Skyline

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SUBSIDENCE POTENTIAL OF HUNTINGTON CREEK AREA
OVER WEST MAINS CROSSING - SKYLINE MINE NO. 3

Dear Mr. Bunnell:

This Report presents the results of our rock mechanics study regarding the subsidence potential of the Huntington creek area due to a development of entries underneath in the Skyline Mine No. 3. This study was performed under the Work Order No. 596W of Contract No. SKCO-86-006.

A review of empirical theories of subsidence indicated that surface subsidence due to driving the West Mains is not expected within the Huntington Creek area for the proposed design layout. Two and three dimensional finite element calculations were performed to further analyze the subsidence potential for the given geologic and geometric conditions.

Based on the results of these analyses, we conclude that there is no possibility of subsidence resulting from the development of the West Mains entry system as proposed.

Respectfully submitted,

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INTRODUCTION AND SUMMARY

The Skyline Mine No. 3 of Utah Fuel Company is being extended by a five-entry system referred to as the West Mains in this report. The western end of the West Mains will be developed beneath a perennial stream, Huntington Creek. Figure 1 shows the general layout of the extended mine area with surface topography. Figure 2 is an enlarged plan view of the West Mains underneath the Huntington Creek.

The purpose of the present study is to resolve the issue of subsidence in the vicinity of Huntington Creek due to the driving of the main entry system below it.

Conventional theories of subsidence based on empirical formulas are not applicable to the given underground configuration as the geometric coefficients are beyond the ranges for experienced surface subsidence (National Coal Board, 1975; Karmis, 1989). That is, the overburden depth the entry openings (1150) is sufficiently great that the eventual collapse of the entry openings as a whole will not be expressed on the surface. Taking 1.2 as the bulking factor, as normally used for roof caving, about five times (60) the room height (12) may cave in when the caved gob starts taking the overburden load. For a long-term (50 or more years) consolidation of the gob, additional 60 above the gob may be fractured. The combined height of 120 feet is too small for the effect of caving to reach the surface.

The subsidence potential is further analyzed using two-dimensional finite element models of the vertical section transverse to the main entry. The basic finite element model for these analyses is shown in Figure 3. This figure shows panels mined beyond the 200 foot barrier pillars adjacent to the main entries, although cases both with and without the mining of these panels have been analyzed. The model consists of the entire region from the mine to the ground surface, and extends for more than 1000 feet on either side of the main entry. Subsidence is taken to be indicated by a zone of yielded rock extending all the way from the mine to the ground surface.

The baseline case incorporates rock properties that are represented as conservatively weak, but a variation on these properties that is even more conservative, in that it moves the overburden down one grade in quality is also analyzed to compensate for the fact that the ground will have to maintain its stability for a very long period of time.

A two-dimensional cross section of the main entry configuration provides a good approximation to the loading in the roof, floor, and barrier pillars, since these structures have very little variation in the out-of-plane direction. There is a slight exception to this in the case of the barrier pillars, where the presence of panel entry junctions every 500 or 600 feet or so will result in some very slight stress abutments, but these should have very little effect on the distribution of stress in the overburden, and therefore, on the likelihood of subsidence.

For the purpose of the finite element analysis, the entry pillar dimensions were reduced to 75' by 75' from the designed dimension of 75' by 100'. It was thought that smaller pillars would result in a greater subsidence potential, if any.

The smaller pillars within the main entry, however, are affected by the presence of crosscuts every 95 feet, and so these structures must be represented in the model using special pillar elements that incorporate the load/deflection characteristics of these pillars. These load/deflection characteristics are determined using an auxiliary three-dimensional calculation involving only a single pillar. From this three-dimensional analysis, the equivalent properties of a two-dimensional pillar element can be determined. Therefore, the analytical strategy for this investigation consists of both two-dimensional and three-dimensional analyses.

The results of analysis of the proposed development plan, that the main entry system crosses beneath Huntington Creek, indicate no possibility of surface subsidence. Even when the strength of the overburden material was reduced to an unreasonably low level, even though there were massive zones of yielding, there were no mechanisms of subsidence observable in the results. Based on these findings, we conclude that there is no possibility of subsidence resulting from the development of the main entry system as proposed.

A brief summary of the capabilities of the finite element code (BMINES) employed in this investigation, and the three-dimensional analysis is described in the Appendix section of this report. The following section incorporates the results of this analysis into the two-dimensional models.

ANALYSES OF SUBSIDENCE POTENTIAL

Three two-dimensional models are used to investigate the potential for subsidence in the Huntington Creek area. Referring to the basic model shown in Figure 3, the first analysis involves only the development of the main entry system, with no mining of the adjacent coal panels. This analysis is the one that corresponds to the mining plans proposed at this time. The second analysis is the same as the first, except that mining of the adjacent coal panels is included in the model. This calculation is significant in that it shows how subsidence is recognized from the output of the finite element models. However, no panels will be mined within the stream buffer, according to the proposed mining plan. The third calculation is the same as the first, except that the overburden material has been modeled as a poor quality rockmass. This analysis represents an extreme in conservatism in assessing the potential for subsidence due to the mining of the main entry system only.

The loading of the main entry cross section is provided by the weight of the overlying rock, which increases in thickness from South to North. The idealized overburden profile employed in the 2-D models is shown in Figure 3. The horizontal component of in-situ stress is assumed to be approximately equal to the vertical component, and so this must be applied through a distributed pressure along one of the side boundaries of the model. This creates a problem in the BMINES code, however, in that gravity loads are applied prior to pressure loads in the computer code software. This means that during the application of the gravity loads, the side boundary of the model is unconstrained. This results in the development of a great amount of artificial plasticity that would not be present if the lateral boundary were pressurized during this load application. In order to circumvent this problem, both components of in-situ stress are applied as an initial stress state, and the side boundaries are both rollered to provide confinement under all circumstances.

Since the vertical and horizontal in-situ stresses are nearly equal, the in-situ stress state has no plasticity, and can be computed using a model that has only elastic elements, removing any issues concerning the order of load application. The in-situ stress state was computed using an elastic model in which one side boundary was pressurized. The stress state resulting from this analysis was then introduced as the initial stress state in the nonlinear subsidence analyses. The presence of entry openings, and the replacement of coal with pillar elements and gob in this latter model provide the perturbations from which the stress state has to relax, possibly resulting in subsidence.

Considering the second of these analyses first, Figure 4 shows a view of the Huntington Creek cross section after development of the main entry system and mining of the adjacent coal panels. The two wide (200') barrier pillars and the four narrower (75') entry pillars are shown in black in the figure. The white spaces between these pillars represent the 20 wide entries, and the long white spaces outside the barrier pillars represent the mined out panels. Elements that are shaded gray are stressed to their yield limit, and the continuous band of gray elements extending from the main entry to the ground surface on the left side of the model indicates a failure mechanism that will allow the entire mass of overburden to the left of the break to drop down onto the gob. This will result in considerable subsidence over the mined out area on the left. It is noted that such a failure system did not develop on the right side of the model. This may be related to the proximity of the side boundaries. These boundaries are planes of symmetry, and since they are 1000' from the barrier pillars, they imply that the total length of the mined out panels is 2000'. However, the greater thickness of overburden on the right side of the main entry may also serve to inhibit the development of a strong subsidence mechanism on this side, whereas subsidence might very well occur if the panel length were substantially longer than 2000' (The right side is in a sub-critical area, according to the Subsidence Handbook by the British National Coal Board).

The Huntington Creek cross section for the first case, that in which there is no mining of the adjacent coal panels, is shown in Figure 5. Note that the adjacent panels, which were white in Figure 4 to indicate that they had been mined, are black in this figure, to indicate that the coal is still in place. Again in this figure, yielded elements are indicated by shading, but there aren't many of them. There are a few very small yielded elements in the roof immediately over the main entry, and one over the coal seam at the extreme right of the figure. The absence of a yield zone extending to the ground surface indicates that there will be no subsidence in this case.

Figure 6 shows the Huntington Creek cross section for the third case, in which the overburden is modeled as being of poor quality. This is a very large reduction in strength from an already conservative strength assessment. It is seen from this figure that there are extensive areas of yielded rock, but the rock is yielding primarily due to an inability to withstand the in-situ stress state. In other words, the rock material is not able to support its own weight. This observation is an indication that the rock properties specified for the overburden are weaker than could possibly exist in nature. But even with these very weak properties, there are no zones of yielding that connect the mine to the ground surface. Thus, it is safe to say that no matter how weak the overburden might be, there will be no subsidence resulting from the development of the main entry alone.

CONCLUSIONS

There is only one main conclusion to be drawn from this set of finite element calculations that there will be no subsidence resulting from the proposed development of the main entry system beneath Huntington Creek.

First, it has been demonstrated that, in a situation in which longwall panels are mined out adjacent to the Mains, the results of the finite element analysis provide a clear message that subsidence is probable. The yield pattern resulting from this configuration included an unmistakable zone of continuous yielding connecting the mine with the ground surface. This is the shear zone along which the material overlying the gob separates from the material overlying the main entry system, and caves in on the mined out area, resulting in subsidence over the lateral panels.

However, the analysis that corresponds to the proposed mining plan, that of only developing the main entry system beneath Huntington Creek, no indication of subsidence was observed in the results of this analysis. When the strength of the overburden material was reduced to an unreasonably low level, even though there were massive zones of yielding, there were no mechanisms of subsidence observable in the results.

Based on these findings, we conclude that there is no possibility of any subsidence, long term or short term, resulting from the development of the main entry system as proposed.

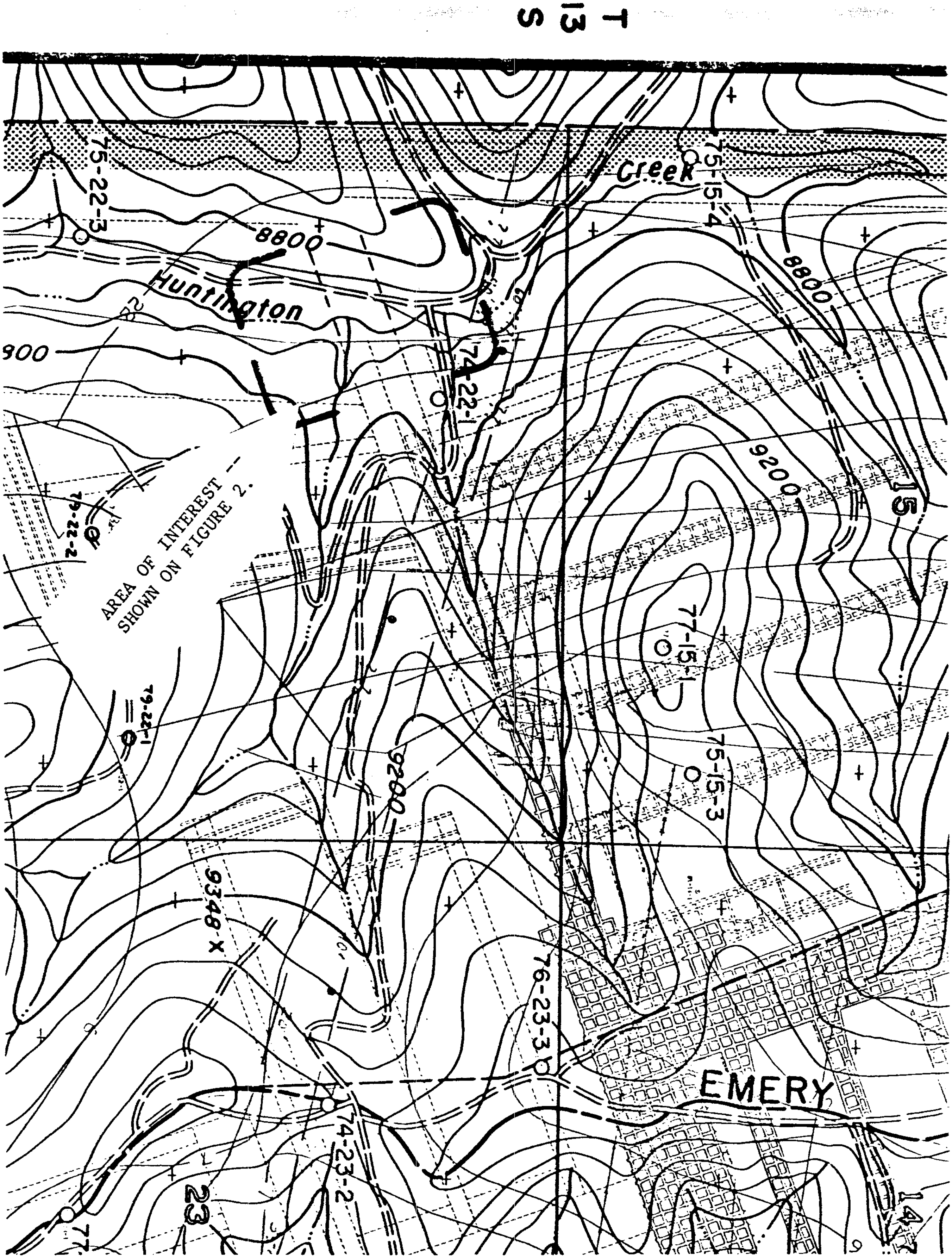

FIGURE 1. LOCATION MAP

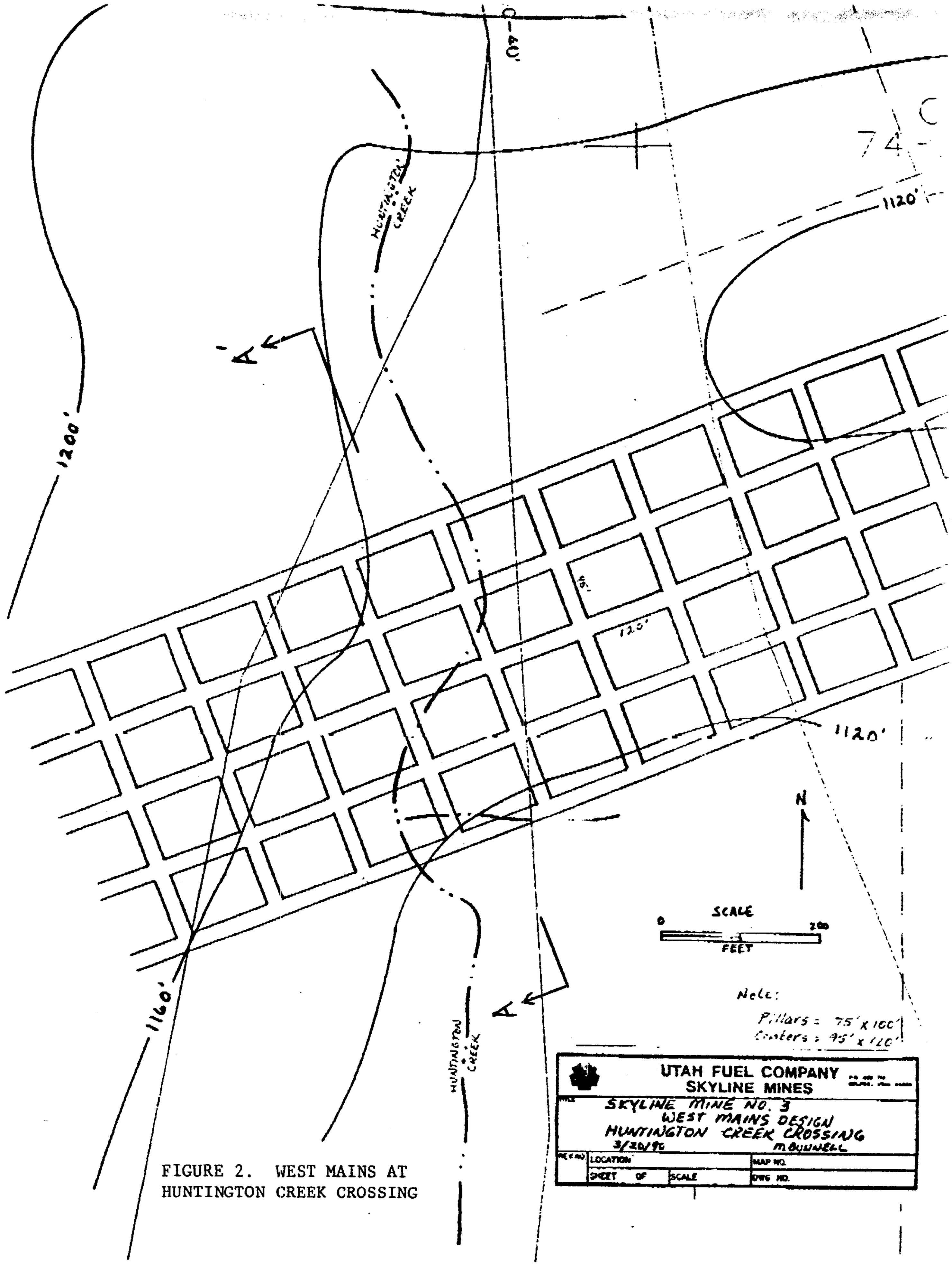

FIGURE 2. WEST MAINS AT HUNTINGTON CREEK CROSSING

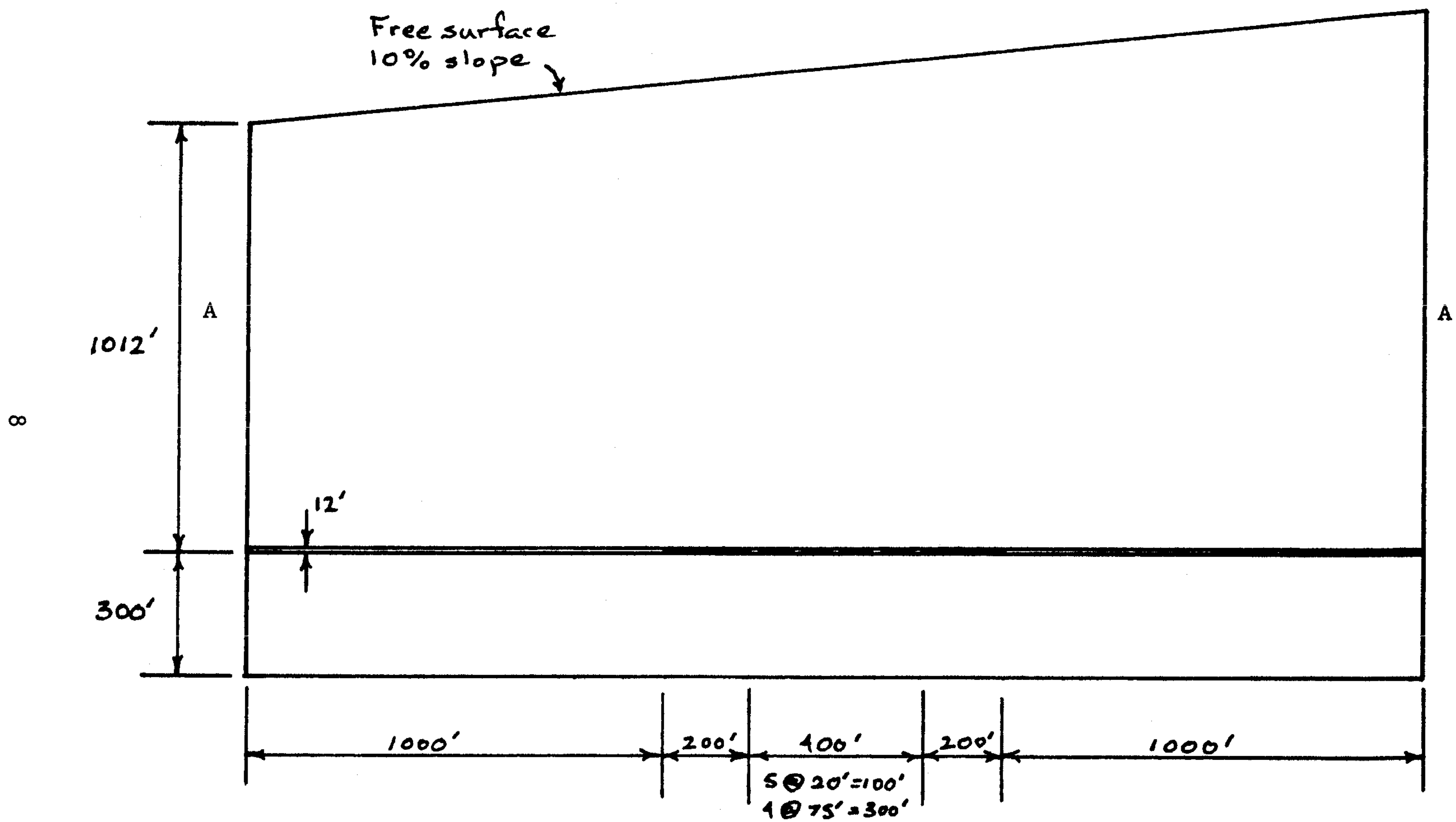

FIGURE 3. TWO DIMENSIONAL MODEL OF MAIN ENTRY CROSS SECTION BELOW HUNTINGTON CREEK
(Section A - A', Figure 2)

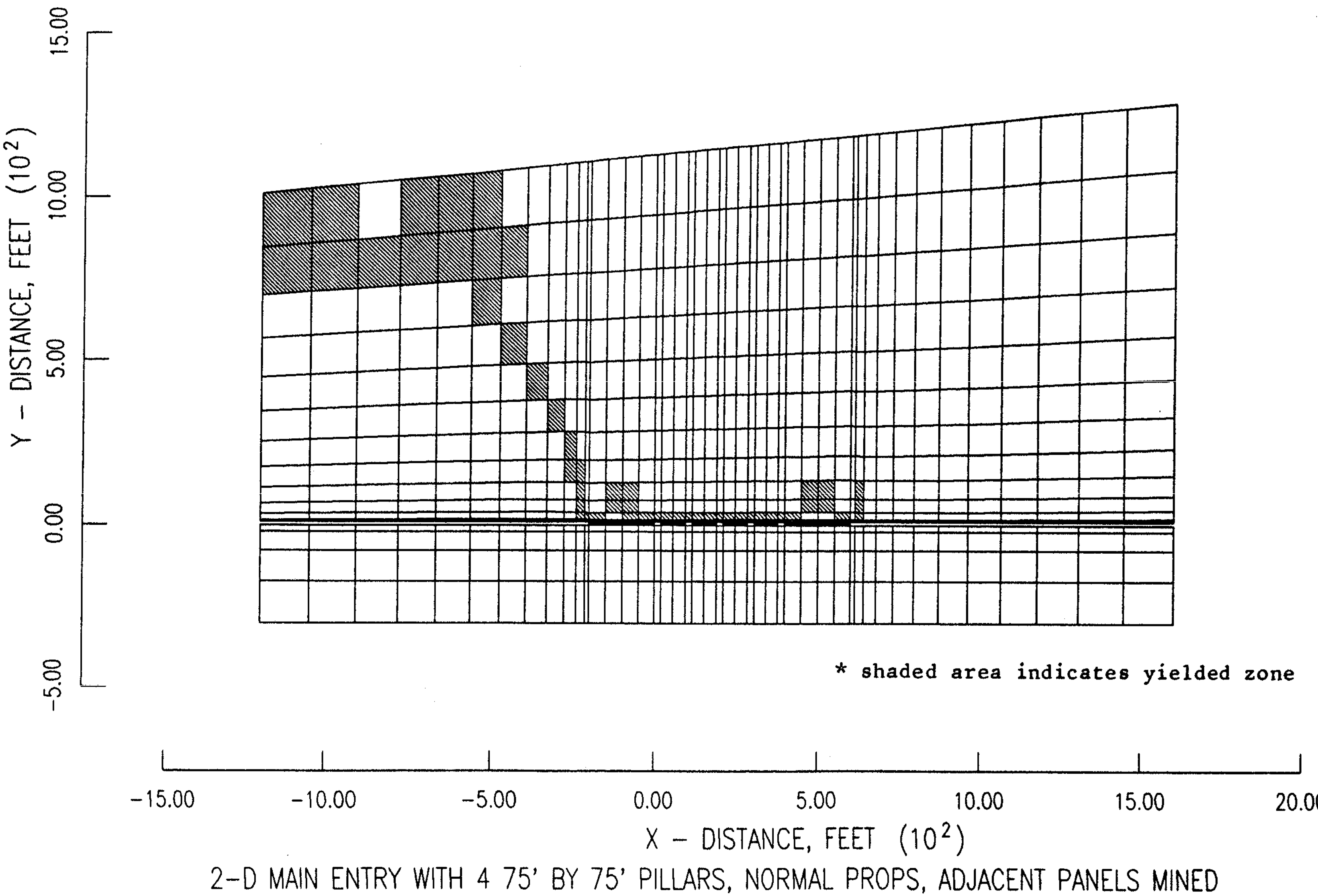

FIGURE 4. HUNTINGTON CREEK CROSS SECTION SHOWING MAIN ENTRY SYSTEM AND MINED OUT COAL PANELS

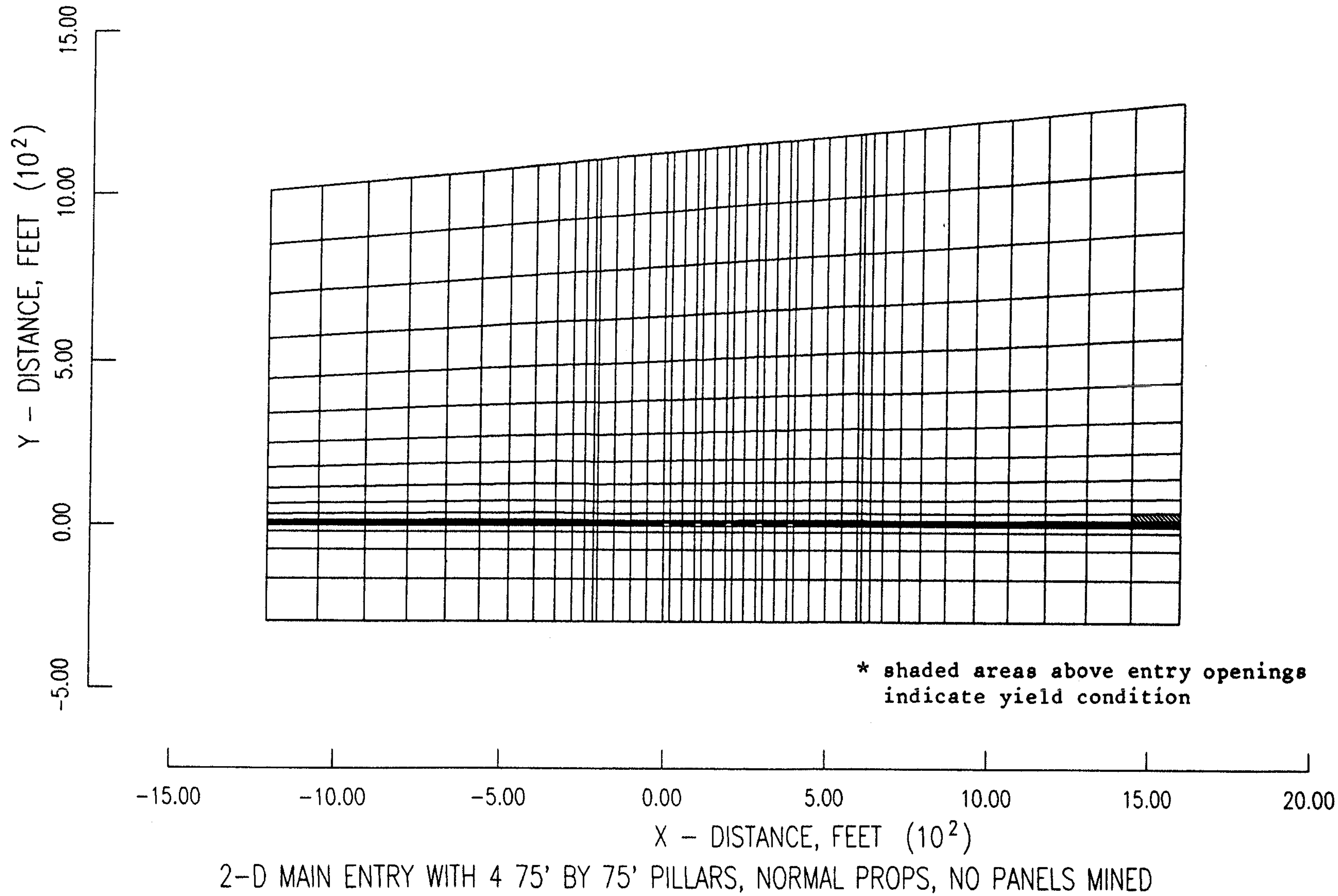

FIGURE 5. HUNTINGTON CREEK CROSS SECTION SHOWING MAIN ENTRY SYSTEM WITH REMAINDER OF COAL SEAM UNMINED

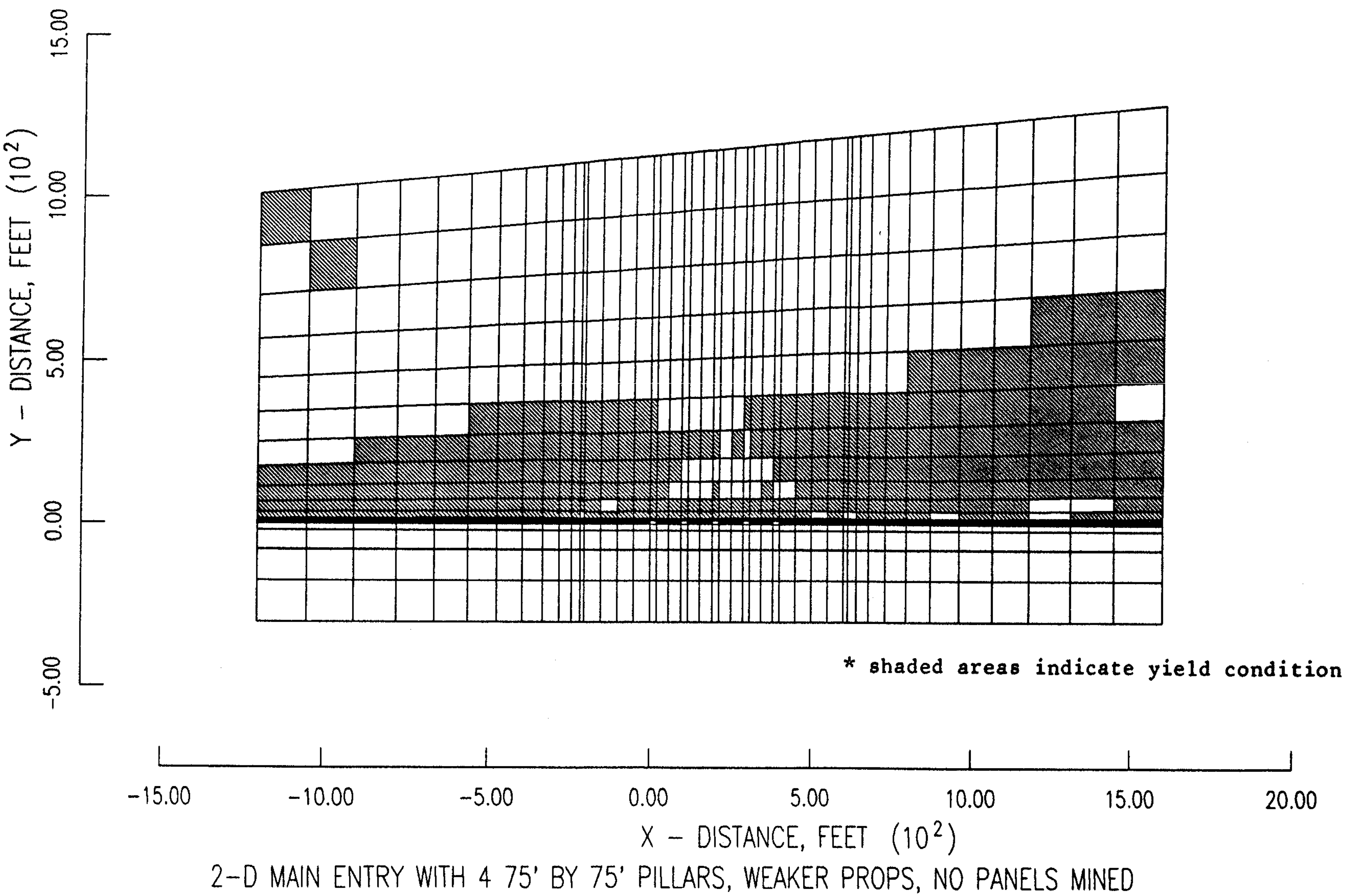

FIGURE 6. HUNTINGTON CREEK CROSS SECTION SHOWING MAIN ENTRY SYSTEM WITH REMAINDER OF COAL SEAM UNMINED -- WEAKENED PROPERTIES IN OVERBURDEN

APPENDIX - FINITE ELEMENT ANALYSIS

DESCRIPTION OF THE BMINES FINITE ELEMENT CODE

The BMINES computer program provides for the static, two- or three-dimensional, linear or nonlinear analysis of structural and geologic systems. The code was specifically designed for application to mining problems involving the simulation of excavation and construction sequences. This program was originally developed for the US Bureau of Mines by Agbabian Associates (Van Dillen et al., 1981) and was recently modified, without government sponsorship, to run on the IBM PC.

The capabilities of the BMINES code that are of particular interest for the investigation considered herein include primarily its ability to handle very large three dimensional models. This is made possible by a non-core-resident equation solver that utilizes disk storage to accommodate stiffness matrices far too large to be contained in random access memory. The mesh generator is invaluable in assembling large three dimensional models in a reasonable length of time and with a minimum of error. The material library contains both linear and nonlinear material models, with a variety of plasticity laws and an ability to represent anisotropic, viscoelastic, and viscoplastic materials.

The load options include externally applied tractions and gravity self weight. Options available for other applications include joint or fault interface elements in both two and three dimensions, element activation and deactivation useful in modeling the sequence of excavation and installation of support systems, and a rockbolt element capable of modeling bolt rupture, bond failure, and dowel shearing across a joint interface. The program is limited to small deformation analyses.

MATERIAL MODELS

Results of laboratory tests on intact specimens of rock taken from the mine have been provided for this study. A summary of the test results for coal are shown in Table 1, and less complete test results for the other rock units are provided in Table 2. The latter table includes a material called "overburden," which is intended to represent the average properties of the layered material that lies above the Lower O'Connor A coal seam. The rockmass quality of this composite material is taken to be "fair," using the quality categories of Hoek and Brown (1980), in order to conservatively recognize the presence of frequent material interfaces and occasional thin coal seams in this rock unit.

The numerical representation of the coal material in the BMINES code consists of linear elastic stiffness moduli with a quadratic representation of the failure envelope. It is well known that the mechanical response of the in-situ coal mass is diminished from the measured response of laboratory specimens due to the influence of joints and inhomogeneities. In accordance with previous experience in analyzing longwall coal mines (Van Dillen, 1978; Van Dillen and Fellner, 1981), the numerical model for in-situ coal was obtained by applying a reduction factor of 0.20 to each of the laboratory tests, and using a polynomial regression procedure to determine the coefficients of the yield envelope. Also in accordance with previous experience, the stiffness properties determined from the laboratory tests were used without reduction. The resulting numerical model, the Mohr-Coulomb representation of the laboratory data, and points showing individual failure stress states for the laboratory specimens are contained in Figure 7.

The remaining rock units contained in the idealized mine profile include sandstone, siltstone, shale, and general overburden, which has been specified as an approximate average of the other three materials in terms of mechanical properties. Laboratory test results for these materials are contained in Table 2, although the parameters provided for overburden were developed by approximate numerical averaging, rather than laboratory testing. All of these materials were judged to be of good rock quality in the sense of the rock mass characterizations tabulated by Hoek and Brown (1980). The text of this rock mass category description from Hoek and Brown is, "Good quality rock mass - fresh to slightly weathered rock, slightly disturbed with joints spaced at 1 meter to 3 meters." For the reason noted above, the quality index for overburden was reduced to fair. The text describing this category is "Fair quality rock mass - several sets of moderately weathered joints spaced at 0.3 meters to 1 meter." In one of the analyses, this rating for overburden is reduced further to "poor," in order to compensate for the long time that the mine site will be exposed to potential subsidence conditions. The text describing this category is

"Poor quality rock mass - numerous weathered joints spaced at 30 mm - 500 mm with some gouge filling / clean waste rock."

Figure 8 shows the failure envelope for the material model of sandstone incorporated into the BMINES numerical models. Also shown in this figure is the Hoek and Brown envelope for intact specimens of sandstone based on the unconfined strength provided in Table 2, and the corresponding envelope pertaining to a rockmass of "good" quality, as defined by Hoek and Brown. The BMINES model was tuned to agree with the Hoek and Brown rockmass envelope in the load range to be expected in the analyses, and it can be seen from this figure that the agreement is quite good.

Figures of the same type are provided for the other materials of Table 2. The model used for siltstone is plotted in Figure 9, shale is shown in Figure 10, and the general overburden is covered in Figure 11. The poor quality overburden model used for the worst case subsidence analysis is shown in Figure 12.

The stiffness of the gob is also required in the analysis of those cases in which the mining of adjacent coal panels is to be considered. The mining of these adjacent panels is not being proposed; however, it is of interest to examine what would be the effect, in terms of subsidence, if these panels were to be mined. This is the most critical load condition for the main entry, and one that must be endured for a number of years with a minimum of problems. The loading to be expected in the structures comprising this entry system is dependent on how much of the overburden over the mined out longwall panels is carried by the fractured rock rubble remaining in these areas. That portion of the overburden not carried by the gob must be supported by the barrier pillars and the interior pillars of the main entry. This distribution of loading is determined analytically by the finite element procedure based on the relative stiffness of the materials involved. Thus a stiffness model for the gob must be ascertained.

It can be reasoned that, since the gob occupies an area in which a considerable amount of material has been removed, initial sag of the secondary roof can occur with very little resistance. Thus the gob model should have a vanishingly small initial stiffness. By the time the secondary roof and floor have converged an amount approaching the thickness of the coal seam removed from the area, the remaining rubble has been compressed to nearly its original density, and its stiffness should be of the same order of magnitude as the original rock units from which it came. A smooth transition between these limits must be assumed, and the fidelity of the model can only be improved by comparing convergence predictions in the mined out panel entries with actual mine measurements, if available.

SINGLE PILLAR RESPONSE TO COMPRESSIVE LOADING

While most of the structures in the main entry configuration under consideration can be modeled effectively in two dimensions, this is not true of the smaller individual pillars in the entry system. The response of a coal pillar to compressive loading is strongly dependent on the magnitude of the horizontal stresses present in the pillar, and the smaller the cross-sectional dimensions of the pillar, the smaller these horizontal stresses will be. The only effective analytical means of determining the effective stiffness of a coal pillar is by a three dimensional analysis. Equivalent pillar elements for subsequent two-dimensional analyses can then be derived.

The entry pillars in the main entry design under consideration are 75′ by 75′ in plan, with 20′ entries and 20′ crosscuts. These pillars contain planes of symmetry passing through the center of the pillar in both grid directions, and along the centerlines of all entries. These planes of symmetry permit analysis using the three-dimensional model shown in Figure 13. This figure shows a quadrant of a pillar and the half-widths of two entries in a mine of height 12′ in the upper portion of a 27′ thick coal seam. Two feet of coal are left between the mine roof and the overlying sandstone stratum, and 13′ of coal lies below the mine floor. The model continues down to include a nearby 2′ layer of coal. Below this bed is an extensive sequence of thick sandstone layers providing a very stiff foundation for this much softer pillar model. This interface between the thin coal seam and the thick sandstone layers is taken as the bottom boundary of the model, and is rollered to simulate this rigidity of the underlying sandstone. Similarly, the model continues upward from the top of the Lower O′Connor A seam through a 4′ thick layer of sandstone and an 11′ thick layer of shale. Above the shale is nearly 20′ of sandstone and siltstone, which provide relatively rigid confinement for the top of the pillar. The interface between the shale and this overlying sandstone and siltstone is taken as the top boundary of the model. Loading of this surface is constrained to take place with planar, non-tilting distributions of displacement only, thereby simulating the rigidity of the overlying members.

The loading applied to a pillar by the convergence of the roof and the floor is not uniform, either in stress distribution or in displacement. In order to allow the pillars to accept load distributions more representative of conditions in the mine, it was necessary to include some of the mine material from both the roof and the floor above and below the pillar. The roof and floor material are continued laterally to the centerlines of the adjacent passageways to assure a realistic lateral distribution of stress and displacement. These considerations are important in allowing the pillar model to develop the correct amount of horizontal stress during deformation. Displacements ranging from 1" to 6" were applied to both models. At each displacement level, the total resistance of the pillar was determined by multiplying the stress in each element in a horizontal plane of the pillar by the cross-sectional area of the element, and adding up the contribution from each element of the cross section. This resultant force in the pillar was then expressed as an equivalent stress for an equivalent 2-D pillar element by dividing it by a plan area consisting of the half width of the pillar in the transverse direction and the half-distance between crosscuts in the longitudinal direction. Average displacements at the top and bottom of each pillar were determined in a similar fashion, and an average strain determined by dividing the difference in these average displacements by the height of the pillar. Average stress and strain values were computed for each load level calculated, and these values were assembled into equivalent stress/strain curves for pillar elements to be used in the 2-D models. The resulting stress/strain curve for the equivalent pillar element is shown in Figure 14.

TABLE 1

RESULTS OF LABORATORY TESTS ON INTACT SPECIMENS OF COAL FROM SKYLINE MINE NO.3

Modulus of Elasticity (E)	0.27×10^{6} psi
Unit Weight	78 pcf
Brazilian Tension	150 psi
Unconfined Compression	2,700 psi
Triaxial Compression	
Confinement @ 500 psi	4,500 psi
Confinement @ 1,000 psi	6,425 psi
Confinement @ 1,500 psi	7,920 psi
Representative Mohr-Coulomb Parameters	
Cohesion	500 psi
Friction Angle	45^{o}
Assumed Poisson s Ratio	0.25

TABLE 2

Nominal Properties of Rock Types at the Skyline Mines

Material	Modulus of Elasticity (ksi)	Poisson's Ratio (-)	Unit Weight (pcf)	Unconfined Strength (psi)	Hoek & Brown Material Category	Quality Index
Sandstone	1340	0.25	140	7000	Arenaceous	Good
Siltstone	2410	0.25	156	11800	Argillaceous	Good
Shale	710	0.25	150	4000	Argillaceous	Good
Overburden	1000	0.25	150	8000	Argillaceous	Fair

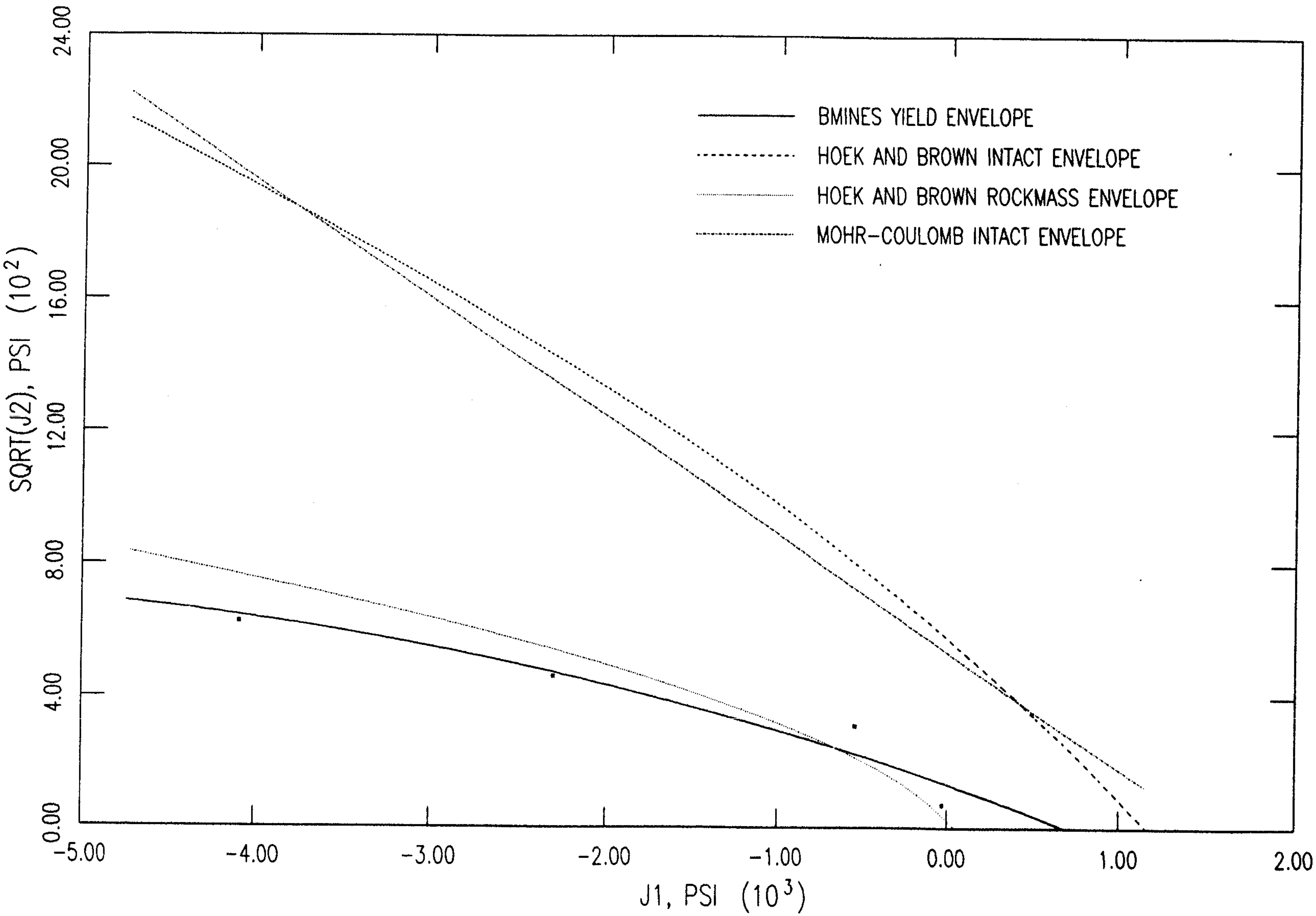

FIGURE 7. FAILURE ENVELOPE FOR COAL

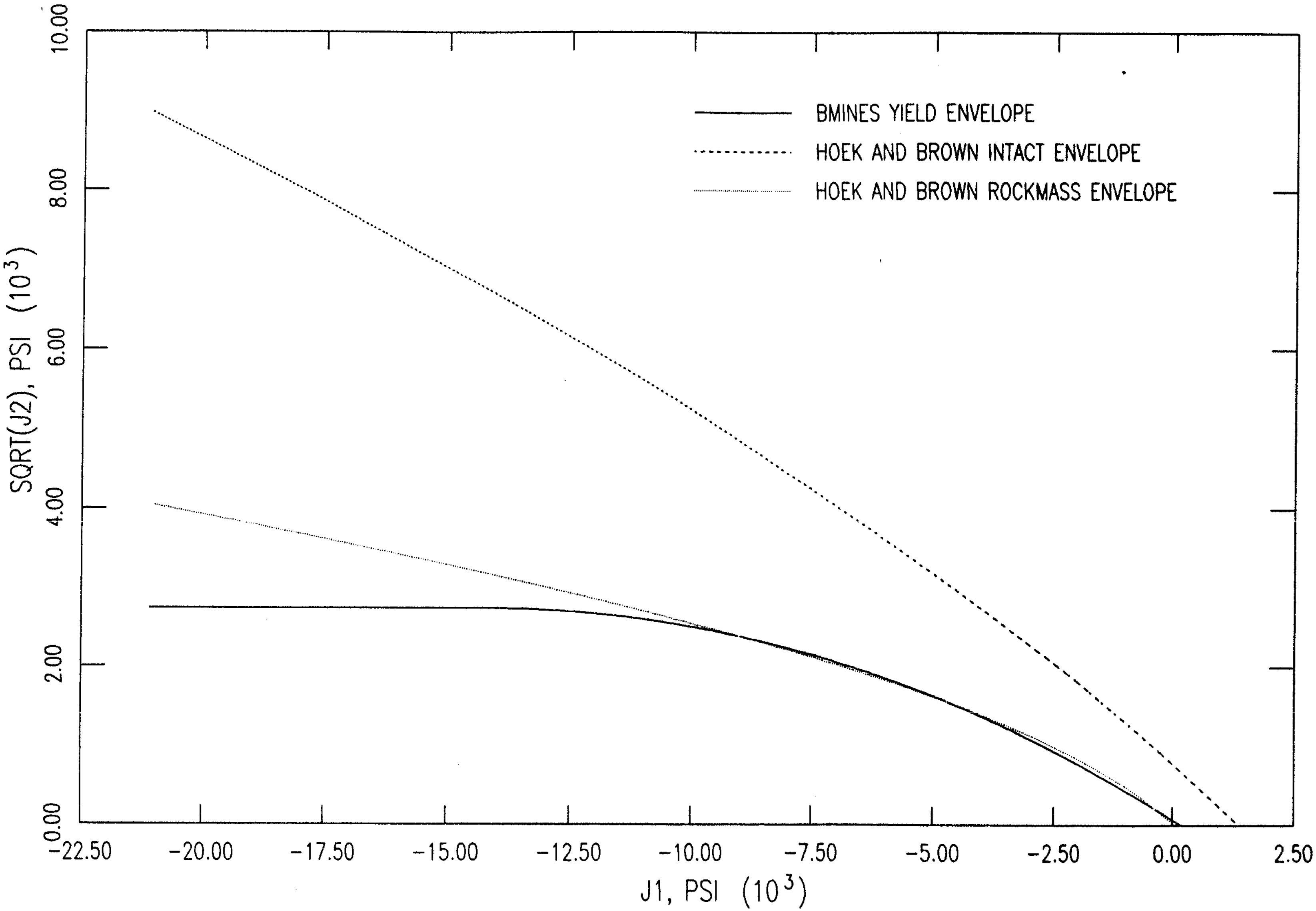

FIGURE 8. FAILURE ENVELOPE FOR SANDSTONE

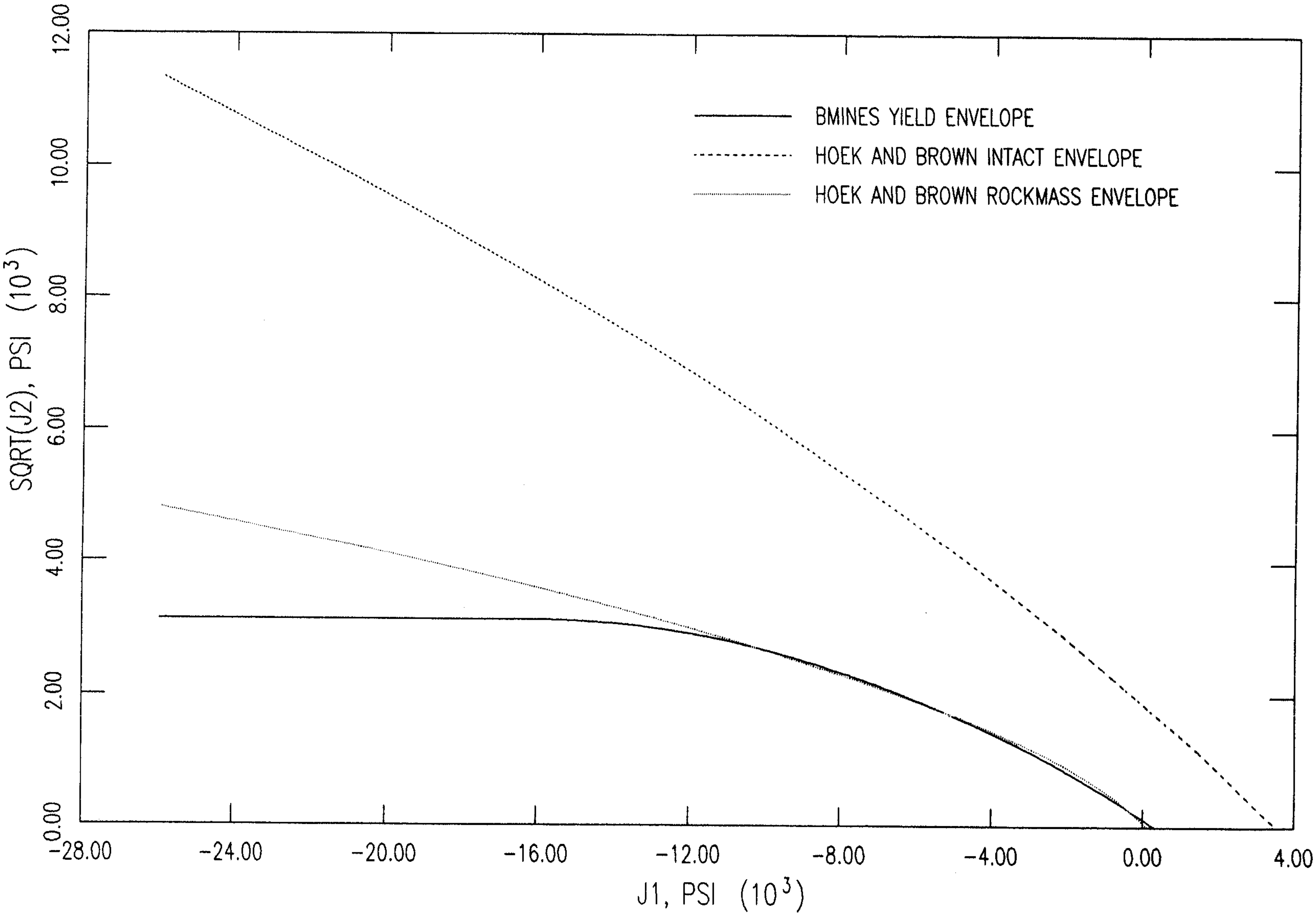

FIGURE 9. FAILURE ENVELOPE FOR SILTSTONE

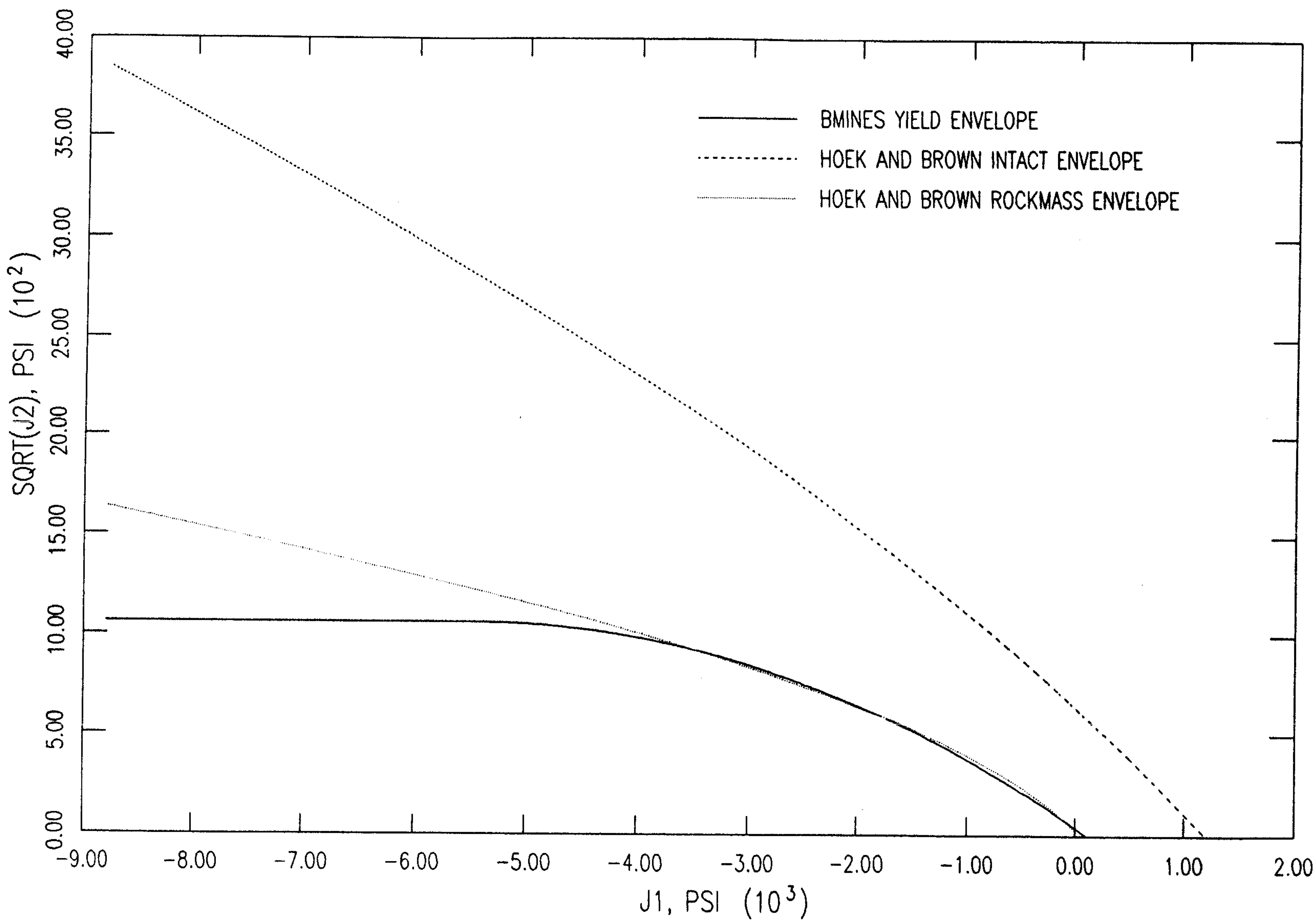

FIGURE 10. FAILURE ENVELOPE FOR SHALE

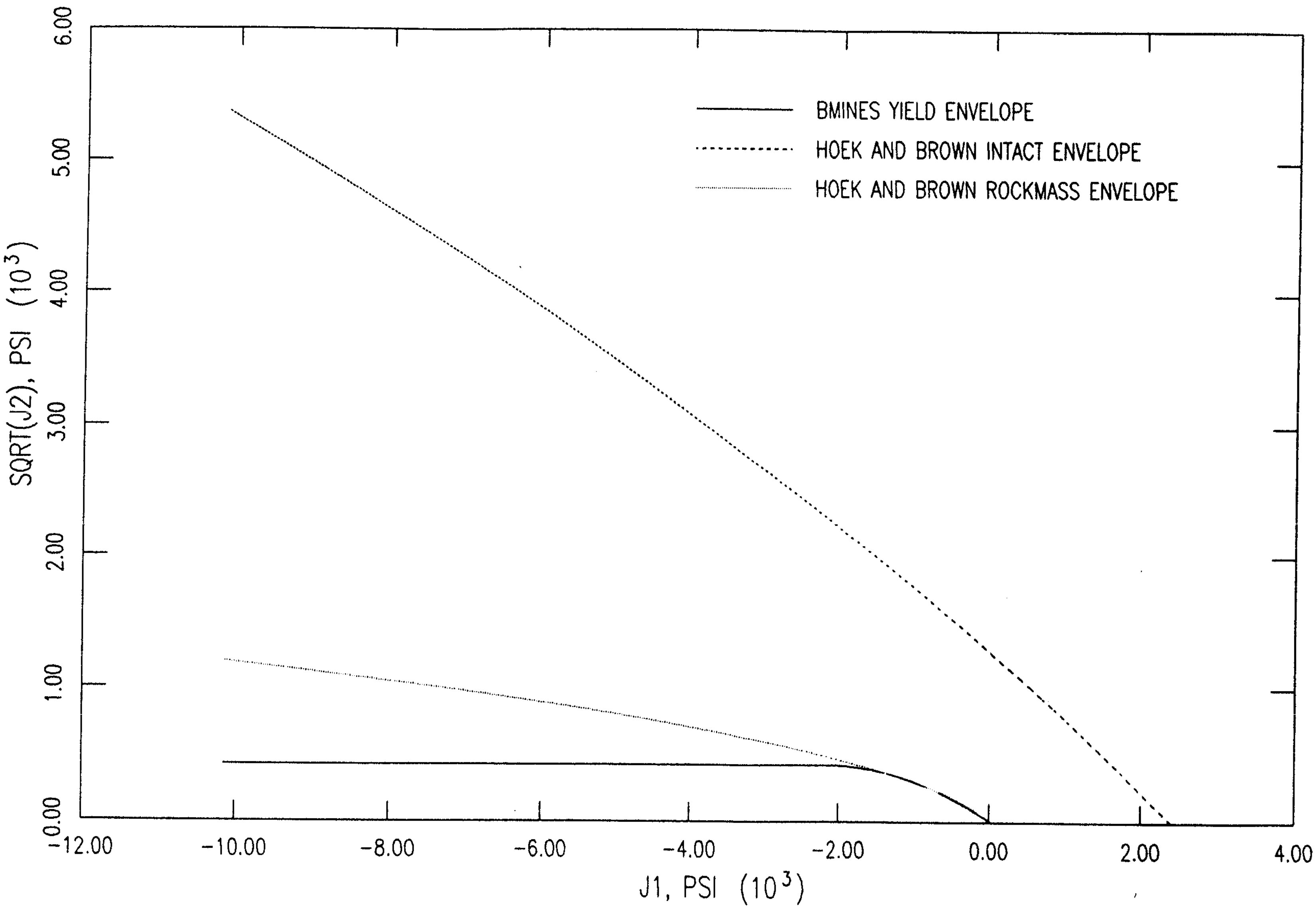

FIGURE 11. FAILURE ENVELOPE FOR OVERBURDEN

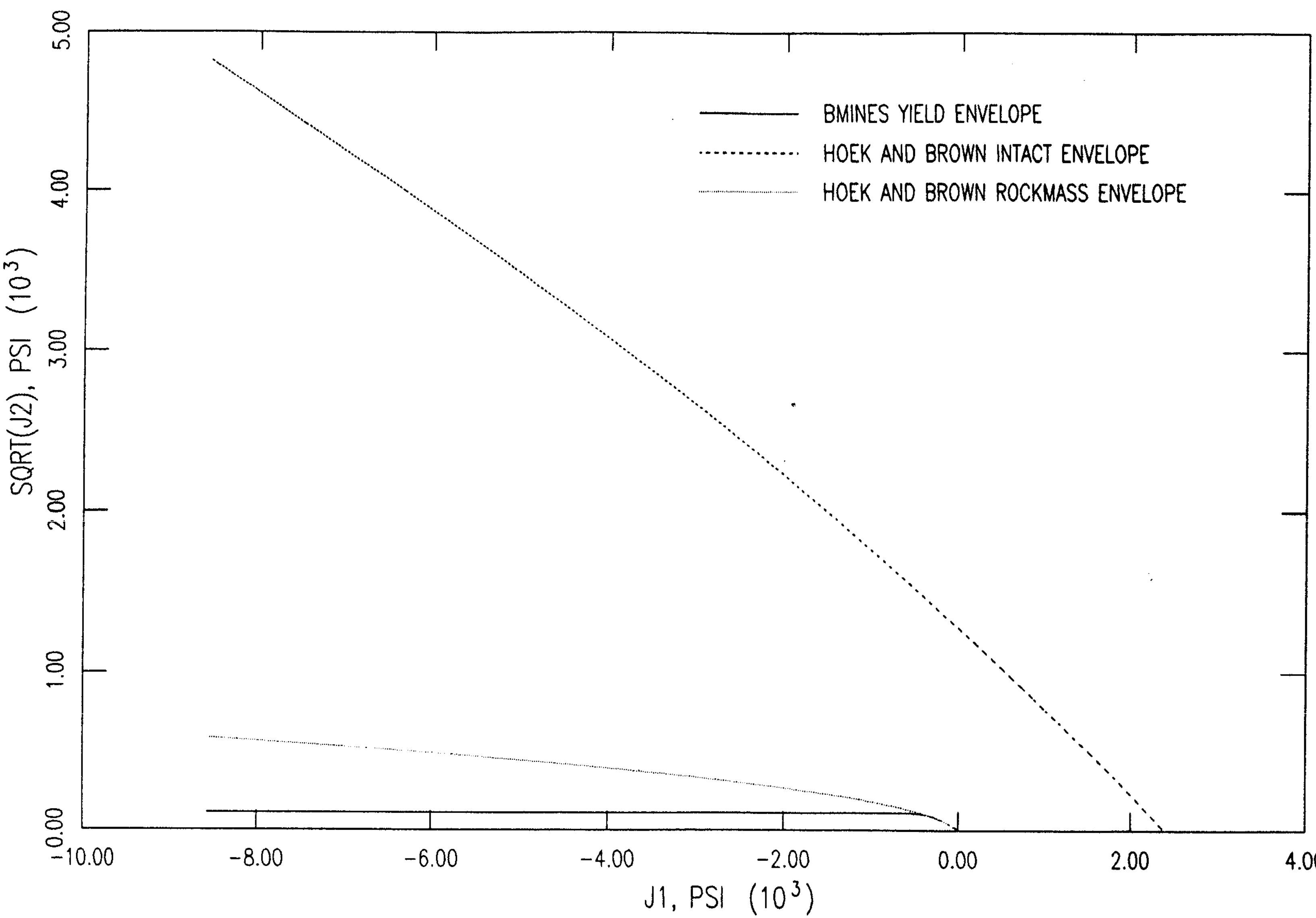

FIGURE 12. FAILURE ENVELOPE FOR OVERBURDEN, POOR QUALITY

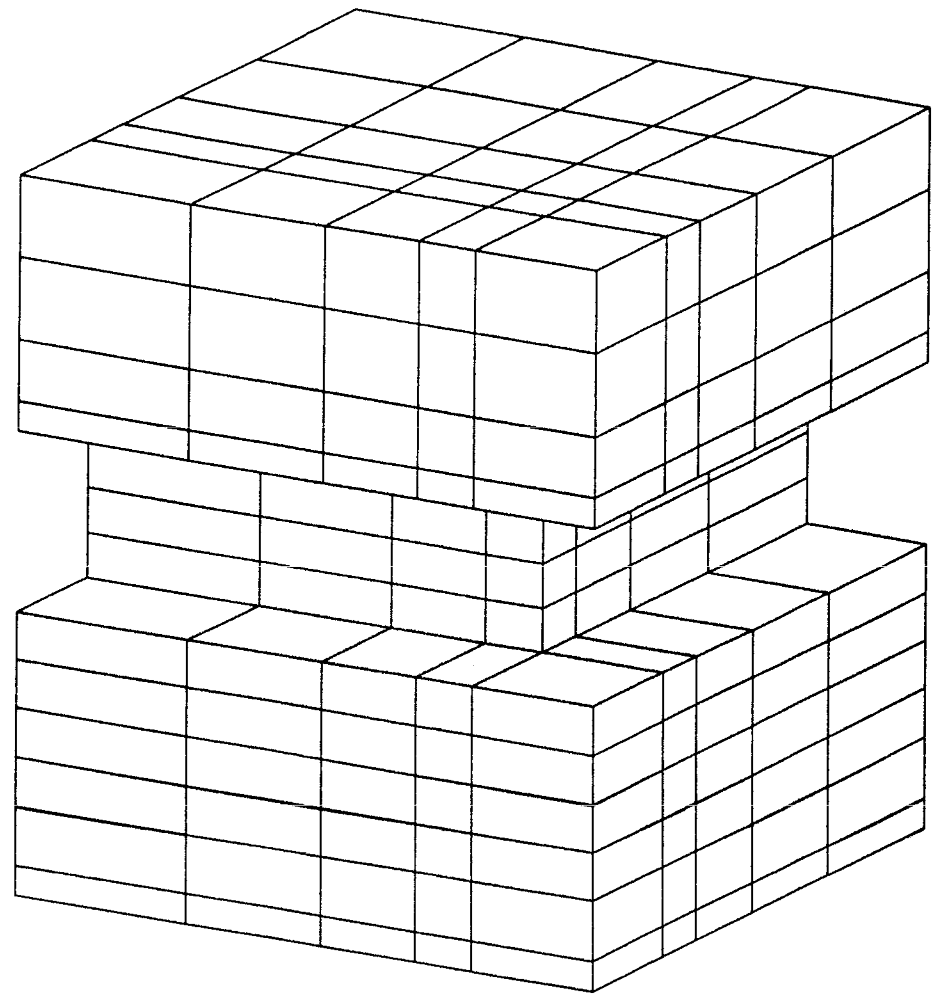

FIGURE 13. THREE DIMENSIONAL MODEL OF SINGLE PILLAR IN MAIN ENTRY

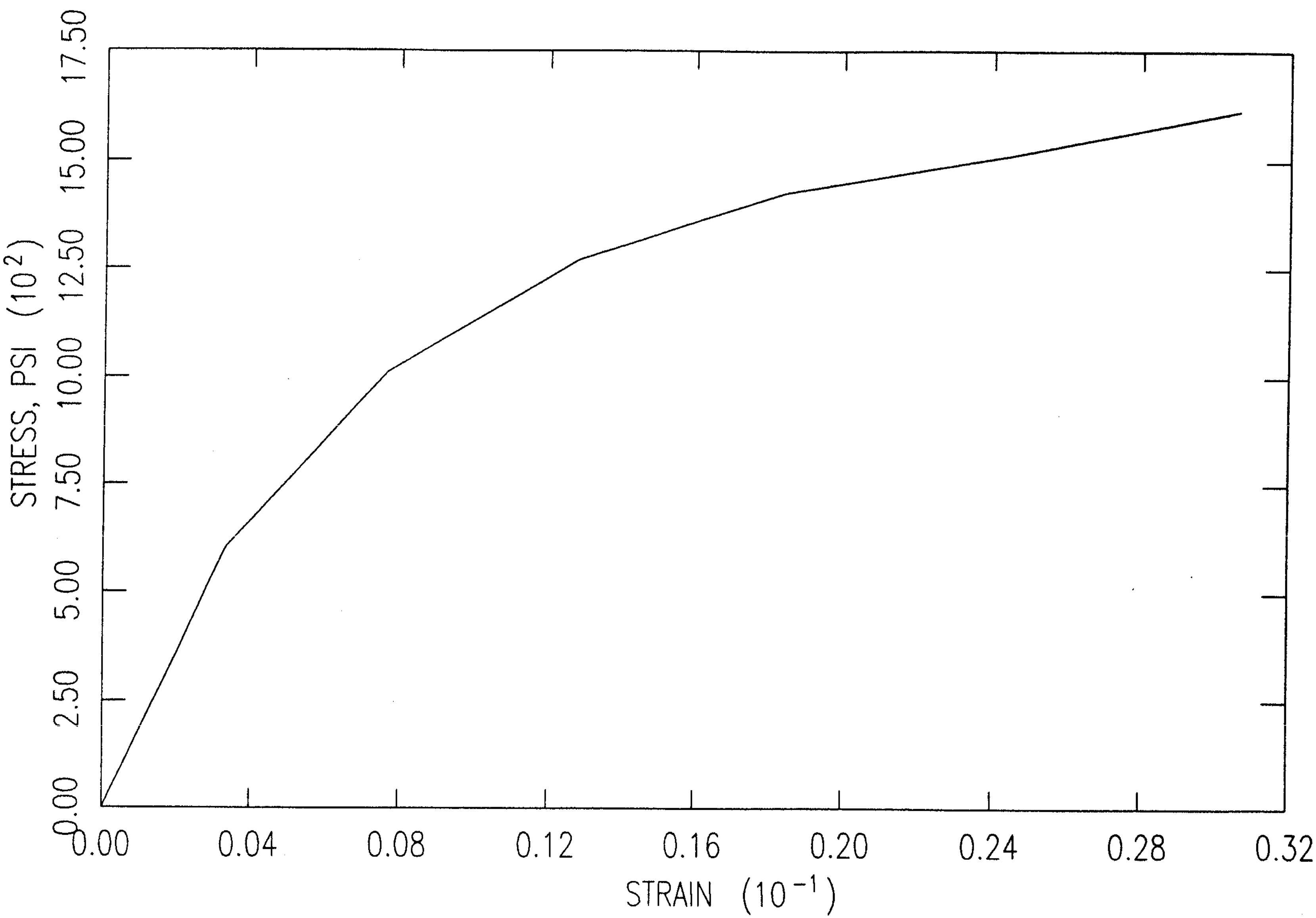

FIGURE 14. STRESS?STRAIN CURVE FOR EQUIVALENT PILLAR ELEMENT

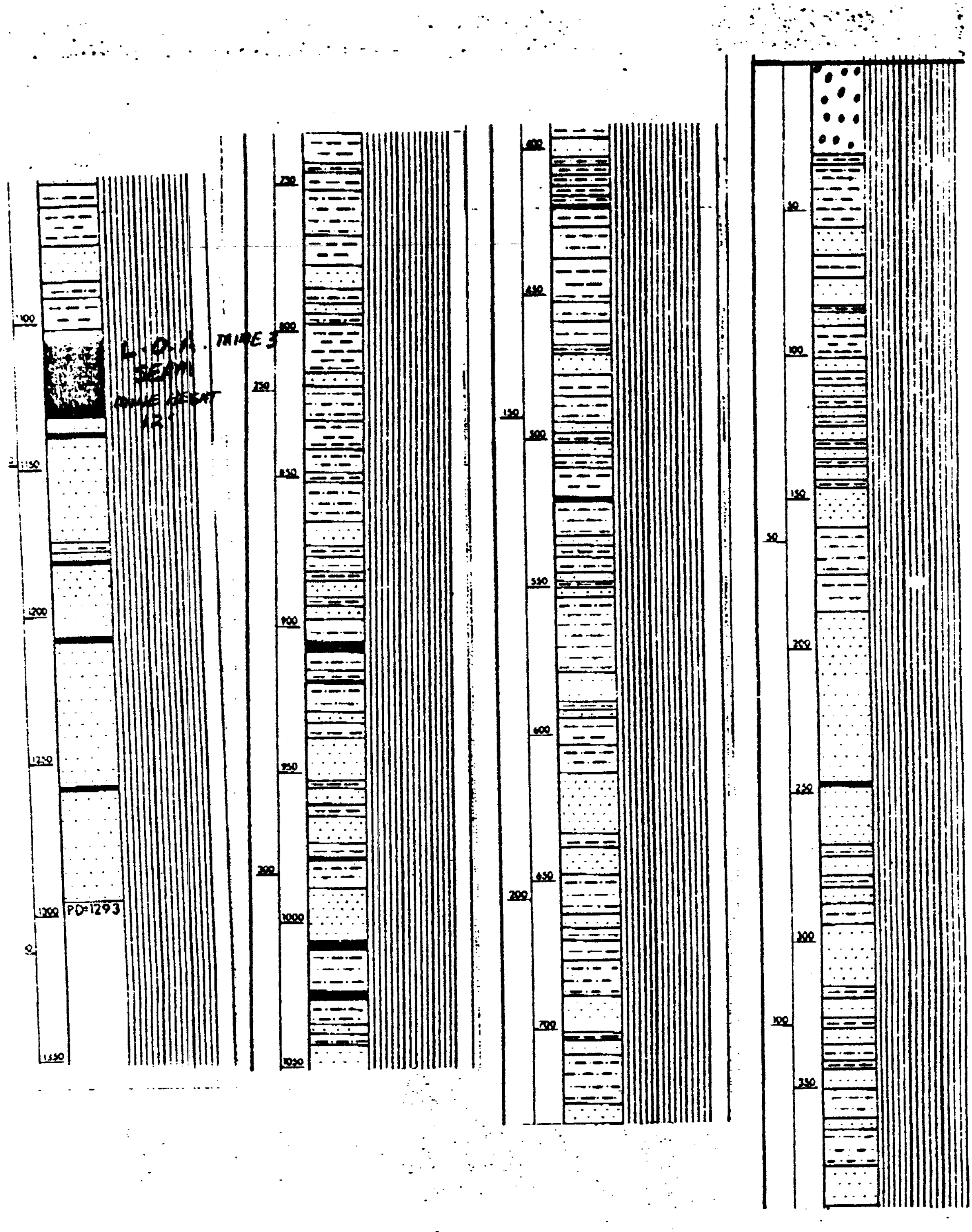

FIGURE 15. GEOLOGIC SECTION OF HUNTINGTON CREEK AREA (Drillhole No. 74-22-1)

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QUALIFICATIONS OF KCKA IN SUBSIDENCE ENGINEERING

Kenneth C. Ko & Associates, Inc. (KCKA) has been providing specialty engineering and consulting services in the area of rock mechanics, ground control and subsidence engineering for the past fifteen years. A selected list of clients is attached. Dr. Kenneth Ko, Principal Engineer of KCKA, has over twenty five years of experience in this field of engineering as the principal investigator. The resume of Dr. Ko is also attached.

Representative projects pertaining to surface subsidence engineering that have been completed by KCKA to date are briefly summarized as follows:

- An investigation of the effects of high pressure surface load on deep-seated underground rock structures, under a DOD contract -- the response of underground openings at 2000' and below was simulated using large scale laboratory models and the finite element method.

- Technical feasibility study of hydrolic and pneumatic backfill as means of surface subsidence and ground control remediation at an abandoned mine site in the City of Rock Springs, Wyoming, under a contract with Department of Environmental Quality, State of Wyoming.

- Consulting services to the US Bureau of Mines in the development and application of the BMINES Code -- applications included the ground control of single-entry panels at Sunny Side longwall mine to mitigate caving problems.

- Subsidence potential studies at a Aspen Public Park and along a County Highway in Boulder, Colorado -- both cases involved relatively shallow abandoned coal mines. Results of KCKA study indicated no subsidence, and clients built surface structures without further remediation.

- Subsidence potential studies, monitoring and prediction programs completed for Skyline Mines, Belina Mines, Homer City Mines, Energy Development Company, and others.

DR. KENNETH C. KO, P.E., PRESIDENT

EDUCATION:
Ph.D., Mining, University of Missouri
M.S., Mining, University of Washington
B.S., Mining, Seoul National University

REGISTRATION:
Professional engineer: Colorado, New Mexico, Wyoming, Nevada, and Utah.

EXPERIENCE SUMMARY:
For over twenty years, Dr. Ko has served as a researcher, consultant, and mining engineer. His experience includes basic research, field investigations, and practical problem solving. His experience also includes feasibility studies, economic analysis, and mine design. He has developed computer techniques that are effectively used in both geotechnical engineering and economic feasibility analyses. He is widely recognized as an expert in engineering applications of rock mechanics to civil and mining projects.

EXPERIENCE HIGHLIGHTS:
(1975-Present) **President and Chief Engineer, Kenneth C. Ko and Associates, Inc.** Dr. Ko has served as project manager and/or chief engineer on over 50 projects. Projects have included feasibility studies, development planning, surface and underground mine design, waste disposal, field investigations, failure mode analysis, instrumentation, laboratory services, and computer applications.

(1973-1975) **Senior Supervisory Engineer, W.A. Wahler & Associates** Assignments included tailings dams, coal waste systems, and open pit and underground mines. Project responsibilities extended from field investigation through final design and construction engineering.

(1972) **Consultant to the State of Virginia** Projects involved determination of the probable cause of the Saunders Dam failure and consultation on embankment regulation.

(1970-1973) **Associate Mining Engineer, Kennecott Copper Corporation** Responsibilities included stability analysis as well as development, and application of slope failure control techniques. Dr. Ko developed methods for stabilizing unstable slopes and parametric techniques for designing stable pit slopes. Stabilization techniques were effectively applied to control of unstable slope condition involving several million tons of rock mass. Dr. Ko also developed and applied computer techniques to feasibility study, mine design, and economic analysis of copper deposits.

(1968-1970) **Senior Research Assistant, University of Missouri** Research responsibilities included development of failure criteria and deformation moduli for heterogeneous rock materials.

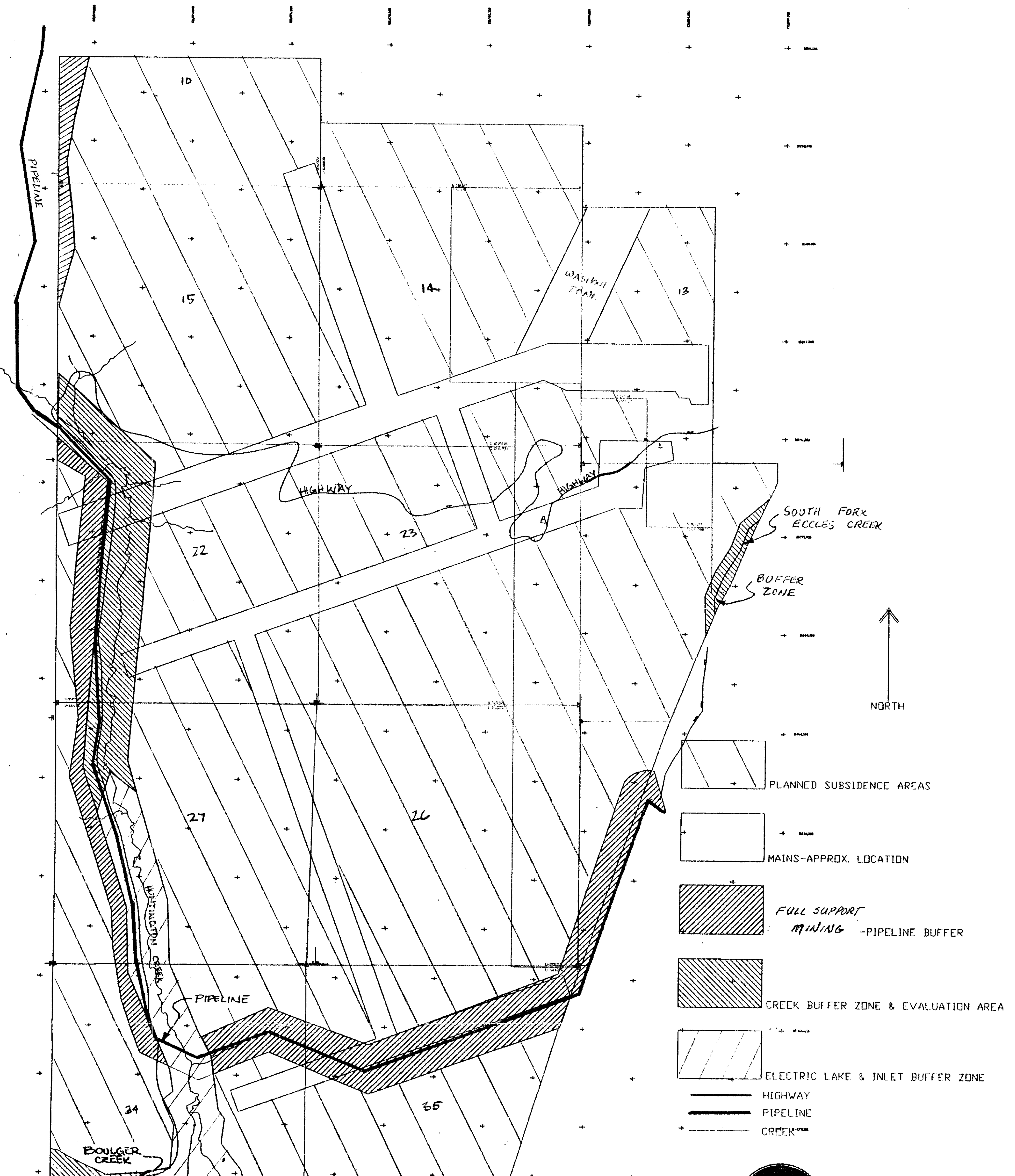
(1966-1968) **Research Fellow, University of California** Activities included post graduate studies and research in soil mechanics and geological engineering.

(1964-1966) **Mining Engineer, Western Nuclear, Sunshine Mining Co. and Susquehanna-Western** Duties included surveying, exploration drilling, feasibility studies, cost analysis, and mine design.

AFFILIATIONS:
SME-AIME, Denver Coal Club, Colorado Mining Association, Denver Mining Club, Northwestern Mining Association, ISRM.

PARTIAL LIST OF CLIENTS

• Adams County, Colorado	Foundation investigation
• Agbabian Assoicates, Inc.	Computer application
• Colo-Wyo Coal Co.	Coal, strip mine
• Continental Oil Co.	Uranium, open pit
• Cooper & Clark	Soil testing
• Cyprus Corporation	Uranium, open pit
• Domestic Power Development Co.	Fluorspar, feasibility study
• Dong-Jin Industrial, Inc.	Hydraulic mining
• Dong-Suh Engineering Co.	Oil storage caverns
• Earth Resource Associates	Soil testing
• Energy Development Co.	Coal, underground instrumentation
• Energy Fuels Corporation	Coal, underground/surface & multi seam
• Kaiser Resources	Coal, underground support system
• KIGAM	Coal, uranium development planning
• Pueblo Coal Co.	Waste dump design
• Rampart Exploration Corp.	Uranium, permit
• Resource Exploration and Mining	Coal, blasting studies
• David S. Robertson & Associates	Highway slope
• Rocky Mountain Energy Co.	Coal, underground
• Sandia Laboratories	Foundation soils at high temperatures
• Seongjoo Coal Co.	Anthracite, feasibility study
• Serata Geomechanics, Inc.	Tailings dam, stability
• State of Wyoming	Subsidence control
• Stearns-Rogers Engineering	Uranium, feasibility
• Stauffer Chemical Co.	Trona, underground
• Union Carbide Corp.	Tungsten, open pit
• U.S. Bureau of Mines	Coal, longwall systems
• Utah Fuel Co.	Coal, multi seam, roof supports
• Valley Camp of Utah	Coal, multi seam, sublevel caving & subsidence



Utah Fuel Company
A SUBSIDIARY OF THE COASTAL CORPORATION

EXTENT OF PLANNED
AND
CONTROLLED
SUBSIDENCE AREAS

DESIGNED BY: MARK BUNNEL DATE: 4-18-91
DRAWN BY: K. BOYD LAKE DWG. #:4.17.1-1

RECEIVED
MAY 10 1991
DIVISION OF
OIL GAS & MINING

2-4-9-2

Coastal
The Energy People

August 21, 1992

Mr. James D. Smith
Reclamation Specialist/Inspector
Dept. of Natural Resourses
Division of Oil, Gas and Mining
355 West North Temple
3 Triad Center, Suite 350
Salt Lake City, Utah 84180-1203

Dear Jim,

The water monitoring well at our Scofield Waste Rock Disposal site was completed on August 6, 1992. Attached is a well construction diagram as well as the field "cuttings" log. I indicated to you at the beginning of drilling that I was not planning to save cuttings, but because the well went much deeper than expected, I decided to save cuttings to ensure we had a good picture of the well.

Rock strata encountered during drilling were poorly consolidated, likely due to its close proximity to a segment of the Pleasant Valley fault system which was previously encountered by mining in the area. Due to its unconsidated nature, the hole was somewhat unstable, making placement of casing difficult. We had originally planned on using 6 in. casing and screen but 4 in. was finally utilized due to numerous blockages encountered as the 6 in. casing was lowered. Also due to unstable hole conditions, we placed a formation packer immediately above the screen to minimize sloughage around the screen.

No grout or cement was used to set casing with the exception of 10 ft. of cement installed at the surface to stabilize the 4 in. casing within the 8 in. casing.

Utah Fuel Company
A SUBSIDIARY OF THE COASTAL CORPORATION
P.O. BOX 719 • HELPER UT 84526 • 801 637-7925 • FAX 801 637-7929
SALT LAKE 801 596-7111

Please contact me if you require additional information. We are planning to survey the well location in the near future and I will forward that information as soon as it is available.

Sincerely,

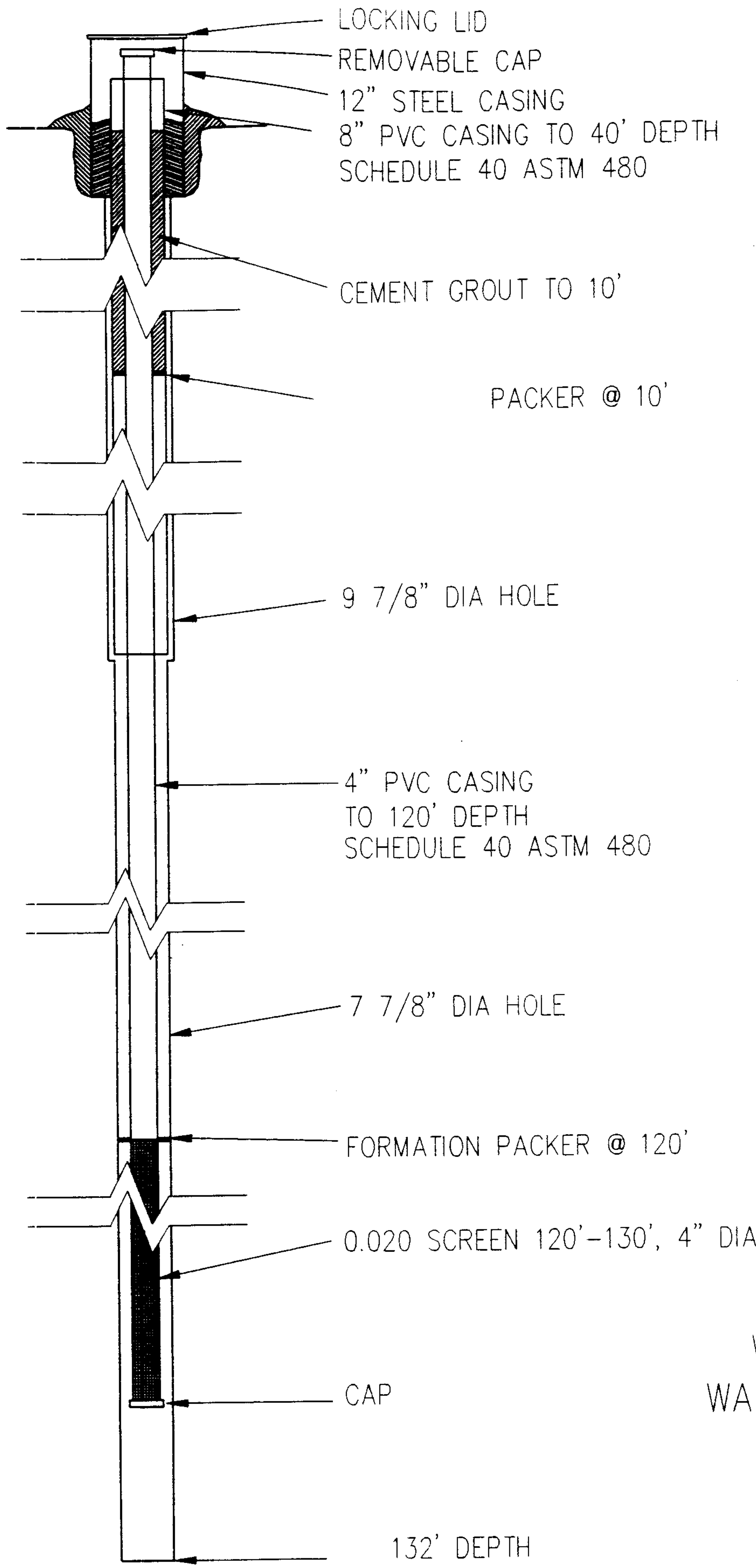
Mark Bunnell

Mark Bunnell
Engineering Geologist
Skyline

MB:dk

Enclosure

cc: Keith Zobell



WASTE ROCK SITE
WATER SAMPLING WELL
COMPLETED 8-6-92
APP. No. 92-91-03MW

Logged by [illegible]

COASTAL STATES ENERGY CO.

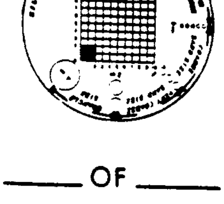
TYPE OF DESCRIPTION	
CUTTINGS	✓
CORE	
OUTCROP	

HOLE NO. Waste Rock Site Well
PAGE 1 OF 2

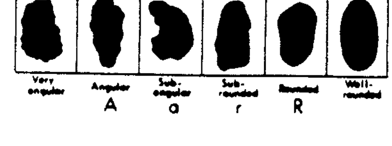
Note: Entire hole was very soft. Likely drilled near fault plane along a segment of Pleasant Valley fault zone. Entire hole drilled mainly w/air.

BOX NO.	SMPL. NO.	DEPTH FROM	DEPTH TO	THICKNESS	STRIP LOG 1"=10'	MEDIAN GRAIN SIZE S VF F M C VC	ROUNDNESS A a r R	SORTING P M W	DESCRIPTION & REMARKS
		0	5						Soil 0-5'
		5	10						5-10 5% Soil 95% Ss, lt br, f gr, calc, unconsol.
		10	15						10-15 100% Ss, a/a
		15	20						15-20 85% Ss, lt br, calc, f gr 15% Sltst, lt gy, calc
		20	25						20-25 95% Ss, lt br, f gr, calc 5% Sltst, lt gy, calc
		25	30						25-30 50% Sltst, lt brgy, calc } Cuttings Damp 40% Clyst, brgy 10% Ss, a/a
		30	35						30-35 70% Clyst - m lt gy 20% Ss, v lt gy, f gr, calc 10% Sltst, lt gy, calc
		35	40						35-40 50% Ss, lt br, vf gr, calc 50% Sltst, lt gry, calc, sndy
		40	45						40-45 40% Ss, lt br, vf gr, calc 60% Clyst, m gy,
		45	50						45-50 80% Sltst, m lt gy, calc 15% Clyst, m gy 5% Ss, lt br, f gr, calc
		50	55						50-55 95% Sltst, m lt gy, calc 5% Ss, lt br, f gr, calc
		55	60						55-60 50% Clyst, m gy 40% ~~Clyst~~ Sltst, m gy, calc 10% Ss, a/a
		60	65						60-65 40% Sltst, lt gy, calc 60% Ss, gy or, f to m gr, unconsol.
		65	70						65-70 100% Ss, gy or, f to m gr, unconsol.
		70	75						70-75 90% Ss, gy or, f to m gr, unconsol. 5% Clyst, m gy 5% Coal, soft
		75	80						75-80 100% Coal - soft (Gouge?)
		80	85			COAL "UR" SEAM 75'-91'			80-85 100% Coal - soft (Gouge?)
		85	90						85-90 100% Coal - soft (Gouge?)
		90	95			STAR POINT Sandstone			90-95 95% Ss, ply1 brn, f gr, unconsolidated, salt & pepper texture. 5% Coal - soft
		95	100						95-100 100% Ss, a/a

C - 1857 (8/79)



Drilling started: 7-29-92
Completed: 8-6-92



PAGE ____ OF ____

HOLE NO. ________

mm 1 2 3 4 5 6 7 8

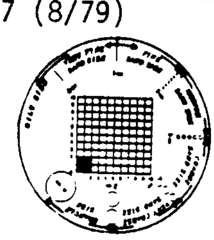
COASTAL STATES ENERGY CO.

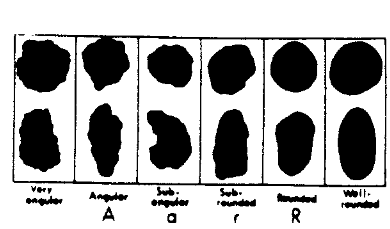
TYPE OF DESCRIPTION	
CUTTINGS	✓
CORE	
OUTCROP	

HOLE NO. Waste Rock Site Well

BOX NO.	SMPL. NO.	DEPTH FROM	DEPTH TO	THICKNESS	STRIP LOG 1" = ___	MEDIAN GRAIN SIZE (VS F M C VC)	ROUNDNESS (A a r R)	SORTING (P M W)	DESCRIPTION & REMARKS
									100-130 Ss, a/a
		100	105						
		105	110						
		110	115						
		115	120						115-130 cuttings wet
		120	125						
		125	130						
					TD				
									Note: well was eventually drilled to 132' TD during construction process.

C - 1857 (8/79)





PAGE ____ OF ____

HOLE NO. ____

mm 1 2 3 4 5 6 7 8