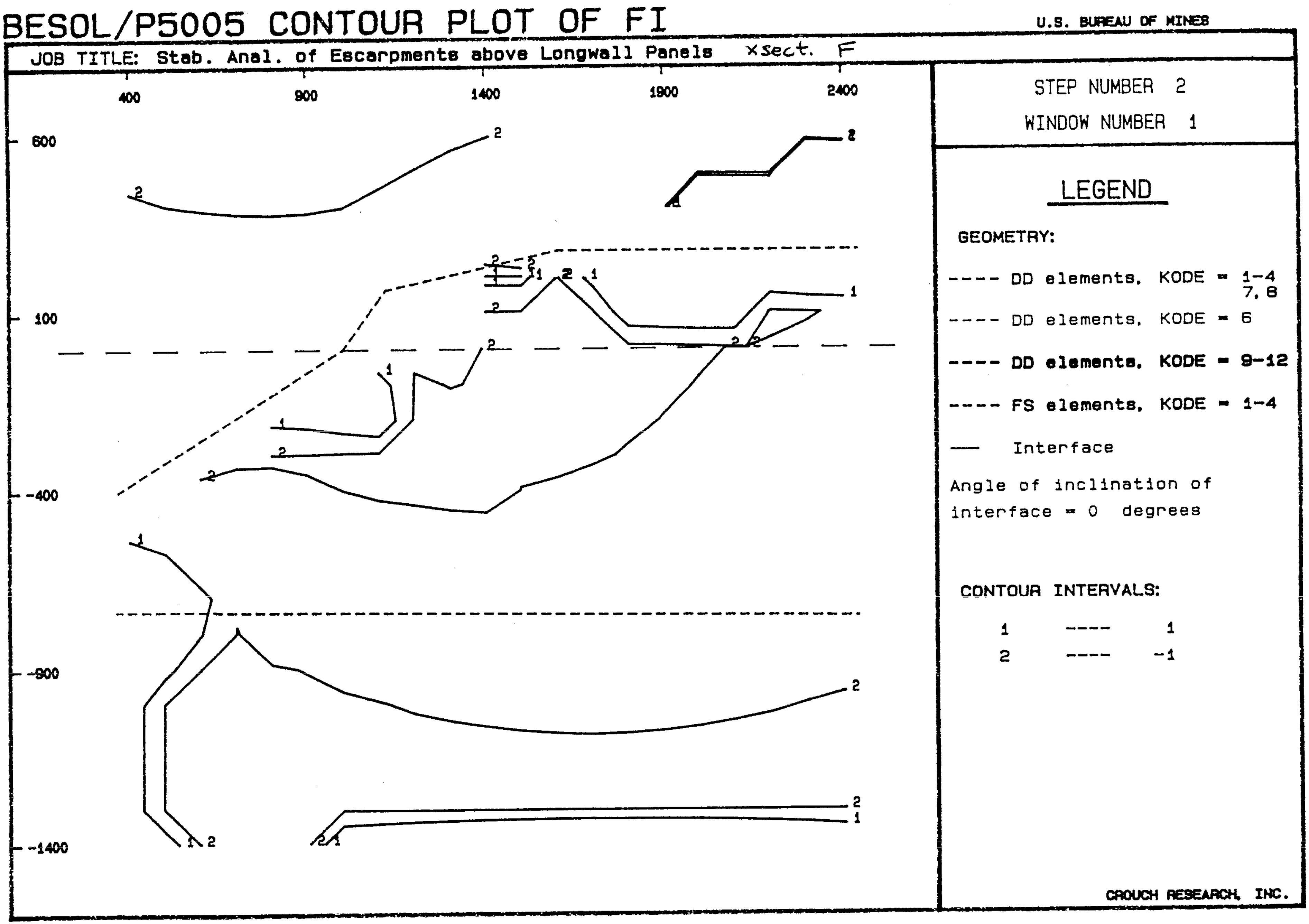
BESOL/P5005 PRINCIPAL STRESS PLOTS




BESOL/P5005 CONTOUR PLOT OF FI
U.S. BUREAU OF MINES
JOB TITLE: Stab. Anal. of Escarpments above Longwall Panels xsect. F
400
900
1400
1900
2400
600
100
-400
-900
-1400
STEP NUMBER 2
WINDOW NUMBER 1
LEGEND
GEOMETRY:
---- DD elements, KODE = 1-4 7, 8
---- DD elements, KODE = 6
---- DD elements, KODE = 9-12
---- FS elements, KODE = 1-4
— Interface
Angle of inclination of interface = 0 degrees
CONTOUR INTERVALS:
1 ---- 1
2 ---- -1
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Section F

BESOL/P5005 CONTOUR PLOT OF S2

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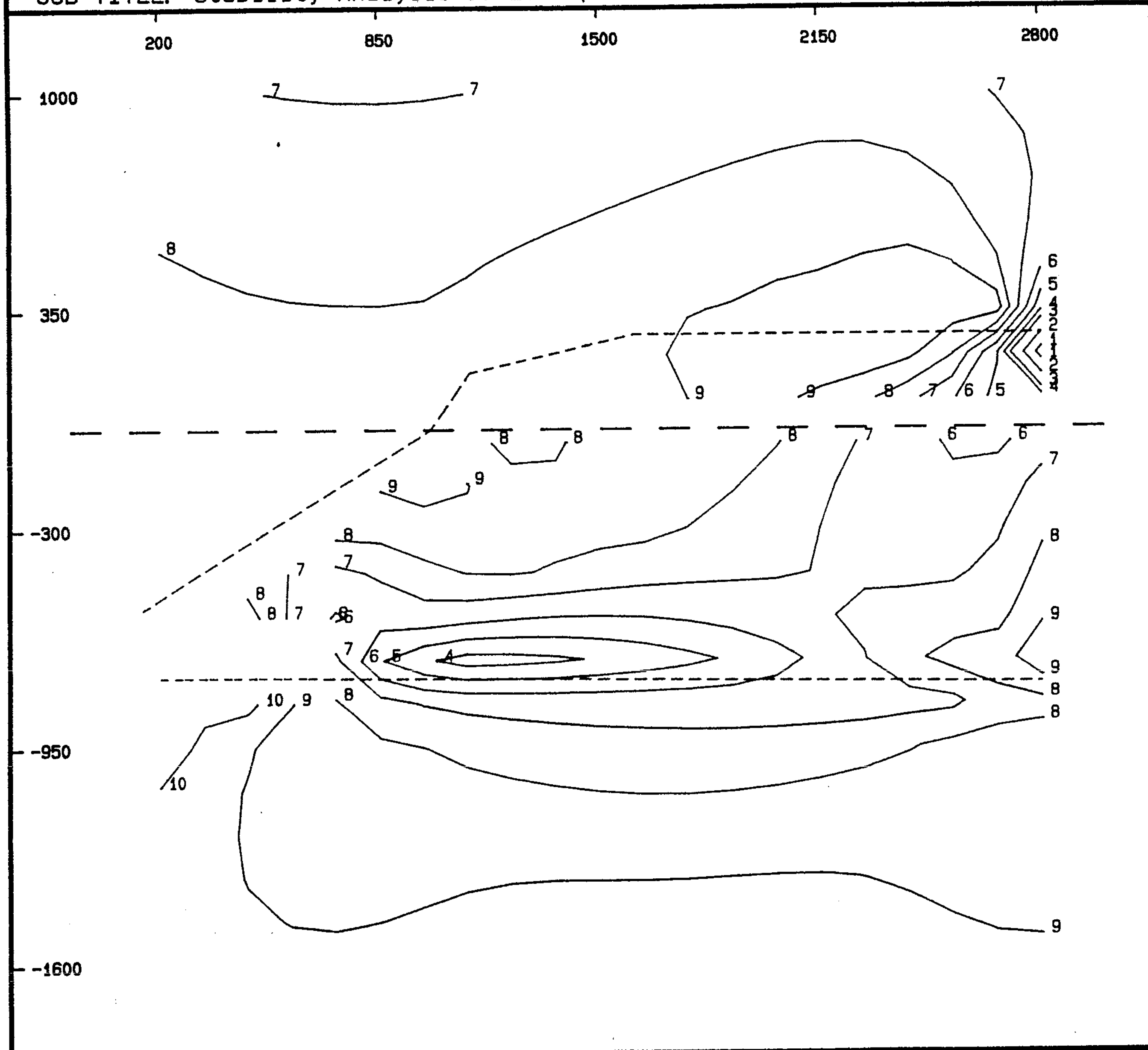
JOB TITLE: Stability Analysis of Escarpments above Longwall Mines Xsect. F



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

—— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	-5000
2	----	-4000
3	----	-3000
4	----	-2500
5	----	-2000
6	----	-1500
7	----	-1000
8	----	-500
9	----	0
10	----	500

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Section

BESOL/P5005 CONTOUR PLOT OF S1

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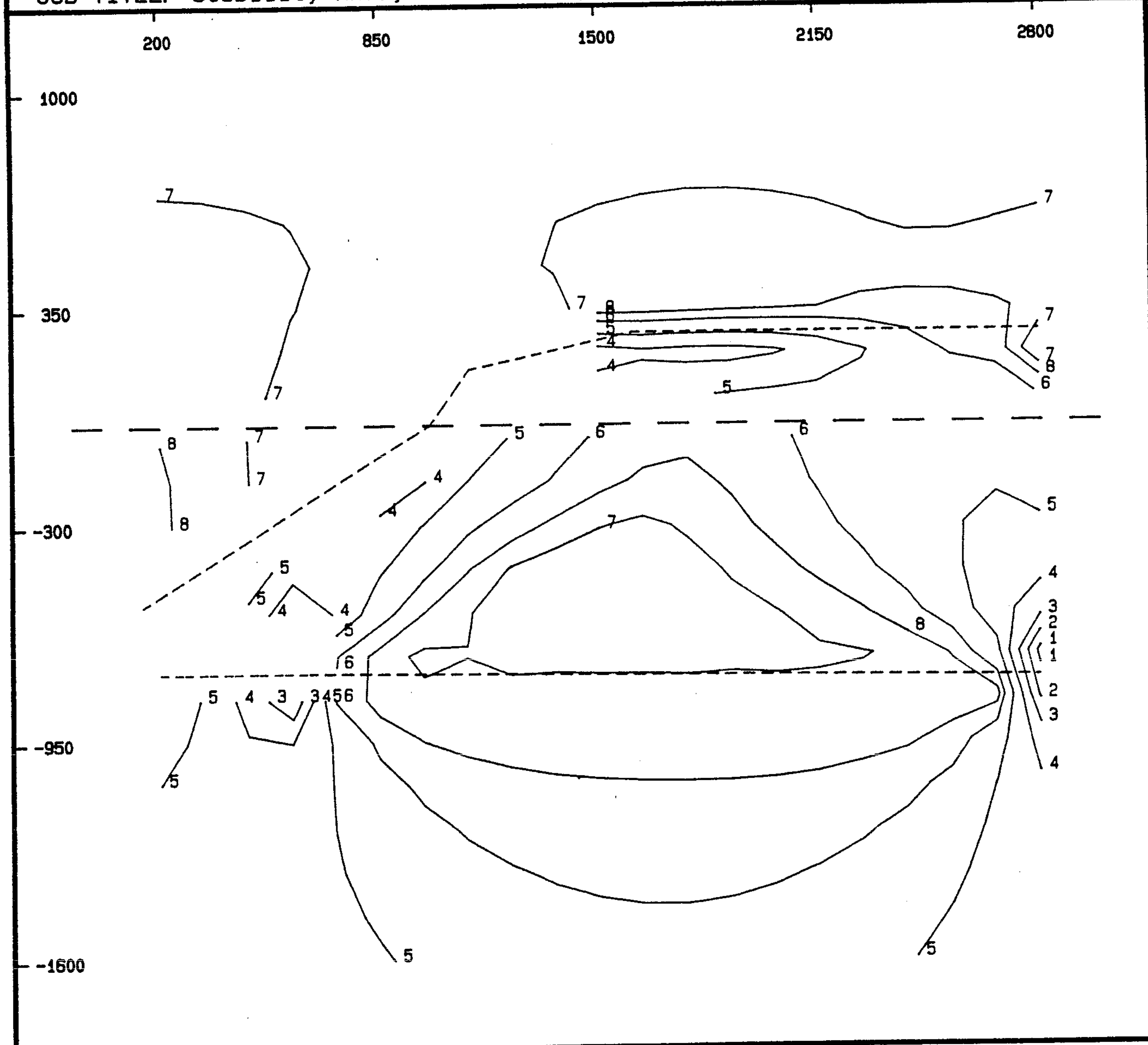
JOB TITLE: Stability Analysis of Escarpments above Longwall Mines Xsect. F



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

—— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	6000
2	----	5000
3	----	4000
4	----	3000
5	----	2000
6	----	1000
7	----	0
8	----	400

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Section

BESOL/P5005 CONTOUR PLOT OF S2

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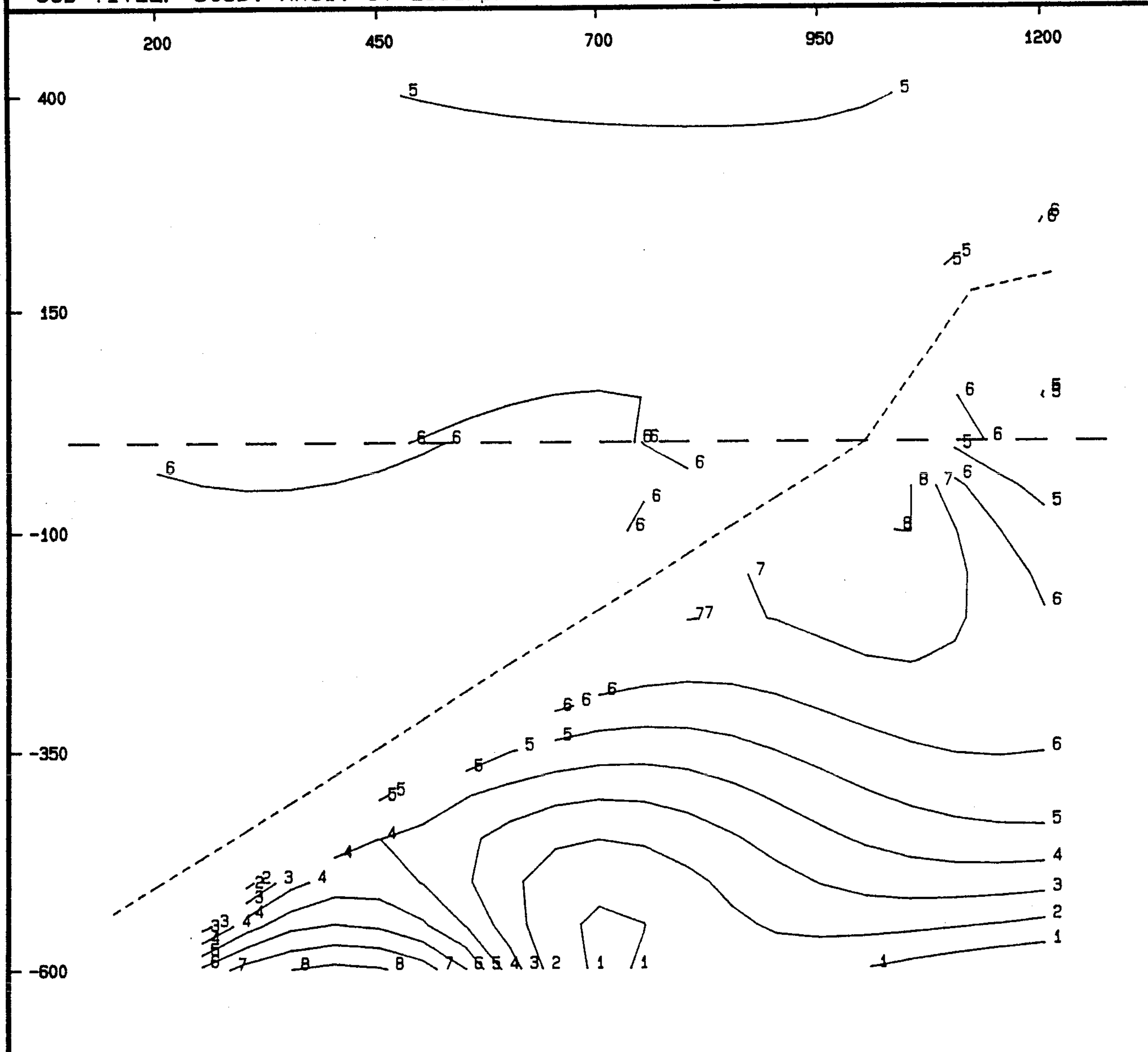
JOB TITLE: Stab. Anal. of Escarpments above Longwall Panels Xsect. F



STEP NUMBER 2

WINDOW NUMBER 1

LEGEND

GEOMETRY:

---- DD elements, KODE = 1-4 7, 8

---- DD elements, KODE = 6

---- DD elements, KODE = 9-12

---- FS elements, KODE = 1-4

— Interface

Angle of inclination of interface = 0 degrees

CONTOUR INTERVALS:

1	----	-1500
2	----	-1250
3	----	-1000
4	----	-750
5	----	-500
6	----	-250
7	----	0
8	----	250

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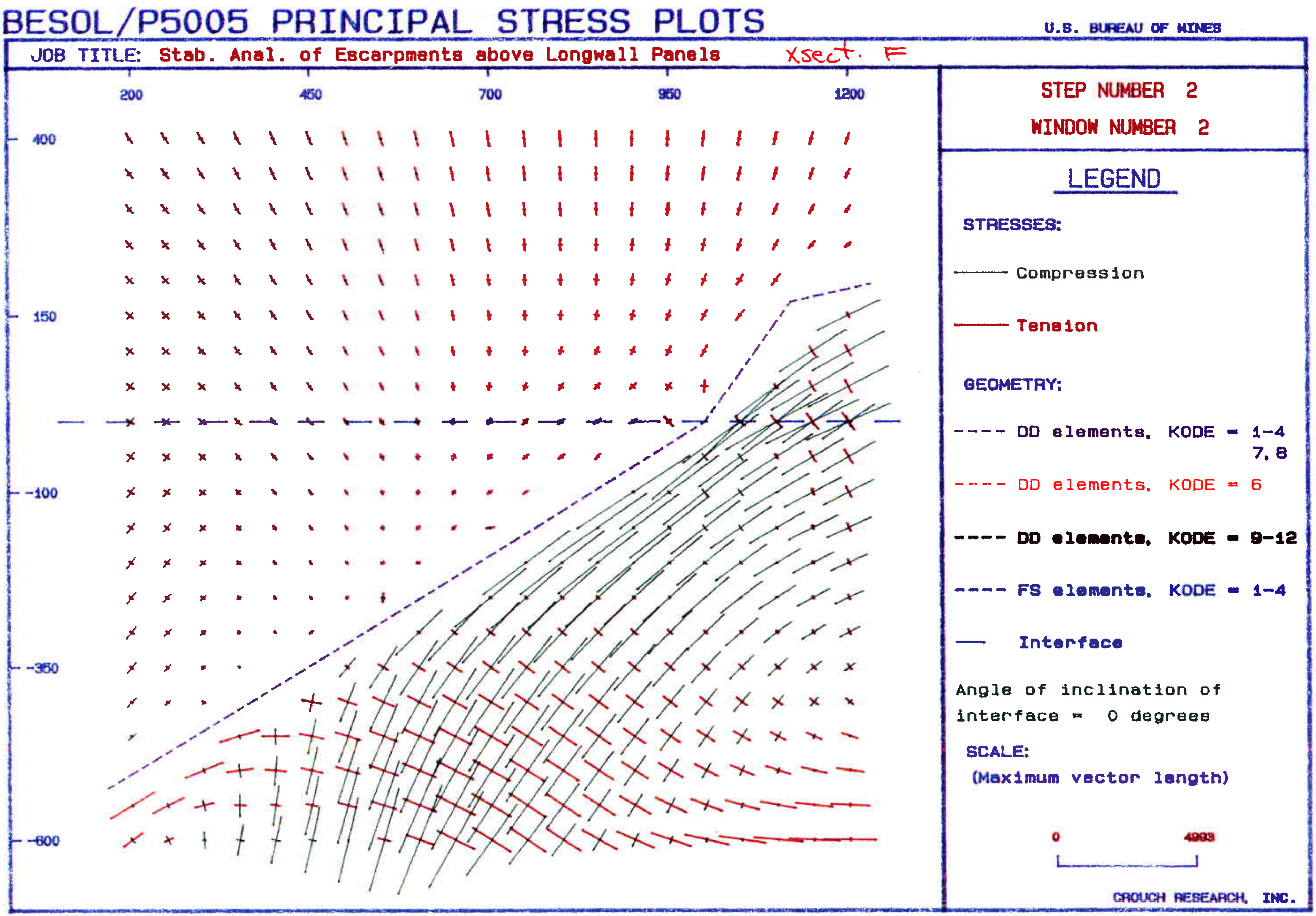

BESOL/P5005 PRINCIPAL STRESS PLOTS
U.S. BUREAU OF MINES
JOB TITLE: Stab. Anal. of Escarpments above Longwall Panels
Xsect. F
200
450
700
950
1200
400
150
-100
-350
-600
STEP NUMBER 2
WINDOW NUMBER 2
LEGEND
STRESSES:
Compression
Tension
GEOMETRY:
DD elements, KODE = 1-4
7, 8
DD elements, KODE = 6
DD elements, KODE = 9-12
FS elements, KODE = 1-4
Interface
Angle of inclination of
interface = 0 degrees
SCALE:
(Maximum vector length)
0
4993
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