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Rock Mechanics for Two-Seam Mining
at
The Big Island Trona Mine
Stauffer Chemical Company of Wyoming

ABSTRACT

This paper describes part of a rock mechanics program being conducted at the Big Island Mine of Stauffer Chemical Company of Wyoming. The program objective is to determine the feasibility of mining two superimposed, 10 ft. (3m) thick, trona seams. The beds are separated by 33 ft. (10m) of marlstones and shales. The lower bed is 850 ft. (259m) deep. The mining method is room-and-pillar with a 60% extraction ratio.

A preliminary assessment based on a simple finite analysis indicated stress overlapping between the beds to be negligible with stability conditions similar to single-seam mining.

At present, part of the test area has been mined with superimposed pillars between the seams. Test mining consists of extracting a panel over an existing mined out area. This sequence was chosen because upper bed mining on a production scale did not commence until 1976 and the finite element analysis indicated there was no appreciable difference in mining either the upper or lower bed first.

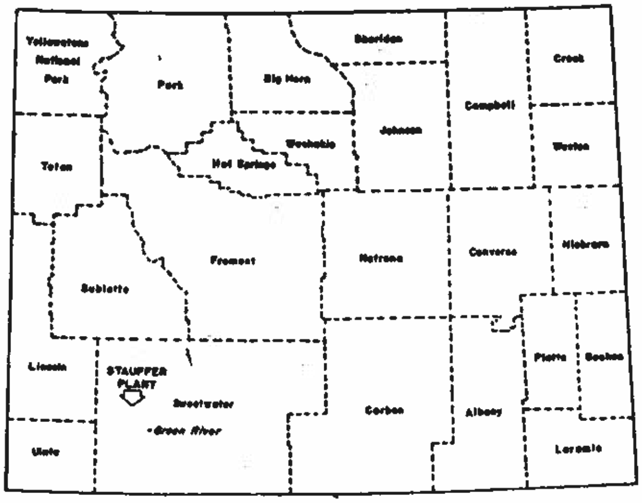
Simple instrumentation showed that prior to upper seam mining the pillars in the lower bed were under full overburden load. Upper seam mining has increased pillar loading in the lower bed by 175 psi (1.2 MPa). This was accompanied by small downward movement of the strata between the seams. Observations and deformation measurements have indicated stable conditions. However, spalling of loose roof slabs and pillar corners has occurred in the lower seam as a result of upper seam blasting and residual fractures left from lower bed extraction.

Two-seam test mining is still in progress; results indicate agreement between the stability analysis done ahead of mining and actual experienced conditions. Instrumentation monitoring will be carried out for months after mining the test area. Future production from two bed mining will be delayed for two years to assess time effects on stress and deformation after completion of the test area.

The program has established rock mechanics in the Big Island Mine as a practical tool to help provide maximum safety, resource recovery, and productivity. Additional stability analysis based on experience and instrumentation results will be used to evaluate future panel layouts and extraction ratios in long range planning.

INTRODUCTION

Stauffer Chemical Company of Wyoming's Big Island Mine and Refinery are located approximately 25 miles (40km) northwest of Green River, Wyoming (Figure I).



STATE OF WYOMING
Figure I

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Mining operations supply trona, a sodium-sesquicarbonate mineral, to the refinery for the production of high purity commercial soda ash. Mining is conducted by a full overburden support room-and-pillar method in two flat-lying seams. The lower seam has been mined since 1962 and the upper seam since 1975. (The superimposed or two-seam mining began in 1977 on an experimental basis.) Production is supplied from four mining sections utilizing a seven-entry advancing and an eight-entry retreating system with a continuous cycle involving roof bolting, top cutting, drilling, blasting, and loading-hauling. A yearly mine production rate of 2.7 million tons (2.45×10^6 tonnes) is needed to meet refinery requirements.

In early 1976, management decided that a rock mechanics program would be needed: (1) to assess the feasibility of the proposed two-seam design, (2) to monitor stability during test mining and (3) to help develop the most efficient design for two-seam mining. A test panel was established in the upper bed above the existing southeast panel #3 which was mined in 1973 (Figure II).

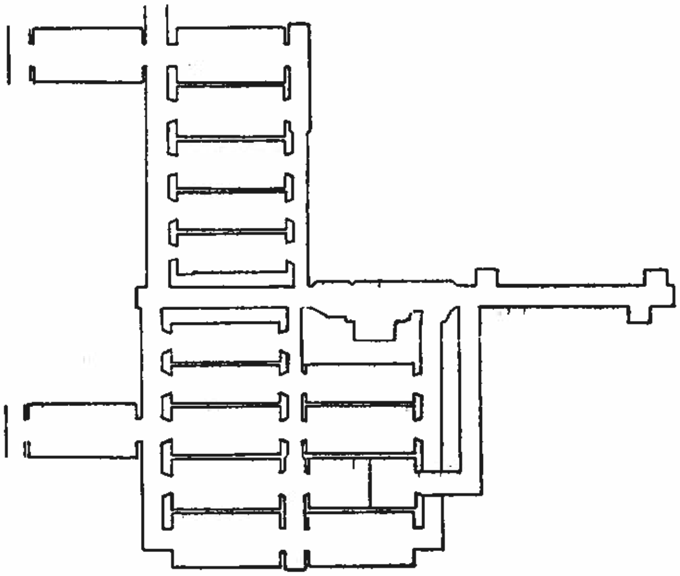
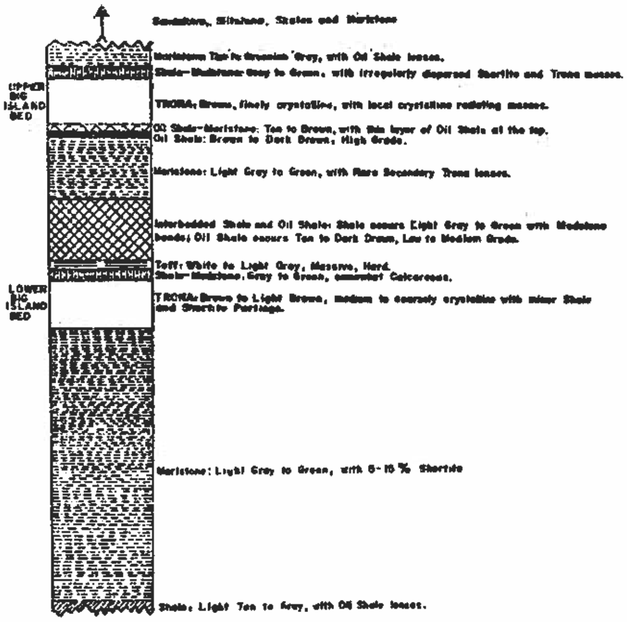


Figure II

Opening dimensions and spacings were kept equal to the lower panel with the exception of 25 ft. spans in the lower panel areas. Pillars were superimposed. Accordingly, pillar dimensions on advance were set at 36 ft. by 40 ft. (11m by 12m) and span dimensions at 22 ft. (6.7m). Retreat pillars and spans were planned respectively at 37 ft. by 45 ft. (11.3m by 13.7m) and 22 ft. (6.7m).

GEOLOGICAL SETTING

Trona deposits in southwest Wyoming occur in the Wilkins Peak Member of the Eocene Green River Formation in 28 beds covering an area of 1400 square miles (3630 km^2). Many of these beds are thin and economically unattractive. Commercial beds presently being mined are 8 to 12 ft. thick (2.4 to 3.7m). The strata in the vicinity of the trona horizons is formed essentially of shale, marlstone and oil shale beds (Figure III).



LITHOLOGIC SEQUENCE

FIGURE III

The overburden strata is composed of a series of thick siltstone, sandstone and marlstone layers.

A primary feature associated with the rock in the vicinity of the openings is the occurrence of well defined planes and steeply inclined natron filled joints. Natron is a hydrated sodium carbonate which when exposed to air loses its consistency and becomes powdery. Mapping these joints from openings between the trona beds indicated the presence of four joint set groups oriented N-S, E-W, NE-SW and NW-SE. Average spacings of bedding planes and steeply inclined joints are 7 and 30 ft. (2.1 and 9.1m) respectively. The dip of steeply inclined joints is almost always vertical with a dip below 70 degrees not observed. The bedding plane joints are horizontal.

Natron filled discontinuities have had little impact on mine stability because of their relatively wide spacings and the presence of a strong lateral stress field. However, during mining, particular attention is paid to the formation of wedges and blocks by these joints that may require support reinforcement. Field instrumentation and structural analysis are planned to evaluate the effect of joint stability in two-seam mining situations.

PHYSICAL ROCK PROPERTIES

Laboratory testing of drill core was undertaken to establish relative strength parameters and elastic properties of the trona seams and other beds in the vicinity of the openings. Tests were performed at the USBM Denver Research Center in 1977 as a part of a Cooperative Agreement between Stauffer Chemical Company of Wyoming and the Bureau of Mines. Table 1 presents a summary of elastic properties, shear, and uniaxial compressive strength values.

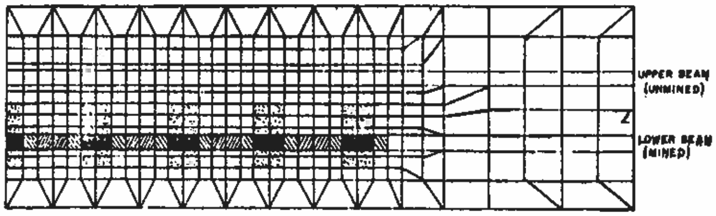
Trona is generally stronger and stiffer than the immediate shale and mudstone in the roof and floor. Therefore, the pillars are the stronger structural element with the present mining dimensions and system. The properties of the trona and marlstone beds above the lower trona seam appear almost identical, but the lower floor marlstone is significantly stronger than any other rock type tested.

STABILITY ANALYSIS

A simple finite element study was conducted to provide insight on the stress levels that would be developed in the immediate vicinity of the openings by mining the upper seam after the lower seam. Results of the study were used to help assess stability in the test panels. The simulation consisted of first mining the lower seam and then mining the upper seam, both with superimposed and staggered pillars. A plane strain multilayer model under gravity loading was used. Table 2 summarizes the material properties and major layers used in the model.

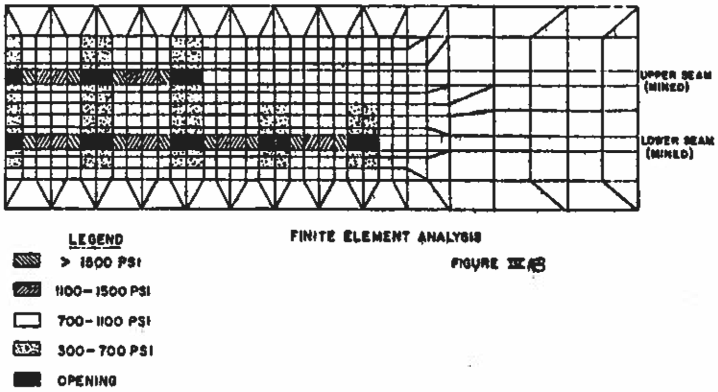
An elastic analysis was chosen because little information was available on time-dependent behavior. Previous convergence measurements and experience through the mine indicated that creep was very small. It was recognized, however, that time effects might be very important in layouts involving higher extractions and pillar yielding methods. Thus, field measurements planned for the future will be used to assess, among other things, time-dependent deformations.

Figure IVA and Figure IVB compare the vertical stress distribution levels for lower seam and two-seam mining with superimposed pillars.



LOWER SEAM

FIGURE IV A



FINITE ELEMENT ANALYSIS

FIGURE IV B

Stresses around upper and lower mine openings overlapped but did not increase significantly. Similar results were obtained with staggered pillars. The stability analysis supported by practical judgement indicated that stable mining conditions should be expected.

INSTRUMENTATION OF THE TEST PANELS

Instrumentation was planned with the two major objectives: first, to monitor stability and ensure safety of personnel and equipment, and second, to obtain basic design information for future mine designs involving higher extractions.

Three types of measurements were conducted to determine stress levels and rock mass displacements: (1) stress-relief overcoring with the USBM type gauge, (2) stress change determinations with photoelastic and vibrating-wire gauges, and (3) rock mass displacements with borehole extensometers. Instrumentation of the lower bed panel was completed three months prior to upper bed mining. Figure V shows the instrumentation plan. The upper bed is being instrumented as mining progresses with borehole extensometers and roof to floor convergence stations.

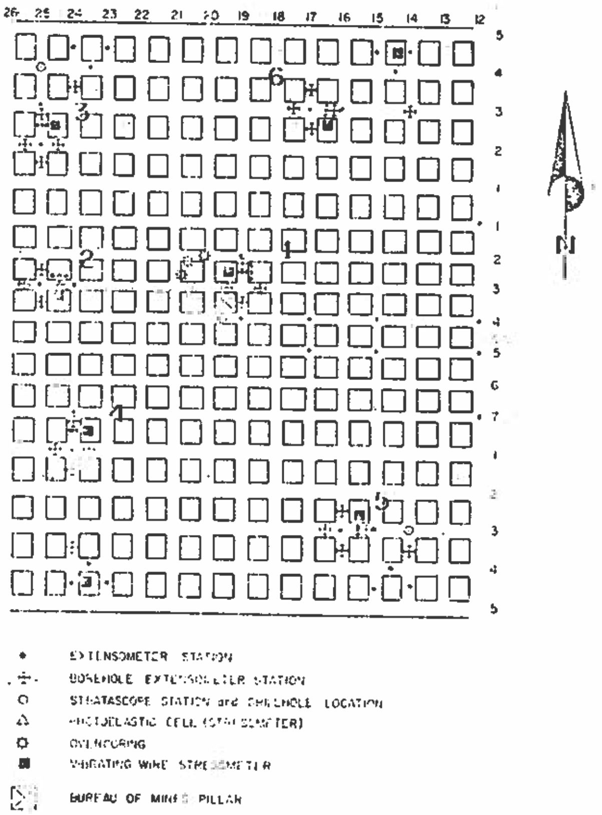


Figure V

Concurrent with this instrumentation plan, the USBM initiated another program under a cooperative agreement with Stauffer Chemical Company of Wyoming. However, their instrumentation and field results are not discussed in this paper.

RESULTS FROM FIELD MEASUREMENTS AND OBSERVATIONS

STRESS DETERMINATIONS

Overcoring measurements in lower bed pillars made before and after upper seam mining indicate the average vertical pillar stresses to have increased 175 psi (1.2 MPa), from 1825 to 2000 psi (12.6 to 13.8 MPa). Figure VI A and Figure VI B show the results of vertical and horizontal stress determinations made to the center of a pillar.

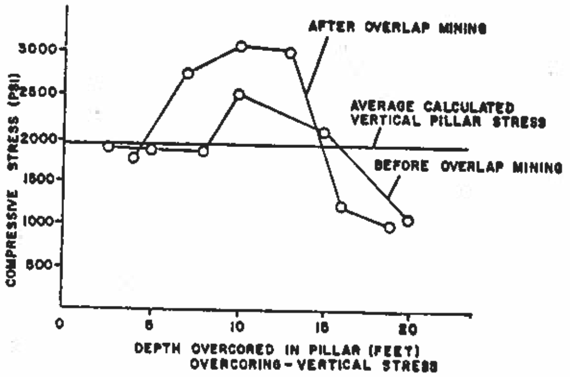


Figure VI A

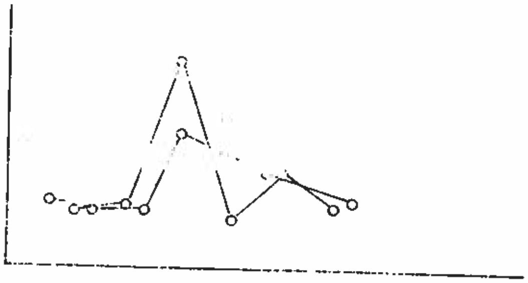


Figure VI B

The increase in vertical stress seems to have occurred in an area 5 to 15 feet (1.5 to 4.6m)

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from the opening. Both stress profiles were very close to the calculated average vertical pillar stress of 1920 psi (13.2 MPa), based on the Tributary Area Theory. Horizontal stresses appear to have increased in an area 7 to 12 feet (2.1 to 3.7m) from the opening even though pillar stresses in both profiles were almost identical, 950 psi (6.6 MPa). Vertical and horizontal stresses are nearly equal in the center of the pillar, supporting stress field determinations that indicate premining stresses for practical purposes to be hydrostatic.

Stress change measurements support the above general stress distribution pattern. While gauges installed to depths of 10 feet (3m) show stress increases of up to 25 to 300 psi (1.7 to 2.1 MPa), no appreciable stress changes have been measured by the deeper stressmeters.

Unloaded pillar cores indicate that pillars should be able to withstand additional loading before appreciable yielding or failure would occur.

ROCK MASS DISPLACEMENTS

Single-point borehole extensometer measurements were made at different depths both from the roof of the lower bed and the floor of the upper bed. Figure VII A indicates the general movement pattern that occurred in the strata between the trona seams as measured in the lower bed extensometer clusters 1 and 2 (Figure V).

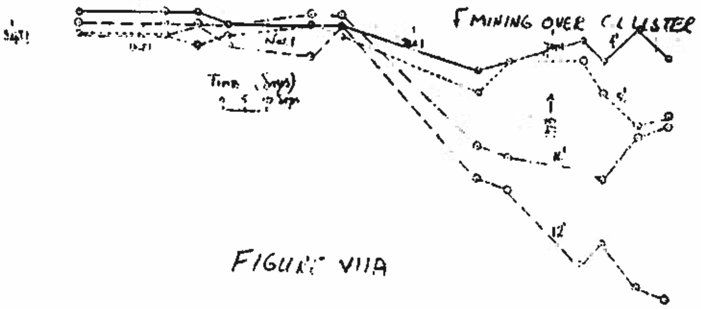
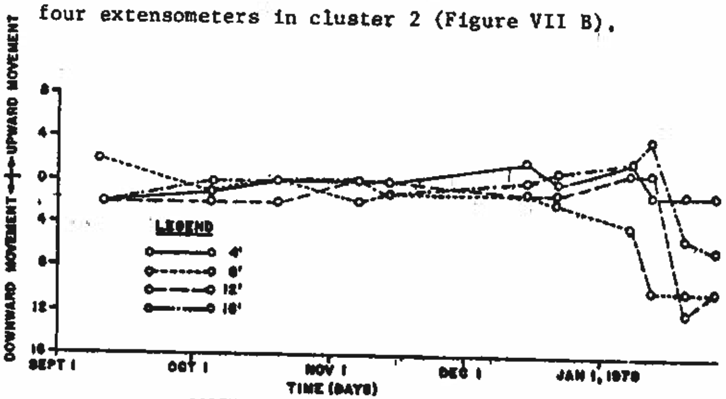


FIGURE VIIA

Each cluster was composed of four extensometers 4, 8, 12, and 16 feet long (1.2; 2.4; 3.7; and 4.9m). The lower anchor in each extensometer was installed immediately above the roof line.

Upper bed mining induced an immediate movement that was registered mostly above the 8 feet horizon. A slight upward movement occurred just prior to mining over the instruments, as shown in three out of four extensometers in cluster 2 (Figure VII B).



BOREHOLE EXTENSOMETER CLUSTER 2

Measurements in cluster 1 were made too far apart in time to register this divergence. Most movement occurred in the 12 ft. (3.7m) extensometer in both clusters. So far total displacements are small, with a maximum of 0.25 in. (0.6mm) approximately two months after overlap mining. A stabilization trend seems to have occurred in most extensometers soon after the upper bed was mined. Measurements will continue to assess time dependent effects.

The above measurements analyzed in terms of strain indicate that downward effects have been more noticeable between the 8 and 12 ft. (2.4 and

3.7m) horizons. At the 16 ft. (4.9m) horizon, or approximately halfway between the two trona seams, downward movement is smaller, and an upward rebound seems to have occurred one month after overlap mining in cluster 1. This correlates with behavior observed in the upper bed floor extensometers. To summarize, upper seam mining causes a downward wave of movement that is gradually transmitted to the lower seam. After this movement, an upward adjustment seems to be taking place midway between the two seams.

VISUAL OBSERVATIONS

Regular inspections of upper and lower panels have indicated sound structural conditions. Upper bed blasting, however, induces spalling of loose roof slabs and pillar corners in the lower bed panel. Spalling occurs in an area approximately 200 ft. (61m) ahead of the upper bed mining face. Damage has been minor but safety consideratons have precluded personnel entering the lower panel while mining the upper seam. This means that concurrent upper and lower seam conventional mining should be conducted with the upper mining face at least 300 ft. (91m) from the lower mining front.

FUTURE PLANS

Two-seam test mining is still in progress. Westward mining advance has stopped, leaving the test panel with a 1620 ft. (494m) length. Retreat mining has begun in a southeast block that will ultimately increase the panel width from 420 to 1020 ft. (182 to 311m). Instrument measurements will continue to assess stability and time effect.

Field data will be used in a comparable manner to help develop safe designs with high extractions. Following the present program, a simpler mine-wide program based mostly on extensometer measurements is planned to characterize the stress-time and deformation-time patterns developed around mine openings. Measurements will be made in layouts with progressively higher extractions, ultimately to evaluate in-situ pillar, floor and roof strengths. Computer stability analyses based on the finite element and displacement discontinuity methods will be performed to help assess stability and safety at higher extraction.

CONCLUSIONS

This study was conducted to help establish the feasibility of safe two-seam mining. At the same time, it was used to develop in-house geotechnical capabilities and establish rock mechanics as a practical tool in the day to day operations of the mine.

A two-prong approach has been used in applying rock mechanics to the mine design; first, development and implementation of simple field measurements to be used in a comparative manner between different test mining layouts, and second, the use of established computer structural analysis techniques based as much as possible on field data, to forecast stability prior to mining and help assess the feasibility of alternate designs.

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TABLE 1

ROCK PROPERTIES OBTAINED FROM LABORATORY TESTING

ROCK TYPE	UNIAXIAL COMPRESSIVE STRENGTH (PSI)	(MPa)	ELASTIC MODULUS (x 10^6 PSI)	(MPa)	POISSON'S RATIO	ANGLE OF INTERNAL FRICTION (Ø) (°)	COHESION (PSI)	(MPa)
Shale-Mudstone	3779	25.9	0.43	2.95×10^{-3}	0.20	33	610	4.2
Oil Shale	4325	29.7	0.41	2.81×10^{-3}	0.16	25	1556	10.7
Shale	4537	31.1	0.44	3.02×10^{-3}	0.22			
Marlstone[1]	6522	44.7	1.22	8.37×10^{-3}	0.21	43	2283	15.7
Marlstone[2]	13205	90.6	2.79	1.91×10^{-2}	0.16	57	1823	12.5
Trona	6435	44.1	2.62	1.80×10^{-2}	0.20	43	1449	9.9

[1] Above lower trona seam
[2] Below lower trona seam

TABLE 2

MATERIAL PROPERTIES OF MULTI-LAYER MODEL

STRATA	ELASTIC MODULUS (x 10^6 PSI)	(MPa)	POISSON'S RATIO
Overburden	1.00	6.86×10^{-3}	0.2
Trona	3.00	2.06×10^{-2}	0.2
Interval Between Trona Seams	1.00	6.86×10^{-3}	0.2
Floor Below Lower Trona Seam	3.00	2.06×10^{-2}	0.2
Below Lower Floor	1.00	6.86×10^{-3}	0.2