mine file UP&L cottonwood
cc. P.G. Lyn

0009

United States Department of Agriculture | Forest Service | Manti-LaSal National Forest | 599 West Price River Dr. Price, Utah 84501

ACT/015/019 #2

Reply to: 2820

Date: September 10, 1990

Lowell Braxton
State of Utah Natural Resources
Division of Oil, Gas and Mining
355 West North Temple
3 Triad Center, Suite 350
Salt Lake City, Utah 84180-1203

Dear Lowell:

Two meetings were held in July to discuss the progress of the geotechnical computer escarpment studies being conducted on the south lease area of Utah Power and Light Company's (UP&L) Cottonwood/Wilberg Mine. The first of the two meetings was held at the Manti-La Sal National Forest office in Price, Utah, on July 19, 1990, and the second meeting was held at the UP&L Office in Huntington, Utah, on July 25, 1990. Escarpment study core committee members from the Forest Service (FS), Bureau of Land Management (BLM), Utah Division of Oil, Gas and Mining (UDOGM), and Utah Power and Light Company (UP&L) were present at the meetings. Sign-in sheets circulated at each of the meetings are enclosed.

At the first meeting held on July 19th, Dr. Pariseau and Richard Jones of the University of Utah (U of U) presented the results of their finite-element model. They distributed a paper entitled Sandstone Escarpment Stability in Vicinity of Longwall Mining Operations (copy enclosed) which was presented at the 1990 U.S. Rock Mechanics Symposium. In general, they felt that the work completed to date is promising, but computer prediction of the failures was not consistent with the actual measured failures which occurred. They feel that a 3-dimensional computer model would be needed to develop a computer modeling technique which could accurately be used to predict failures. They have already commenced a 3-D study which will utilize the university's main frame computer rather than the PC's used to date.

At the second meeting held on July 25th, Chris Dyni and Al Fejes of the Bureau of Mines (BoM), Denver Research Center, presented information on the BoM escarpment study. They essentially overviewed a paper presented at the 1990 U.S. Rock Mechanics Symposium entitled Geomechanical Evaluation of Escarpments Subjected to Mining Induced Subsidence (copy enclosed). Copies of the paper were distributed.

The results of their boundary-element model were essentially the same as those for the U of U's finite-element model. They concluded that a 3-D finite-element model would be necessary to predict a predictive model of the escarpments. They will employ a software system to be installed in August called Finite Element Graphics System (FEGS). This software should allow them to construct 3-D models very rapidly. They will model the escarpments on this software starting in Fiscal Year 1991.

At both of the meetings, the commitment and ability to continue with the study was discussed. Dr. Pariseau of the U of U stated that they intend to continue with the study but that Richard Jones will move on and will probably be replaced with another graduate student. Chris Dyni and Al Fejes of the BoM indicated that there has recently been more interest in environmental issues in the west, which should help produce funding. They, however, indicated that lobbying at the Washington level would be necessary to insure funding for continued research. The BLM and FS indicated that they would request continued funding for the project through appropriate agency channels, but that the overall responsibility to insure continuation of the study lies with UP&L under the terms of the Mining and Reclamation Plan, and resolution of UP&L's appeal of the FS escarpment mining decision.

The status of the wildlife study (golden eagle nests) was discussed. The Forest Service stated that the meeting to be held in Newberry Canyon has not yet been scheduled, but that it is in the works.

Sincerely,

Jams L Horne

for
GEORGE A. MORRIS
Forest Supervisor

Enclosures

Escarpment Study Meeting 7-25-90

Name	Organization	Location
Jeff Emmons	DOGM	SLC
Dennis Kelly	USFS	Price
Carter Reed	USFS	Price
VAL PAYNE	UP&L	HUNTINGTON
Dale Harber	U.S.F.S.	Ferron
Chris Dyni	U.S.B.M	Denver
Al Fejes	US.B.M.	Denver
BART HYITA	UP+L	HUNTINGTON
Gary S. Takenaka	UP+L	Huntington
CHUCK SEMBORSKI	UP&L	HUNTINGTON

Sign-In Sheet

7/19/90 | UP&L Escarpment Study Meeting, Price, Utah

Name	Representing	Office Location
Carter Reed	USFS	Price, Utah
RICHARD JONES	U. OF UTAH	SLC, UT
Jim Egnew	USFS	Price UT
AARON HOWE	"	" "
Stephen Falk	BLM	Price UT
VAL PAYNE	UP&L	HUNTINGTON
PAMELA GRUBAUGH-LITTIG	DOGM	SLC, UTAH
Gary TORRES	BLM	Moab, UT
Becky Hammond	USFS	Price, UT
Pete Kilbourne	USFS	Price, UT
BART HYITA	UP&L	HUNTINGTON
Gary S. Takenaka	UP&L	Huntington
Bill Parizeau	U. of U.	SLC, UT

Castlegate Sandstone Escarpment Study

Review of Work Performed by U. of Utah Dept. of Mining Engineering

July 19, 1990

- Field Observations and Review of Field Data

  - Geologic setting
  - Field observations
  - Survey measurements
  - Consideration of possible failure modes

- Numerical Modeling of Mechanical Effects of Longwall Mining on Escarpment

  - Modeling as elastic/plastic continuum by Finite Element method
  - 2 Dimensional Finite Element models
  - Modeling as discontinuous block assemblage by Distinct Element method
  - 2 Dimensional Distinct element model
  - Limitations of 2-D modeling and motivation for 3-D modeling
  - Applicability and limitations of numerical modeling

- East Mountain Core Testing

  - Brazil tests for tensile strength (106 samples)
  - Uniaxial compressive strength testing (53 samples)
  - Biaxial testing

- Work in Progress and Anticipated Future Work

  - 3 Dimensional Finite Element model
  - 3 Dimensional Distinct Element model
  - Analysis of surface subsidence (comparing observations with 3-D models)

UP&L East Mountain Core Testing

Brazil Test Statistical Summary by Rock Type and Formation
(Ranked by tensile strength)

Rock Type	Fm	Unit Wt. (pcf) Mean	s.d.	c.v.	n	To (psi) Mean	s.d.	c.v.	n
Limestone	Fl	154.8	1.9	1%	6	921	151	16%	6
Siltstone	Bh	164.5	2.0	1%	6	920	217	24%	6
Mudstone	Nh	162.3	3.5	2%	11	841	369	44%	11
Interbeds	Bh	165.1	6.8	4%	8	813	348	43%	8
Mudstone	Bh	137.9	52.4	38%	7	741	379	51%	7
Carbmudstone	Pr	158.6	0.2	< 1%	3	702	204	29%	3
Conglomerate	Pr	156.2	7.8	5%	3	694	291	42%	3
Carbmudstone	Nh	151.4	3.7	2%	4	671	59	9%	4
Siltstone	Nh	160.1	0.9	1%	3	637	68	11%	3
Sandstone	Bh	148.8	7.9	5%	8	573	196	34%	8
Mudstone	Pr	156.6	0.9	1%	5	530	79	15%	5
Sandstone	Cg	139.7	3.8	3%	14	455	125	27%	14
Mudstone	Cg	141.1	1.1	1%	2	405	115	28%	2
Sandstone	Sp	132.8	0.9	1%	4	362	45	12%	4
Sandstone	Pr	134.5	1.6	1%	9	295	93	32%	9
Interbeds	Cg	131.1	5.9	5%	6	276	101	37%	6
Sandstone	Nh	128.1	0.9	1%	3	214	24	11%	3
Coal	Bh	77.1	2.2	3%	4	60	34	57%	4

Key to Abbreviations:

Fm = formation (geologic)
Nh = North Horn formation
Pr = Price River formation
Bh = Blackhawk formation
Cg = Castlegate sandstone
Sp = Starpoint sandstone
Fl = Flagstaff limestone
pcf = pounds/cubic foot
s.d. = standard deviation
c.v. = coefficient of variation
n = number of samples

UP&L East Mountain Core Testing

Uniaxial Compression Test Statistical Summary by Rock Type and Formation
(Ranked by compressive strength)

		Unit Wt. (pcf)				E (psi)				Co (psi)			
Rock Type	Fm	Mean	s.d.	c.v.	n	Mean	s.d.	c.v.	n	Mean	s.d.	c.v.	n
Carbmudstone	Nh	164.6	-	-	1	4.4E+06	-	-	1	27,845	-	-	1
Limestone	Nh	154.3	-	-	1	5.1E+06	-	-	1	23,722	-	-	1
Interbeds	Bh	165.2	5.5	3%	3	5.3E+06	2.4E+06	45%	3	22,760	9,424	41%	3
Limestone	Fl	158.7	1.6	1%	2	6.5E+06	1.2E+06	18%	2	20,381	667	3%	2
Siltstone	Nh	164.7	0.8	<1%	2	3.7E+06	5.8E+05	16%	2	18,631	770	4%	2
Mudstone	Bh	162.2	0.9	1%	4	3.4E+06	5.3E+05	16%	4	16,385	2,706	17%	4
Siltstone	Bh	164.5	0.4	<1%	3	3.9E+06	5.6E+05	14%	3	14,504	3,615	25%	3
Mudstone	Cg	160.6	-	-	1	2.8E+06	-	-	1	13,644	-	-	1
Mudstone	Pr	160.1	-	-	1	2.5E+06	-	-	1	13,122	-	-	1
Interbeds	Nh	166.8	-	-	1	2.8E+06	-	-	1	12,592	-	-	1
Mudstone	Nh	160.6	0.7	<1%	2	2.6E+06	9.1E+05	35%	2	11,880	1,536	13%	2
Sandstone	Bh	152.2	8.6	6%	4	3.7E+06	3.7E+05	10%	4	11,775	2,333	20%	4
Conglomerate	Pr	133.9	23.0	17%	2	5.7E+06	9.9E+05	17%	2	11,732	810	7%	2
Carbmudstone	Pr	159.6	-	-	1	2.1E+06	-	-	1	11,202	-	-	1
Sandstone	Cg	138.4	3.1	2%	8	3.2E+06	5.1E+05	16%	8	9,737	910	9%	8
Sandstone	Sp	134.6	0.8	1%	6	2.6E+06	2.5E+05	10%	6	9,638	511	5%	6
Sandstone	Pr	137.5	3.0	2%	5	3.4E+06	6.2E+05	18%	4	9,057	1,504	17%	5
Sandstone	Nh	131.4	-	-	1	1.6E+06	-	-	1	5,887	-	-	1
Interbeds	Cg	130.7	2.2	2%	3	1.5E+06	6.7E+05	45%	3	3,788	1,498	40%	3
Coal	Bh	77.6	0.1	<1%	2	3.3E+05	5.0E+04	15%	2	2,032	585	29%	2

Key to Abbreviations:

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Fl = Flagstaff limestone
pcf = pounds/cubic foot
s.d. = standard deviation
c.v. = coefficient of variation
n = number of samples

UP&L East Mountain Core Testing

Biaxial Test Data and Calculations

Load cell calibration factor:	9,780 lb/volt

Sample No.	Test Date	Rock Type	Fm	Sig.3 (psi)	Dia. (in.)	Len. (in.)	L/D	End // (in.)	Mass (g)	Load Time (s)	Plot Scale F-V/in.	Ult. Plot in.	Ult. Load (lb)	Load Rate (psi/s)	Unit Wt. (pcf)	Sig.1 Ult. (psi)
136-03A	17 Apr 90	Mudstone	Nh	2,000	2.489	4.792	1.9	0.0012	1019.3	143	3.000	5.64	165,478	237.8	166.5	34,009
136-03B	17 Apr 90	Mudstone	Nh	4,000	2.489	4.877	2.0	0.0020	1036.8	128	5.000	4.56	222,984	358.0	166.4	45,828
136-05A	12 Apr 90	Sandstone	Nh	2,000	2.482	4.846	2.0	0.0013	814.1	100	3.000	3.48	102,103	211.0	132.3	21,103
136-05C	12 Apr 90	Sandstone	Nh	4,000	2.480	4.814	1.9	0.0013	804.2	140	5.000	2.78	135,942	201.0	131.7	28,142
137-01B	17 Apr 90	Interbeds	Nh	3,000	2.493	4.906	2.0	0.0016	1042.6	127	5.000	4.22	206,358	332.9	165.9	42,275
137-03A	17 Apr 90	Conglomerate	Pr	3,000	2.501	4.715	1.9	0.0011	899.3	171	3.000	3.52	103,277	122.9	147.9	21,023
137-04B	17 Apr 90	Sandstone	Pr	3,000	2.498	4.768	1.9	0.0031	837.0	117	5.000	2.54	124,206	216.6	136.5	25,344

Sandstone escarpment stability in vicinity of longwall mining operations

R.E.Jones
W.G.Pariseau
Department of Mining Engineering, University of Utah, Salt Lake City, UT

V.Payne
G.Takenaka
Mining Division, Utah Power and Light Company, Huntington, UT

1 INTRODUCTION

The Mining Division of Utah Power and Light Company operates two longwall coal mining operations in east-central Utah. Production is 5 to 6 million tons of steam coal annually. Mining activities are conducted in a region characterized by steep-walled plateaus and deep canyons. Typically, the coal seams outcrop about 2,000 ft below the summit of the plateaus and about 500 ft above the canyon floor. One of the mines, the Cottonwood mine, is shown in Figure 1. The Cottonwood mine is situated on the southeastern edge of East Mountain which is a segment of the Wasatch Plateau. A predominant geological feature in the region is the Castlegate Sandstone. The Castlegate Sandstone forms vertical escarpments 200 to 300 ft high along the perimeter of the plateaus. In late 1986 and through most of 1987, extraction of the 6th East and 7th East longwall panels in the Cottonwood mine near the escarpment was accompanied by rock falls in several zones along the escarpment face (Payne 1987). The area lies on U.S. Forest Service controlled property and provides golden eagle nesting habitat. Concern was raised for the impact of escarpment failure on animal and plant life in the area. The critical issue became one of meeting the requirements of prudent resource recovery while at the same time developing a mining strategy that minimizes the impact on the surrounding environment.

Research work focused on developing numerical models of the escarpment region and calibrating the models with observations from the escarpment failure. Initially, a finite element (FE) approach was chosen for modeling. A two dimensional elastoplastic finite element model was constructed to represent the escarpment zone and the two nearby longwall excavations. A comparison of FE model displacements with the observed motion of the escarpment indicated that the FE model did not account for the relatively large horizontal displacements observed along the escarpment crest prior to failure. A two dimensional distinct element (DE) model was subsequently developed to represent the escarpment itself and the nearby rock mass. Displacements from the FE model were then used as input to the smaller scale DE model in order to determine their effect on the stability of slabs and blocks in the escarpment face. The combination allows for the testing of possible mechanisms of escarpment instability under differing sets of conditions such as joint spacing, block size, orientation, and panel proximity.

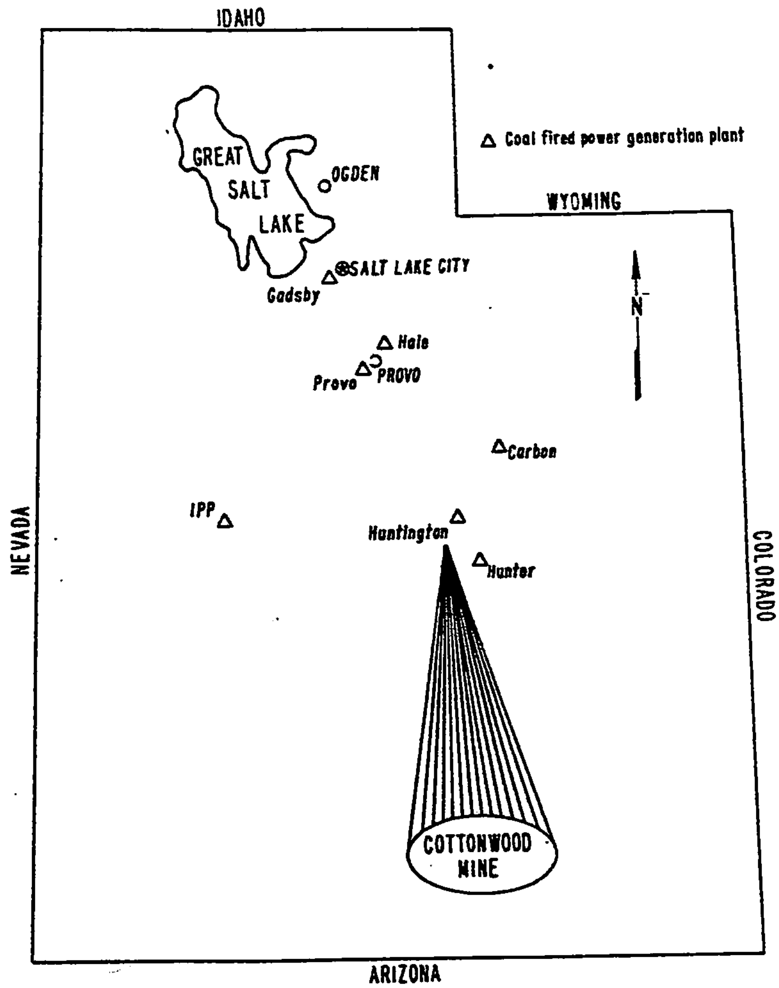

Figure 1. State of Utah and location of Cottonwood mine.

2 ANALYSIS OF FIELD DATA

Several sedimentary units outcrop in the vicinity of the Wasatch Plateau coal field, ranging in age from Jurassic to Tertiary (Doelling 1972). The major stratigraphic formations associated with the East Mountain area are (in ascending order): Mancos Shale, Starpoint Sandstone, Blackhawk Formation, Castlegate Sandstone, Price River Formation, North Horn Formation, and Flagstaff Formation. The minable Hiawatha coal seam is located immediately above the Starpoint Sandstone in the Blackhawk Formation and averages about 10 ft thick in the vicinity of the 6th East and 7th East longwall panels. Rock strengths and elastic moduli vary considerably for the sedimentary units. Laboratory scale mechanical properties for the geologic units pertinent to this study are given in Table 1.

Table 1

Material Properties for East Mountain Rock Types

Geologic Unit or Rock Type	C_o psi	T_o psi	E 10^6 psi	v
North Horn, Price River, Blackhawk Formations	15,320	1,440	4.5	0.26
Castlegate Sandstone, Starpoint Sandstone	24,500	1,530	5.9	0.22
Mancos Shale	10,300	510	2.2	0.35
Hiawatha Coal Seam	1,800	280	0.6	0.37

C_o = Uniaxial compressive strength
T_o = Uniaxial tensile strength
E = Young's modulus
v = Poisson's ratio

The pre-mining stress state in the region of interest has not been measured, but ground conditions in the Cottonwood mine do not indicate stress magnitudes or orientations beyond that which would be expected for normal gravity loading. The East Mountain area contains numerous large scale geologic structures, including faults and grabens. In the immediate vicinity of the 6th East and 7th East longwall panels, however, there is an absence of larger structures. A discontinuity mapping program was conducted at the surface along the escarpment crest. The program identified a major vertical joint set running roughly parallel to the crest and a minor vertical joint set perpendicular to the major set (Seegmiller 1987). Joint spacing averaged 20 ft and joint continuity also averaged about 20 ft. Visual inspection of the escarpment face in the failed zones confirmed the existence and orientation of the joint sets. It appears that the joint sets extend through the entire thickness of the Castlegate Sandstone. An aerial inspection of the escarpment zone on East Mountain revealed many locations remote from mining activity where substantial portions of the escarpment face have naturally spalled in large slabs or are in the process of spalling. Field observations suggest that failure of the sandstone escarpment is a continuous, naturally occurring process which may only be accelerated in some instances by mining.

The 6th East and 7th East longwall panels are oriented parallel to the escarpment crest. The mid-span of the 6th East panel is directly beneath the crest; the 7th East panel is between the 6th East panel and the seam outcrop. Each panel is 650 ft wide and 4,000 ft long. Prior to mining the 6th East and 7th East longwall panels, four survey monuments were mounted along the escarpment crest in order to track ground movement during the mining process. During the twelve month period that the 6th and 7th East panels were mined, displacement measurements were taken on a weekly basis from the survey monuments. Significant ground movement was detected for each of the panels after the longwall face had advanced about 400 ft beyond a particular monument. As the 6th East longwall panel neared completion, one survey monument was lost in a rockfall event.

Ground movement during mining was predominantly outward, with a fairly consistent outward/downward ratio of 1.5:1. At the completion of mining of the 6th East and 7th East longwall panels, most of the escarpment crest over the panels had moved outward 83 inches and downward 55 inches. For full extraction of the Hiawatha seam (120 inches), the downward movement of the escarpment crest constitutes about 46% of the excavation height.

Since survey monuments were located only on the crest of the escarpment, the kinematics of escarpment failure cannot be uniquely determined. One possible motion is rotation of slabs on the escarpment face, with the base of the slab fixed and the top of the slab rotating outward in toppling fashion. This mode would be consistent with the observed movement if virtually all of the downward motion could be attributed to ordinary subsidence. The top of a slab with a rotational radius of 200 ft would show an apparent downward movement of only 1.4 inches for 83 inches of apparent outward movement. Reverse rotation in slump-like fashion is also inconsistent with large horizontal crest displacement.

Another possible mode of escarpment movement is pure translation due to the base of a slab sliding on a slip plane. This mode is consistent with the observed outward and downward movement at a relatively constant 1.5:1 ratio during mining. It is possible that the actual escarpment movement is due to some combination of two or modes.

3 NUMERICAL MODELS

Finite element modeling was initially selected for the escarpment study because of its ability to handle real world complexities such as surface topography, variable geometry of geologic units, their elastic moduli and strengths, the pre-mining stress state, panel geometry and proximity to the escarpment, and simulation of mining sequence. The elastoplastic UTAH-II FE code was use for the model calculations. Information provided by a FE model includes stresses, strains, displacements, and their changes with advance of the face.

A plane strain cross section was taken perpendicular to the escarpment and the longwall panels. The FE model for the cross section covered a horizontal distance of approximately 6,000 ft and extended to a depth of 4,400 ft from the summit of the Wasatch Plateau. The model included six material layers representing the North Horn, Price River, and Blackhawk formations, the Castlegate Sandstone, the Starpoint Sandstone, and the Mancos Shale. Approximately 1,000 elements and nodes were used in the mesh.

While the cross section represented a region over a mile wide and nearly one mile in depth, the Hiawatha coal seam (which is 10 ft thick) needed to be explicitly represented in the model since the excavation occurs in the Hiawatha seam and the coal material properties are significantly different from the material properties of the surrounding geologic units. The need to represent a feature with dimensions on the order of 10 ft in a model thousands of feet wide and deep presents some practical modeling problems. In order to stay within the 5:1 aspect ratio limit required for numerical stability, it would be necessary to model the Hiawatha seam with 10 ft by 50 ft elements. A row of elements this small would dictate the use of many thousands of elements in a model of this scale. A recent advance in the modeling of field scale elastic properties (Pariseau and Moon 1988) permitted the use of elements that possess the composite elastic properties of the coal seam and the surrounding rock. This approach enabled the coal seam to be represented as 100 ft by 100 ft elements above and below the seam horizon. As a first approximation to overall field scale material properties, the laboratory scale strengths and elastic moduli of the geologic units in the model (including the compliant elements) were reduced by a factor of 10 prior to running the FE analysis.

The FE analysis for the two dimensional plane strain cross section was conducted in three stages. The first stage loaded the model with a gravity induced stress state. Stages two and three extracted the 6th East and 7th East longwall panels in that order. During the modeling of the extraction of the longwall panels, a full seam closure condition was applied (50% roof sag and 50% floor heave). Figure 2 shows a portion of the two dimensional model and the extent of yield zones after each of the three stages. As Figure 2 shows, for stage one, there is a small yield zone at the base of the escarpment prior to excavation of the longwall panels. This confirms the existence of a naturally high stress concentration at the base of the escarpment.

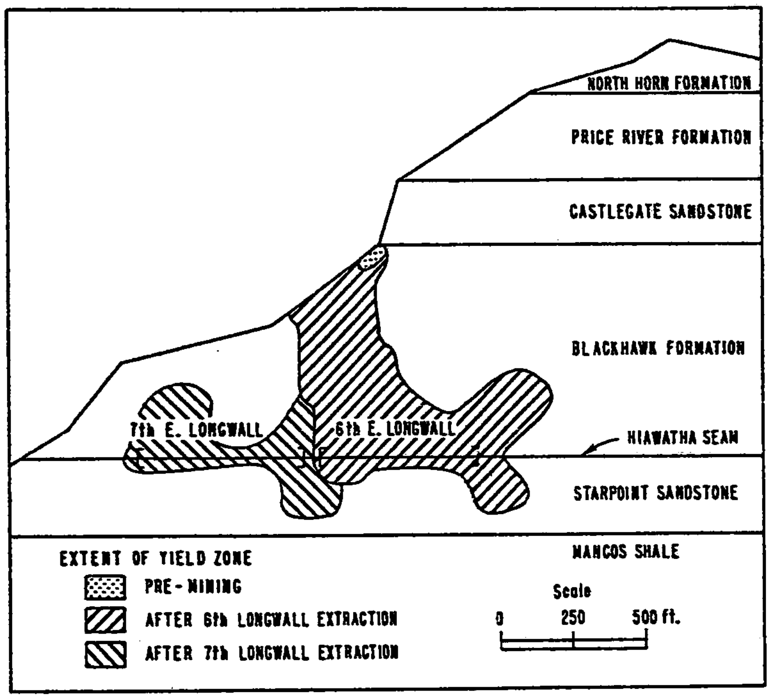

Figure 2. Cross section for FE model showing topography, stratigraphy, and extent of yielding from FE analysis.

Extraction of the first longwall panel creates a yield zone that is localized around the opening itself but which "chimneys" up to enlarge the yield zone which existed at the escarpment base prior to mining. After extraction of the second panel, the yield zone enlarges somewhat to include a localized region around the 7th East longwall excavation. It is interesting to note that the model shows no plastic yielding in the Castlegate Sandstone. The Castlegate Sandstone is such a massive member that it was not stressed beyond the elastic range by excavating beneath it. The fact that the face of the escarpment does fail from time to time suggests that discontinuities in the Castlegate Sandstone play a significant role in creating localized conditions of instability.

Most of the FE model displacement at the escarpment crest occurred during the extraction of the first (6th East) longwall panel, with about 20 inches of downward movement and 4 inches of outward movement. Extraction of the second longwall panel from the model resulted in a cumulative total of 25 inches of downward movement (about 21% of the excavation height) and 6 inches of outward movement. Compared with the observed motion of the escarpment crest, the FE model shows about 50% of the observed downward movement and 7% of the observed outward movement prior to fall of rock from the escarpment. Prescription of greater downward roof motion at the seam level would undoubtedly bring the calculated and observed vertical escarpment displacements into closer agreement. However, it appeared that the horizontal displacement was beyond the FE model capability because of large displacement on joints in the escarpment and possible sliding near the escarpment base.

In order to better understand the mechanical behavior of the escarpment itself, a two dimensional distinct element model was constructed. The DE model represented the immediate vicinity of the escarpment face as shown in Figure 3.

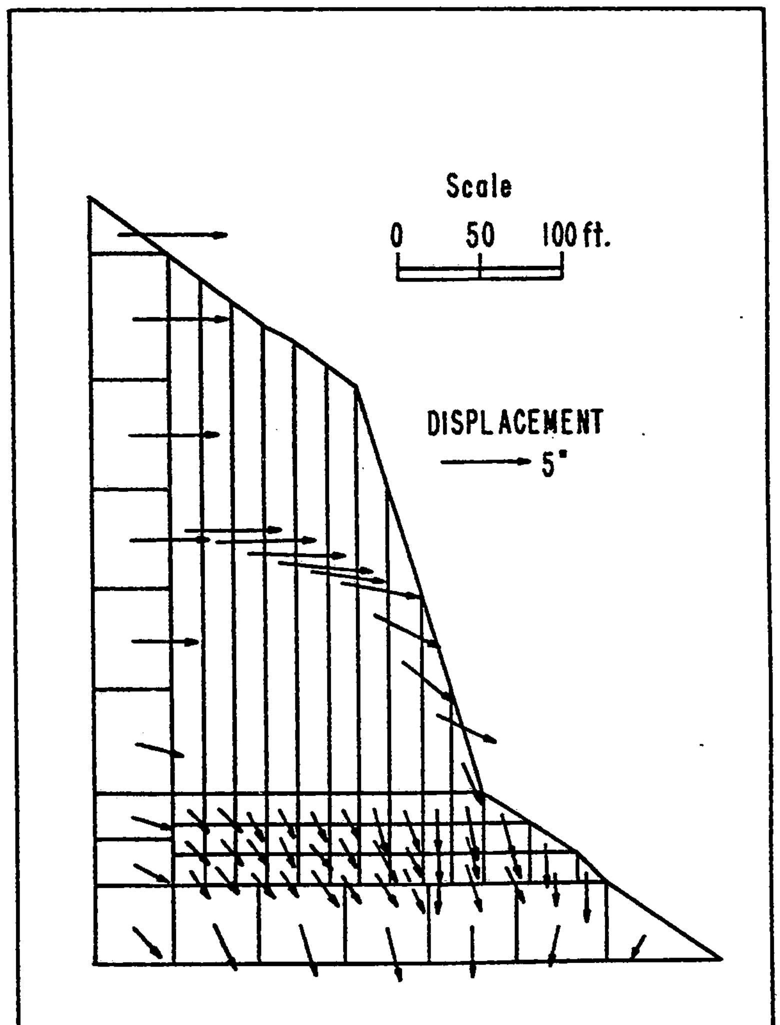

Figure 3. Two dimensional DE model of escarpment showing applied displacememnts from FE model. Approximately 20 inches of common downward translation have been removed for clarity.

The region in Figure 3 extends 250 ft into the Castlegate Sandstone and about 100 ft above the crest and 100 ft below the base of the escarpment. A total of 61 elements (blocks) were used in the model. A special feature of this DE model is a border of blocks which correspond in location and dimension to elements from the FE model. This feature enabled the application of FE model displacements to the blocks in the DE model. A distinct element code called CBLOCK was used for this analysis. CBLOCK is a variation of the original Cundall DE code (Ryu 1989). Also shown in Figure 3 are the displacements applied to the DE blocks from the cumulative displacements of the FE model. For clarity, a common downward translation of 20 inches was removed from the FE displacements in order to show the vertical and horizontal displacement contrasts for that portion of the FE model. The DE model was composed primarily of 20 ft thick vertical slabs corresponding to the 20 ft average spacing of the joints mapped from the surface. Two rows of small, square blocks beneath the slabs represent a portion of the less massive Blackhawk Formation which may be in a state of yield at that location.

Application of the FE generated displacements to the DE model did not result in loss of static equilibrium of any of the blocks. Subsequent analysis by hand showed that for a slender, rectangular slab, the top would have to be rotated outward by a distance approximately equal to the thickness of the slab before rotational acceleration would occur. Of course, the thickness of the slabs in the DE model could be reduced such that the FE scale displacements would induce toppling, but such an approach would be artificial since visual inspection of the escarpment confirms the existence of slabs with thicknesses on the order of 20 ft. The results of this analysis, combined with visual evidence from natural escarpment spalling suggest that rotation is not likely to be a dominant mechanism in escarpment failure.

4 CONCLUSIONS

The escarpment formed by the Castlegate Sandstone has many locations where large scale natural spalling has occurred, in addition to the rockfall events coincidental with mining of the 6th East and 7th East longwall panels. If the Castlegate Sandstone were devoid of structural discontinuities, its massive nature would preclude any type of failure, whether natural or as the result of mining. Structural discontinuities, including very localized features such as joint sets, appear to be the primary controls that determine whether a particular portion of the escarpment is capable of large scale failure. The failures near the 6th East and 7th East longwall panels provide good evidence of the role of localized structural features.

Research by analytical and numerical methods has shown that a natural stress concentration occurs at the base of the escarpment which creates some degree of yielding. Simulation of mining beneath the escarpment with a finite element model indicated that the Castlegate Sandstone is relatively unaffected by longwall extraction. However, the natural yield zone at the base of the escarpment may be enlarged by the mining of longwall panels directly beneath the escarpment crest. The coupling of a distinct element model with the displacements from a finite element model has proven to be a useful tool in evaluating possible modes of escarpment failure. Based on the results of the coupled model and observations of natural escarpment spalling, it is unlikely that rotation is a significant mechanism in escarpment failure. The existence of a naturally high stress concentration at the base of the escarpment and the relatively uniform outward and downward movement of the escarpment crest suggest that failure may be caused by yielding of the "foundation" material at the base of the escarpment.

REFERENCES

Doelling, H.H. 1972. Central Utah coal fields. Utah Geological and Mineralogical Survey: Salt Lake City.

Pariseau, W.G. and H. Moon 1988. Elastic moduli of well-jointed rock masses. Proceedings of sixth international conference on numerical methods in geomechanics, p. 815-822. Balkema: Rotterdam.

Payne, V.E. 1987. Assessment of mining related impacts in Newberry Canyon. Utah Power and Light Co.: Huntington, Utah.

Ryu, C.H. 1989. User's guide to CBLOCK. University of Utah: Salt Lake City.

Seegmiller, B.L. 1987. Surface stability evaluation, 6E/7E and 9W/10W panels, Cottonwood mine. Seegmiller International: Salt Lake City.

Rock Mechanics Contributions and Challenges, Hustrulid & Johnson (eds)
© 1990 Balkema, Rotterdam. ISBN 90 6191 123 0

Geomechanical evaluation of escarpments subjected to mining induced subsidence

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ABSTRACT

This paper presents preliminary results of numerical modeling conducted by the Bureau of Mines, Denver Research Center, to illustrate the capabilities of the boundary-element method in predicting, comparing, and assessing the effects of mining beneath massive sandstone escarpments. Mining under escarpments is rapidly becoming a major environmental concern in the Western United States. As an escarpment is undermined, the resulting subsidence induced by the mining has the potential to cause blocks of material to fail along existing joint planes and slide or topple down the talus slope below. This failure has the potential to impact wildlife habitat, raptor nesting sites, vegetation, and other land uses.

A two-dimensional boundary-element analysis was conducted along a vertical cross section through the Cottonwood Mine near Huntington, Utah. The analysis along this section took into account mining of both the 6th and 7th East longwall panels underlying the massive Castlegate Sandstone. Stress and displacement plots show the effect of mining these two longwall panels on the stability of the overlying Castlegate Sandstone escarpment, based on an elastic continuum model. An additional analysis was conducted to show the effects of altering the layout of these two panels on reducing the potential for escarpment instability.

1 INTRODUCTION

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. Erosional degradation has caused these massive outcroppings to become relatively unstable, meaning that much of the outcropping material is highly fractured and jointed. The subsidence created as a result of mining the underlying coal seams can cause these already unstable blocks of rock to slide or topple down the slope. Since the majority of escarpments in the West are located in remote areas, the main concern has been the environmental impact on resident wildlife, particularly eagles nesting along the escarpments. Another impact with undermining escarpments is the visual effect that can accompany escarpment failure. This impact is greatest in the immediate vicinity of the escarpment failure; however, the significance of the impact is minimal when viewed from a distance.

The specific study site for this analysis was the Newberry Canyon located in the south lease area of the Cottonwood Mine near Huntington, Utah. The mine is owned and operated by the Utah Power & Light Company. Photos 1a and 1b show a section of the Castlegate Sandstone escarpment on the north side of Newberry Canyon before and after mining of the 6th and 7th East longwall panels in the underlying Hiawatha coal seam. Figure 1 is a typical two-dimensional cross section through this area showing the location of these two panels in relation to the escarpment outcropping. Photo 1b depicts several locations along the escarpment where failure has occurred. A recent assessment of the mining related impacts in the Newberry Canyon area of the Cottonwood Mine is given by Payne (1987).

As a result of this potential environmental impact, increasingly strict regulatory stipulations are encouraging western coal mine operators to assess the effects of mining beneath escarpments. Mine

a. Condition of escarpments prior to mining the 6th and 7th East panels

b. Condition of escarpments after mining the 6th and 7th East panels, with arrows showing locations where failure has occurred.

Photo 1 Section of the Castlegate Sandstone escarpment on the north side of Newberry Canyon above the 6th and 7th East longwall panels.

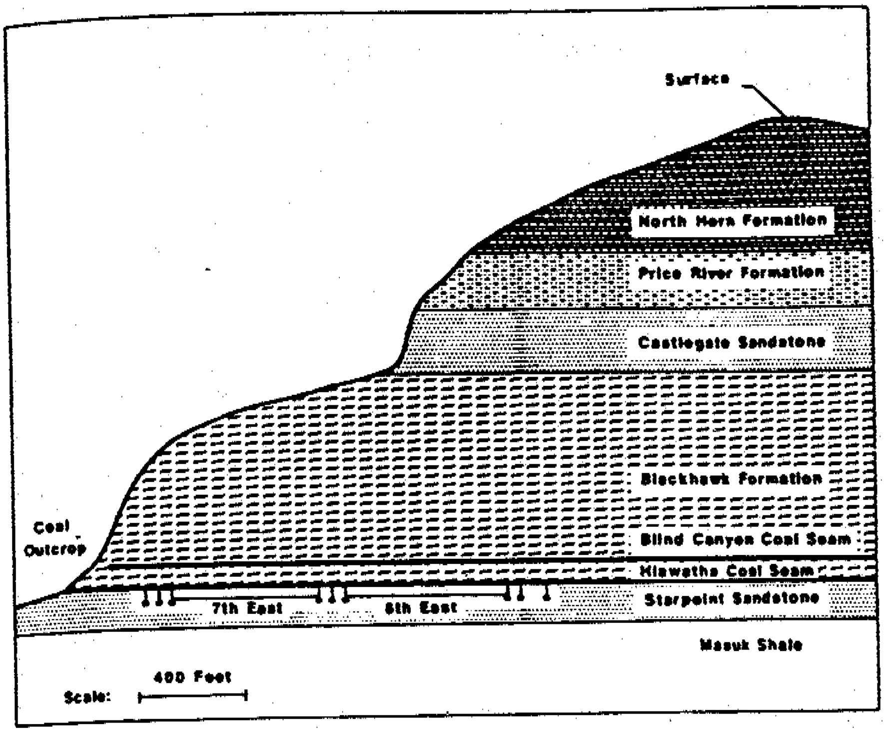


Figure 1 Cross section A showing location of longwall panels in relation to escarpment outcropping.

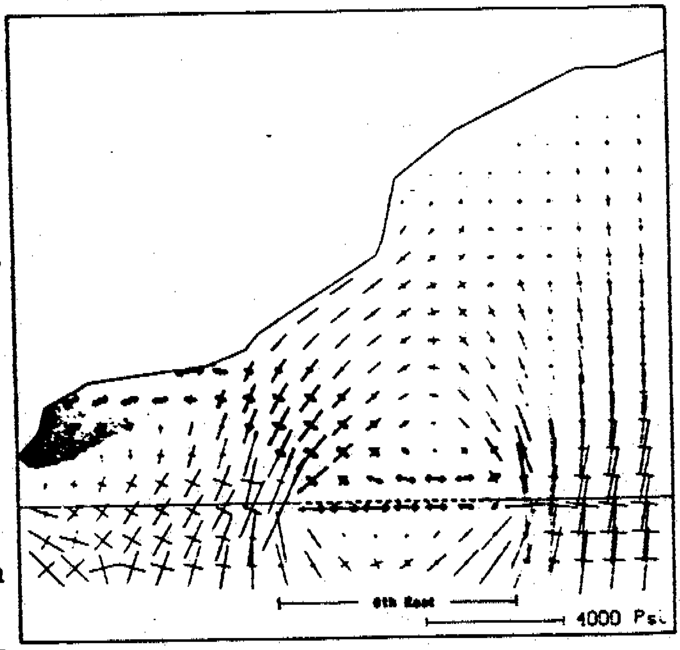
plans are developed to achieve maximum resource recovery while minimizing environmental impacts. This paper demonstrates the attempt to use the boundary-element method as a tool toward accomplishing this goal. A similar study was conducted by Jones and Pariseau (1990) using the finite-element method.

2 BOUNDARY-ELEMENT ANALYSIS

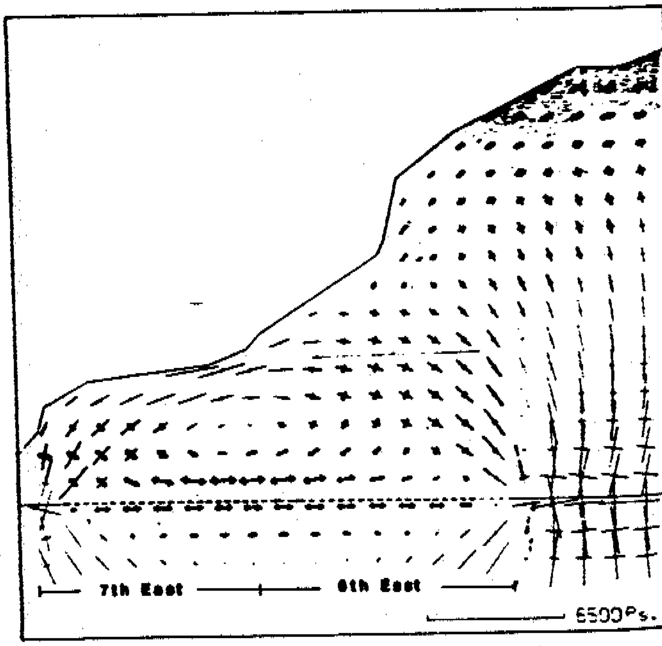
The boundary-element method is similar to the finite-element method in that the region of interest being modeled, i.e. a rock mass, is treated as a continuum. The two methods differ in that the boundary-element approach requires discretization only along the boundary of the problem, for example, the surface of an excavation. A two-dimensional boundary-element analysis, under plane strain conditions, was conducted along cross section A (figure 1) to compute the stresses and displacements associated with mining the 6th and 7th East longwall panels underlying the massive Castlegate Sandstone. The 6th East panel was extracted first followed by extraction of the 7th East panel. Both panels had a width of 650 feet, and mining progressed into the plane of the cross section. The model assumed the rock mass behaved as an infinite, homogeneous, linear elastic continuum. The particular boundary-element approach used for the study was the displacement-discontinuity method (Crouch 1976).

Displacement-discontinuity boundary elements were placed along the slope and escarpment regions and prescribed zero normal and shear stresses to represent the free surface. Displacement-discontinuity elements were also 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. The rock mass was assigned an elastic modulus of 1.5E6 psi and a Poisson's ratio of 0.2. In situ stresses were generated by gravity loading alone.

Figures 2a and 2b show plots of principal stress vectors as a result of mining the 6th and 7th East longwall panels, respectively. Figure 2a illustrates that high tensile stresses are generated 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. Extraction of 6th East panel.



b. Extraction of 6th and 7th East panels.

Figure 2 Principal stress vectors. The shaded areas depict zones of tension, with the direction of tensile stresses indicated by diverging arrows.

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A compression arch is formed well above the coal seam beyond which no tensile stresses are present, even in the vicinity of the escarpment. Tensile cracking would not be expected in this area at this stage of mining. Figure 2b shows tensile stresses extending up into the escarpment region after the 7th East panel is mined. At this stage of mining, the potential for escarpment instability exists if these stresses were to exceed the rock strength and create additional tensile fractures. Figure 3 shows the final displacement profile as a result of mining both the 6th and 7th East longwall panels. The displacement vectors are predominantly in the vertical direction; however, a small outward horizontal displacement component exists near the escarpment outcropping. The presence of tensile fractures in this area could induce larger outward horizontal displacements that may lead to toppling or ejection of escarpment material. It should be noted that the boundary-element program for this study assumed an infinite region. Thus, the free surface along the escarpment and slope represented a boundary to the problem. In order to meet the required traction-free boundary conditions, i.e., zero normal and shear stresses, displacements and stresses were induced within the rock mass. These displacements could be visualized as those developed over the geologic period in forming the cliff. In order to isolate the displacements induced as a result of mining alone, one run was made in which no mining took place. These displacements were then subtracted from all subsequent mining stages to obtain those displacements resulting only from mining. The displacements shown in figure 3 are a result of subtracting off the initial displacements prior to mining.

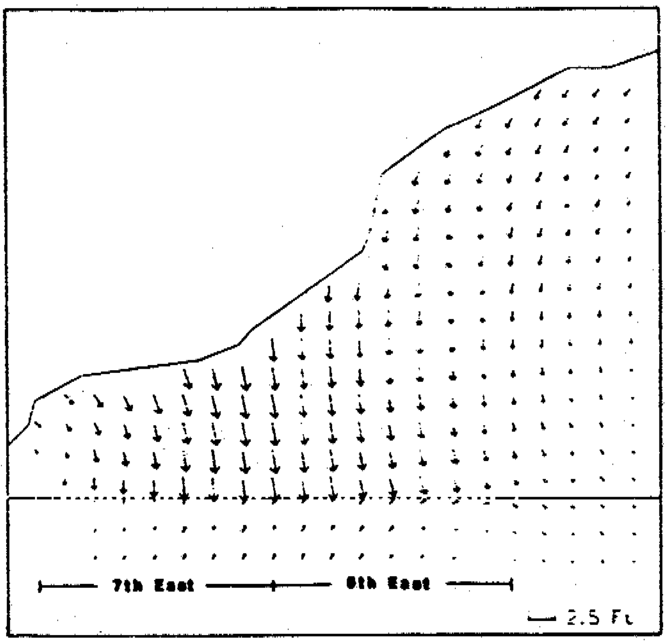
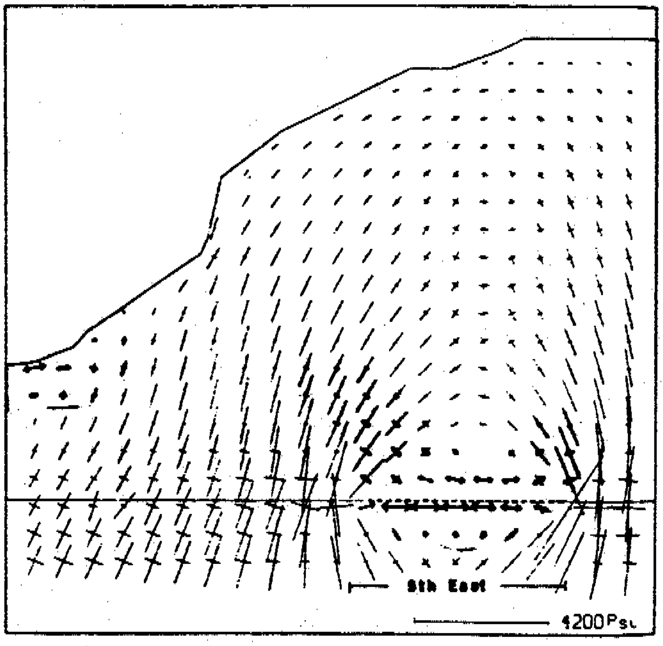


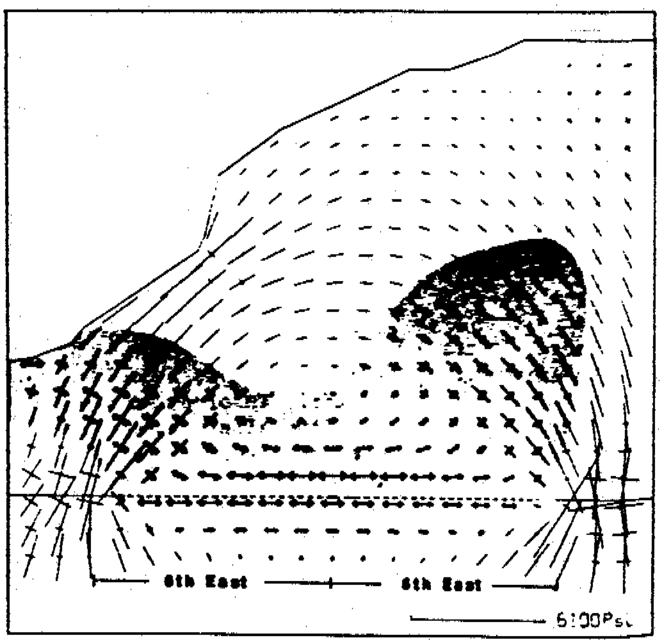
Figure 3 Displacement vectors after extraction of both 6th and 7th East longwall panels.

An additional analysis was conducted assuming a hypothetical 5th East longwall panel being mined adjacent to the actual 6th East panel. For this case, the 5th East panel was located to the right of the 6th East panel, so that mining of these two panels halted just beyond the escarpment outcropping. Figures 4a and 4b show principal stress vector plots as a result of this hypothetical mining of the 5th and 6th East panels, respectively. Results show that no tensile stresses would be generated within the escarpment region after extracting both panels. Figure 4b shows the entire escarpment region located within the compressive arch formed after extracting both the 5th and 6th East panels. For this case, much higher compressive stresses can be seen near the toe of the escarpment than in the previous analysis of the 6th and 7th East panel extractions. Localized yielding could occur in this area if these stresses were to exceed the rock strength. Figure 5 shows the final displacement profile after mining both the 5th and 6th East panels. Again the displacement vectors are predominantly in the downward vertical direction; however, in the vicinity of the escarpment outcropping there exists a small horizontal component directed inward. Theoretically, this may contribute to reducing escarpment instability.

The actual escarpment region in the area of the study site contains numerous vertical joints running parallel to the escarpment, with average spacings of approximately 10 to 20 feet. This particular analysis did not take



a. Extraction of 5th East panel.



b. Extraction of 5th and 6th East panels.

Figure 4 Principal stress vectors. The shaded areas depict zones of tension, with the direction of tensile stresses indicated by diverging arrows.

into account the presence of joints within the escarpment region. The displacement-discontinuity method does, however, have the capability of modeling the non-linear slip and separation along joints according to, for instance, a Mohr-Coulomb failure criterion. One might expect that modeling the presence of such joints in the escarpment region would increase the amount of any outward horizontal movement than that calculated from a purely continuum analysis.

3 CONCLUSIONS

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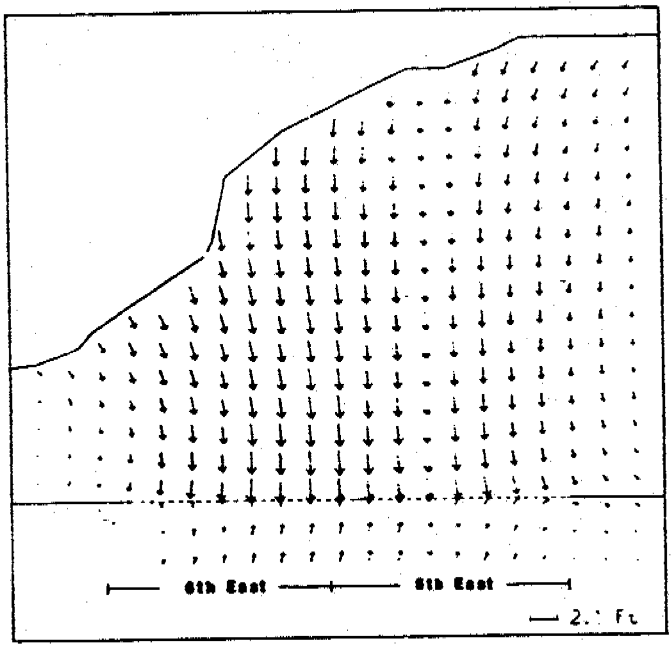

Figure 5 Displacement vectors after extraction of both 5th and 6th East longwall panels.

3 CONCLUSIONS

A numerical analysis is presented to demonstrate the use of the boundary-element method in assessing the stability of escarpments subjected to mining-induced subsidence. The results show that even with a fairly simple model, useful information can be obtained in locating zones of high tension or compression as well as overall displacement profiles toward formulating, for example, decisions on optimum panel layouts. The main advantage of the method is that it gives the analyst a tool to conduct a number of parametric studies in a relatively short period of time, and obtain useful information toward setting up more complex models. Certain assumptions are also made in this analysis, such as assuming the rock mass behaves as a homogeneous, linear elastic continuum. It needs to be determined through field investigation studies, therefore, whether or not these assumptions are acceptable. Other methods such as finite-element or discrete-element may be better suited depending on whether complex nonlinear or discontinuous rock mass behavior are the governing features. A detailed escarpment stability study should utilize results based on a number of different modeling approaches.

REFERENCES

Crouch, S.L. Analysis of stresses and displacements around underground excavations: An application of the displacement discontinuity method, Geomechanics report to the National Science Foundation, Minneapolis: University of Minnesota, 1976.

Payne, V.E. 1987. Assessment of Mining Related Impacts in Newberry Canyon, Cottonwood Coal Mine, Emery County, Utah. Prepared for Utah Power & Light Company Mining Division, Technical Services, Huntington, Utah.

Jones, R., and B. Pariseau. Sandstone escarpment stability in the vicinity of longwall mining operations. To be presented at the 31st U.S. Symposium on Rock Mechanics, Colorado School of Mines, Golden, CO, June 18-20, 1990.

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1 INTRODUCTION

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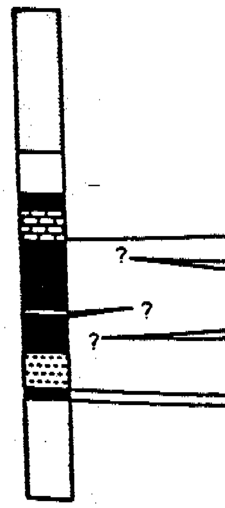

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COLORADO SCHOOL OF MINES / GOLDEN / 18-20 JUNE 1990

Rock Mechanics Contributions and Challenges: Proceedings of the 31st U.S. Symposium

Edited by

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US Bureau of Mines, Denver

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1990