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# Rock Mechanics Study of a Longwall Panel

Lewis V. Wade and Peter J. Conroy

**Abstract**—Old Ben Coal Co. successfully completed the first longwall panel in Illinois. The panel was mined using shield supports and was part of a cooperative agreement with the US Bureau of Mines. This paper describes the rock mechanics studies which were performed to monitor: the performance of the supports, the stress changes in the coal and floor, convergence in entries, and caving mechanism of the roof. From this study, maximum support loads were obtained as well as the stress distribution in the panel, floor and adjacent pillars.

## Introduction

This paper summarizes the results of some of the rock mechanics monitoring performed as part of Old Ben Coal Co.'s longwall coal mining demonstration project conducted in cooperation with the US Bureau of Mines (USBM). The work described herein included installation of instruments, collection of data, and data analysis performed during mining of the first

longwall panel in mine No. 24. The rock mechanics monitoring program including both surface and underground instrumentation and was designed to achieve the following purposes:

1) To provide the capability to observe unusual situations during mining so that remedial measures could be instituted quickly.

2) To formulate design guidelines for future longwall mining efforts.

To evaluate surface subsidence, its character, rate, and potential effects on cultural features; and to develop criteria to

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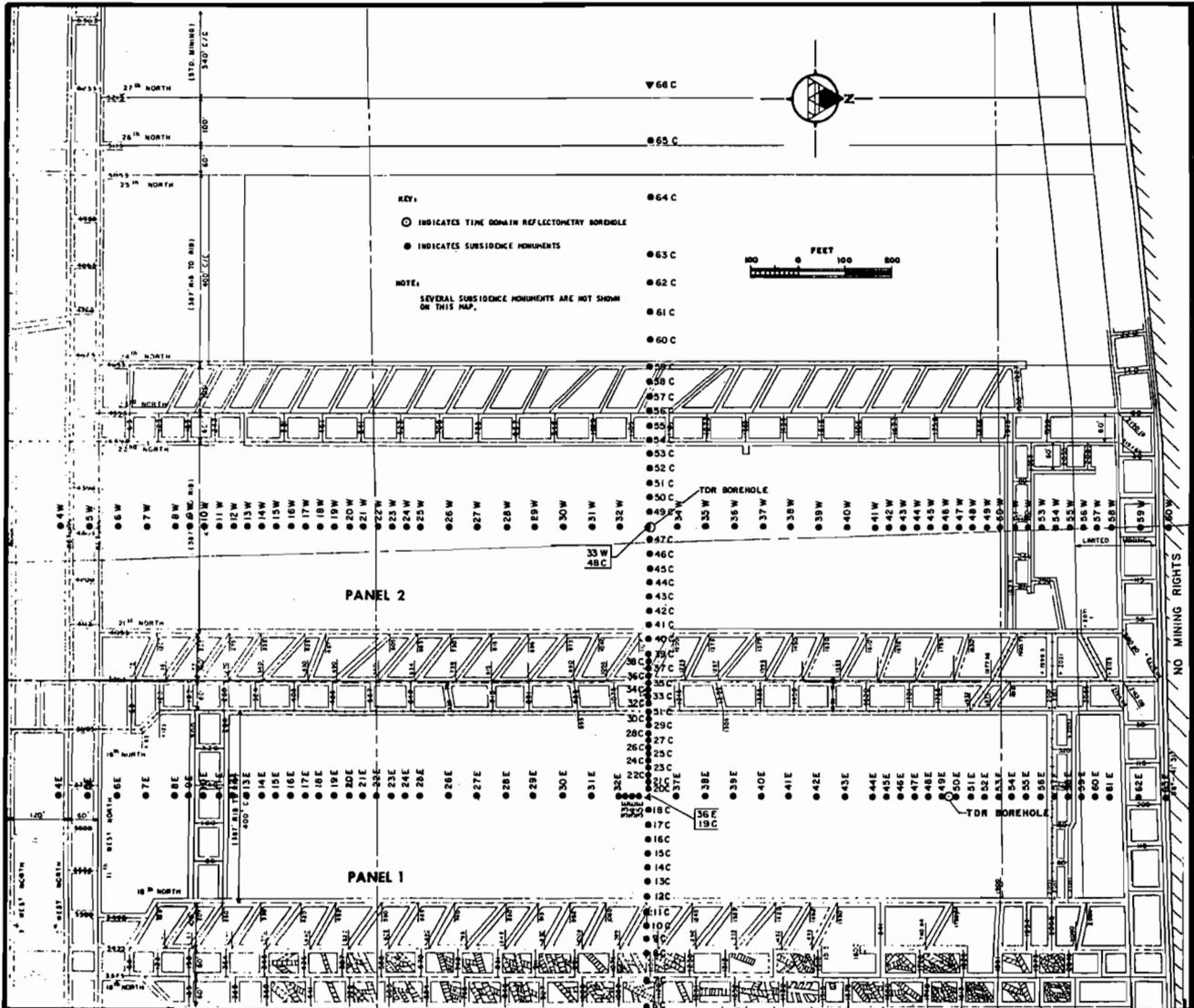
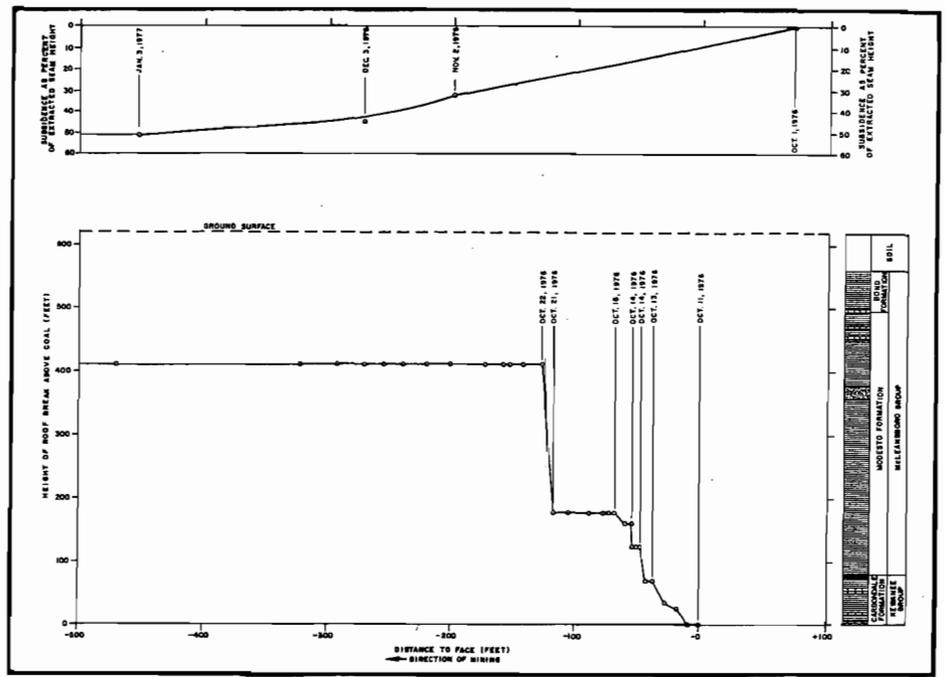


Fig. 1— Surface subsidence monument locations.

Fig. 2— Roof break vs. face advance.



assist in predicting subsidence for other mines having similar roof conditions.

Six previous attempts with longwall methods in Old Ben Coal Co.'s mine 21 had been unsuccessful due to roof control problems. A description of these attempts is given by Moroni (1973). In preparation for the present longwall operation a study was performed to review existing data on the previous unsuccessful attempts to establish coal- and floor-strata bearing capacities in mines Nos. 21 and 24, and to analyze the damage to supports used in previous longwall attempts. The design criteria for the supports to be used in this demonstration were developed from this study.

The longwall demonstration consisted of three panels in Old Ben's mine No. 24. The mine is located 3.2 km (2 miles) northwest of Benton, Franklin County, IL, and is producing coal from the Herrin (No. 6) seam. Panel No. 1 measured 140.2 m (460 ft) wide by 528.8 m (1735 ft) long with a seam height of 243.8 to 264.2 cm (96 to 104 in.). The equipment used in this operation included 95 Rheinstahl shield-type supports, an Eickhoff double drum bidirectional shearer, and an Eickhoff single strand armored face conveyor with head and tail drive units.

The surface investigation was designed to monitor the development of roof cave and to observe the effects of subsi-

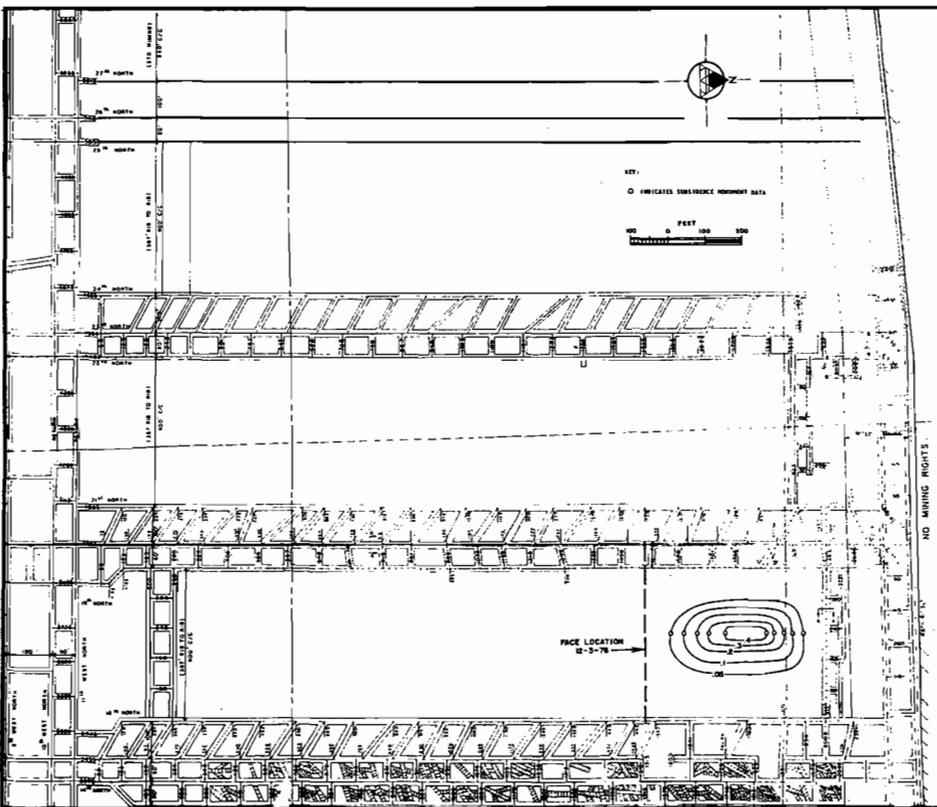


Fig. 3— Surface subsidence contours, Dec. 3, 1976.

dence at the surface. This investigation was based on stratigraphic and geophysical data obtained from a borehole drilled from the surface into panel 1 and on a system of benchmarks located on the surface over all the panels. The benchmarks were installed by Old Ben Coal personnel with USBM assistance and direction. Old Ben personnel performed monthly surveys to monitor subsidence.

The underground investigation was designed to collect data on roof pressure, changes in rock stress, differential movement of floor and roof strata, and floor-roof convergence. A variety of instruments were used in this program. Pressure gages and recorders monitored roof pressure at the face by recording hydraulic pressure in the shield supports. Stressmeters were installed in the coal and floor at various locations around the

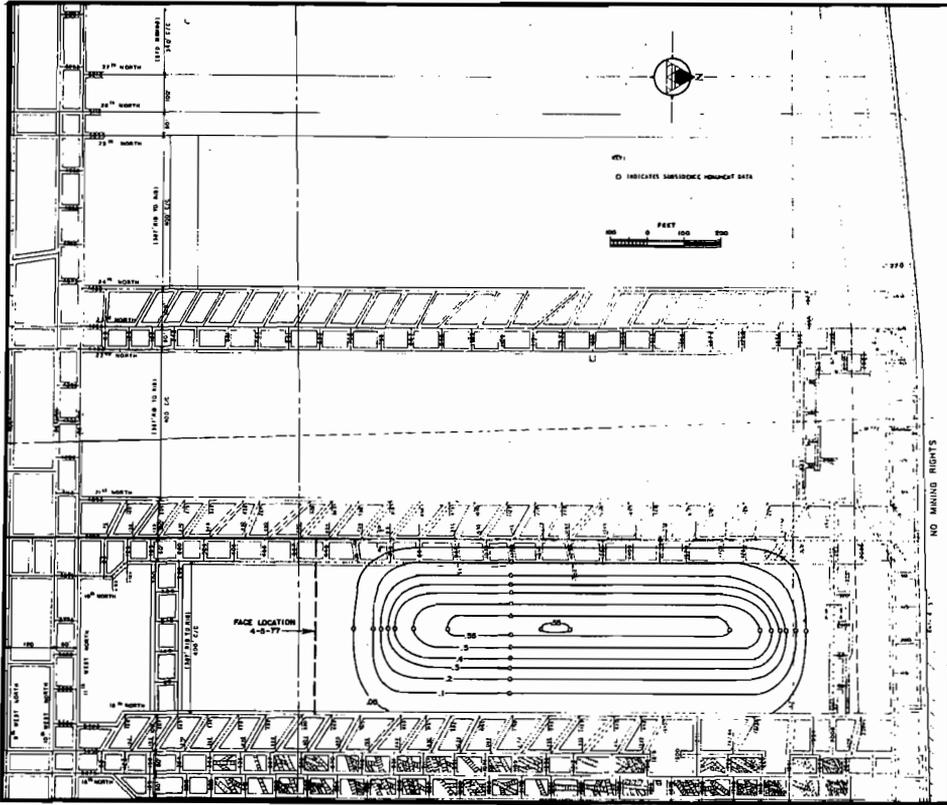


Fig. 4— Surface subsidence contours, April 5, 1977.

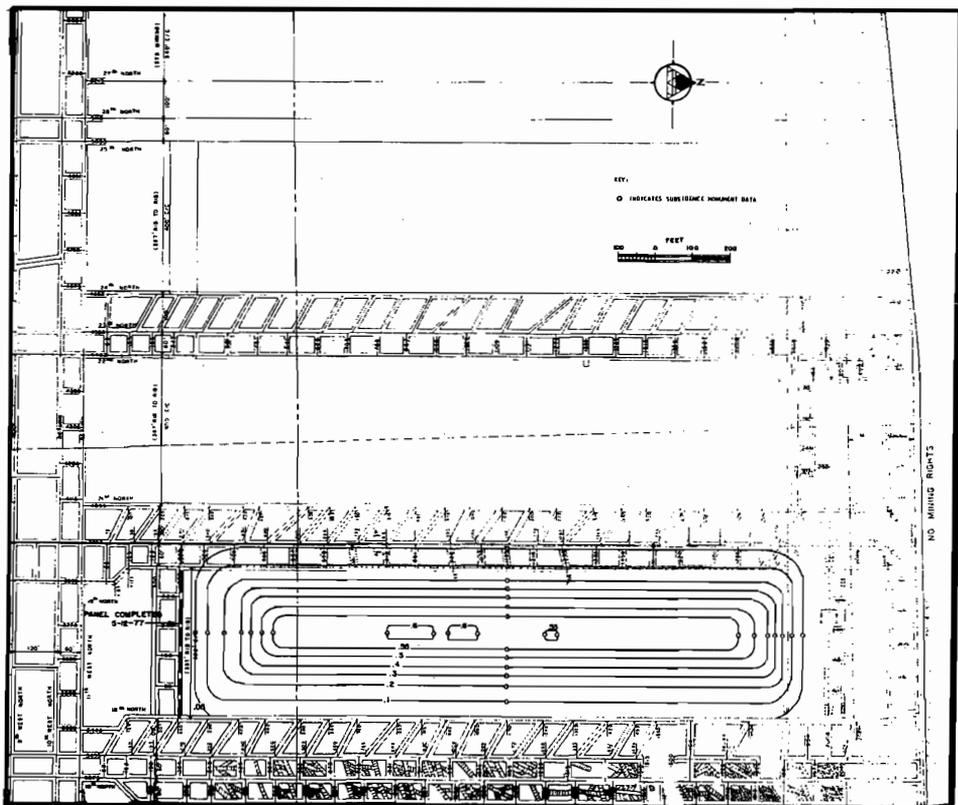


Fig. 5— Surface subsidence contours, May 31, 1977.

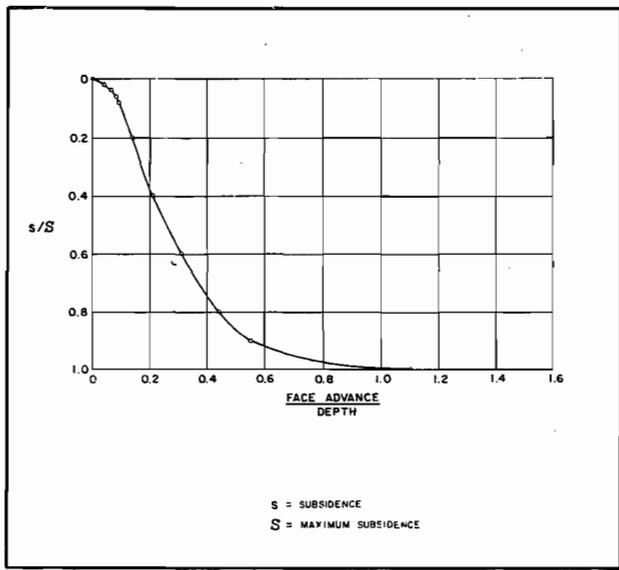


Fig. 6— Generalized subsidence development curve.

panel. Installations were also made at various locations in the entries around the panel to allow measurement of floor-roof convergences and differential movement of floor and roof strata.

### Surface Instrumentation and Monitoring

Time domain reflectometry (TDR) was used to monitor the successive collapse of roof strata after mining and the propagation of the resulting cave toward the surface. A 22.2 mm (7/8-in.) diam coaxial cable 204.2 (670 ft) long was placed

in a borehole drilled at the location shown in Fig. 1. The cable extended from the surface to the bottom of the boring, 15.2 m (50 ft) below the top of the No. 6 coal. The cable was then securely grouted into place with a cement grout.

The condition of the cable was monitored using a Tektronix 1502 time domain reflectometry cable tester. This instrument is commercially available and uses radar principles to detect cable faults. The device transmits an electrical pulse into the cable and monitors the returning signal. Cable faults such as crimps, short circuits, or breaks are indicated as characteristic signals on a cathode ray tube screen and on a paper record. Calibration of the TDR instrument allows the exact point of the cable fault to be located. Prior to installation, the cable was crimped at measured 3.0-m (10-ft) intervals to provide deflections in the returning signal as an aid in calibration. Readings were obtained weekly after mining began.

When the coal was mined the cable was cut and the termination of the cable was observed on the TDR record. At that time, the schedule of readings was changed to twice each day. The collapse of the mine roof after mining and the successive failure of strata above the mine caused breaks in the cable which could be observed in the TDR records. Fig. 2 shows a plot of the height of strata separation above the coal vs. the distance to the face.

Surface subsidence was measured by installing 197 survey monuments in three lines over the panels as shown in Fig. 1. These monuments were installed by Old Ben personnel with direction and assistance from USBM. Each monument consisted of a 1.5-m (5-ft) length of 50.9-mm (2-in.) diam pipe driven 0.9 m (3 ft) into the soil. A 3.0-m (10-ft) length of 25.4-mm (1-in.) diam pipe was driven through the large pipe into the soil and used as the monument reference. The space between the pipes was packed with silicon grease to allow the smaller pipe to move freely within the larger protective pipe. These monumented survey lines were used to evaluate the rates and amounts of subsidence which resulted from mining operations.

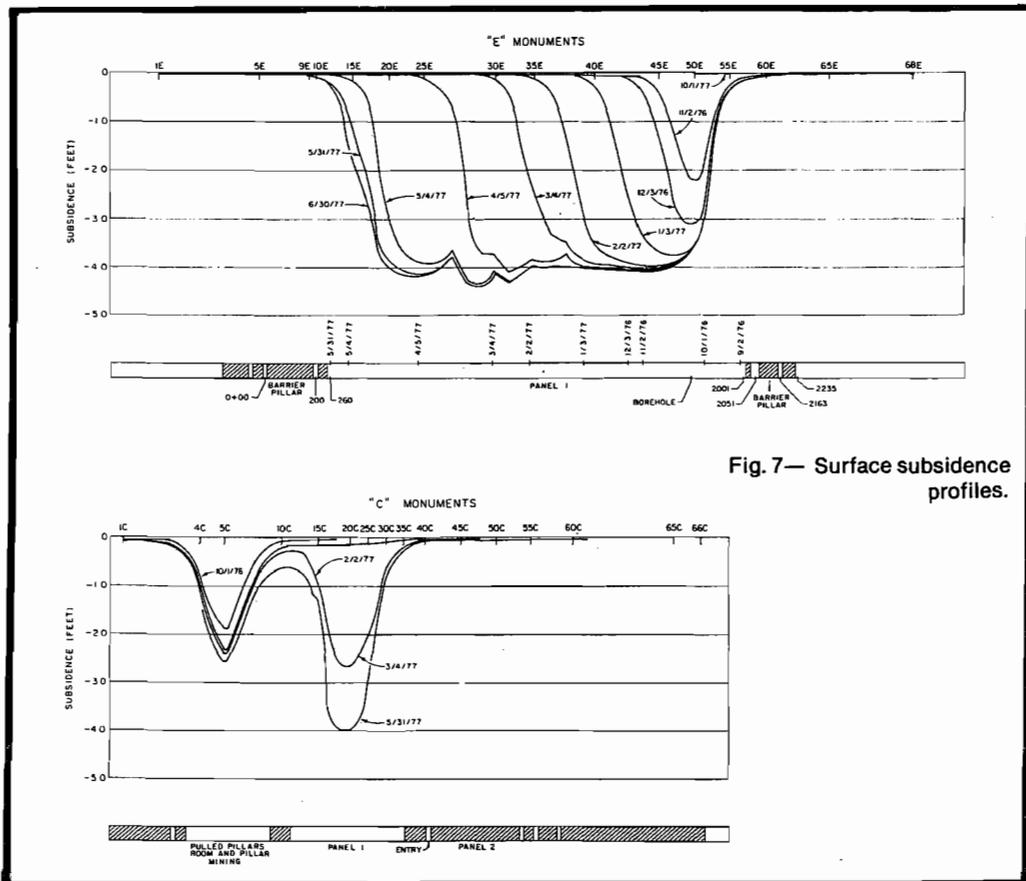


Fig. 7— Surface subsidence profiles.

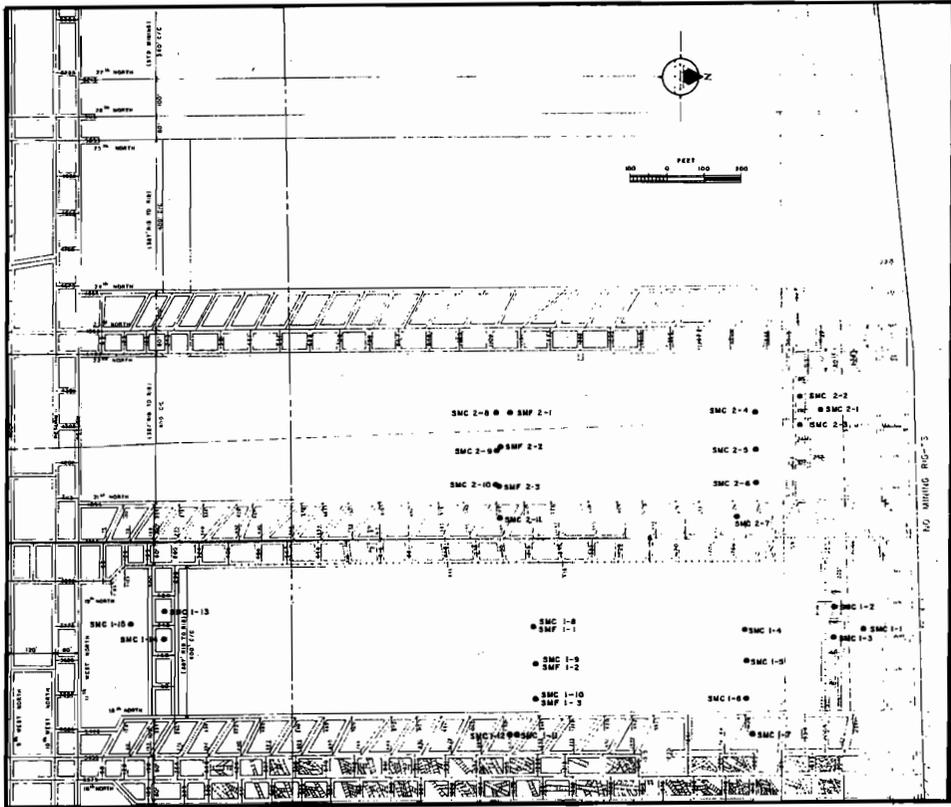


Fig. 8— Stressmeter locations.

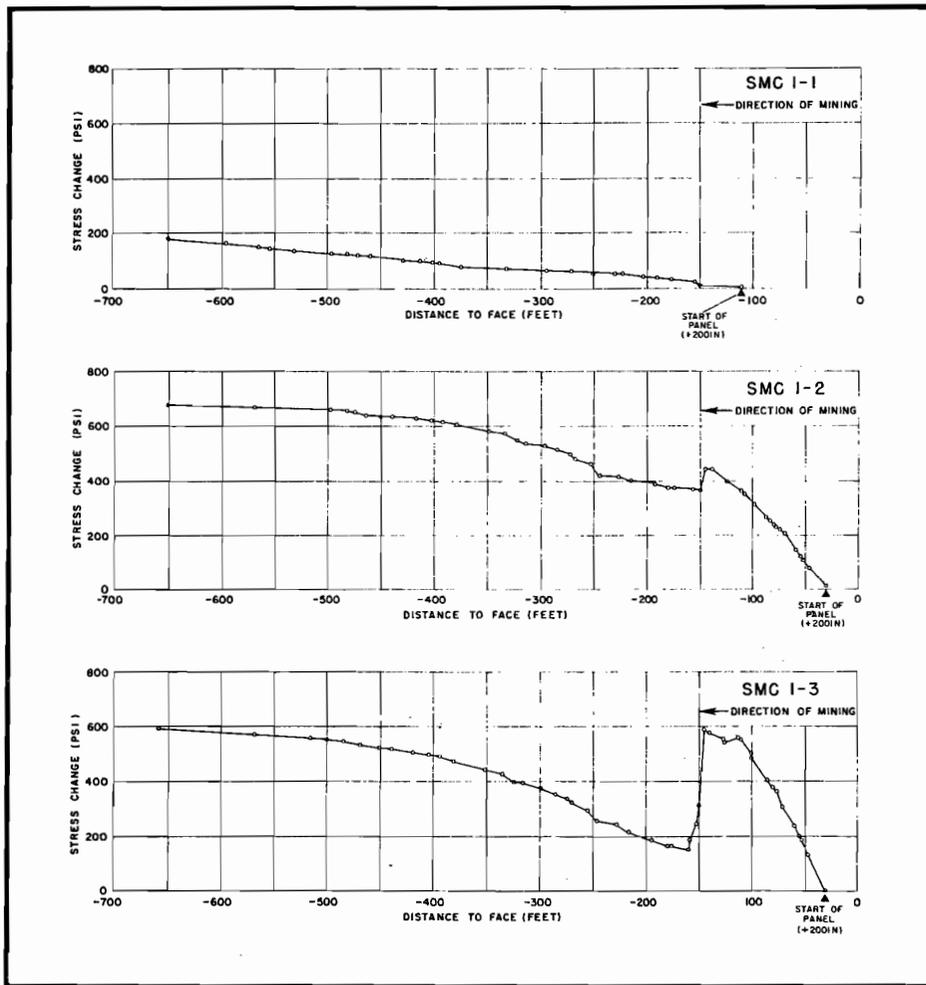


Fig. 9— Stress change vs. distance to face stressmeters, SMC 1-1, 1-2, and 1-3.

Subsidence contours were drawn for three different face positions as shown in Figs. 3, 4, and 5. The contour ratios are the measured subsidence over the average extracted seam height which is 2.1 m (7 ft). Multiplying the contour ratio by 7.0 will give the actual subsidence for the contour line.

A generalized subsidence development curve was constructed using representative development curves from several monument locations. This development curve shown in Fig. 6 indicates that 100% subsidence occurs at a distance approximately equal to overburden depth.

Subsidence profiles were plotted using the line of monuments running north-south over panel 1 and the line of monuments that runs east-west. These profiles are shown in Fig. 7. The mining with pillar extraction east of Panel 1 has contributed to the subsidence in that area.

### Subsurface Instrumentation and Monitoring

The subsurface monitoring was designed to measure pressure in the support hydraulic system, changes in stress in coal and floor, differential strata movement, and roof-floor convergence. Particular attention was given to stress changes and strata movements with respect to face position.

Stress changes were measured underground in the coal seam and in the siltstone floor at various locations in and around panel 1. Stresses were measured using vibrating wire stressmeters manufactured by Irad Gage, Inc. of Lebanon, NH. The stressmeter consists of a cylindrical gage containing a highly tensioned steel wire mounted diametrically across the gage. A portable readout device vibrates the steel wire at its resonant frequency to monitor changes in the length of the steel wire which result from stress changes. The readout device displays

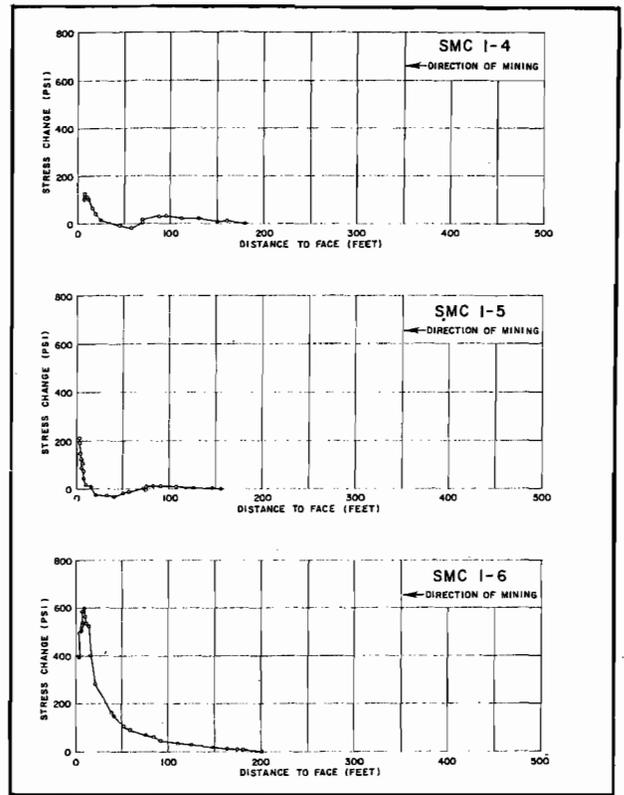


Fig. 10— Stress change vs. distance to face stressmeters SMC 1-4, 1-5, and 1-6.

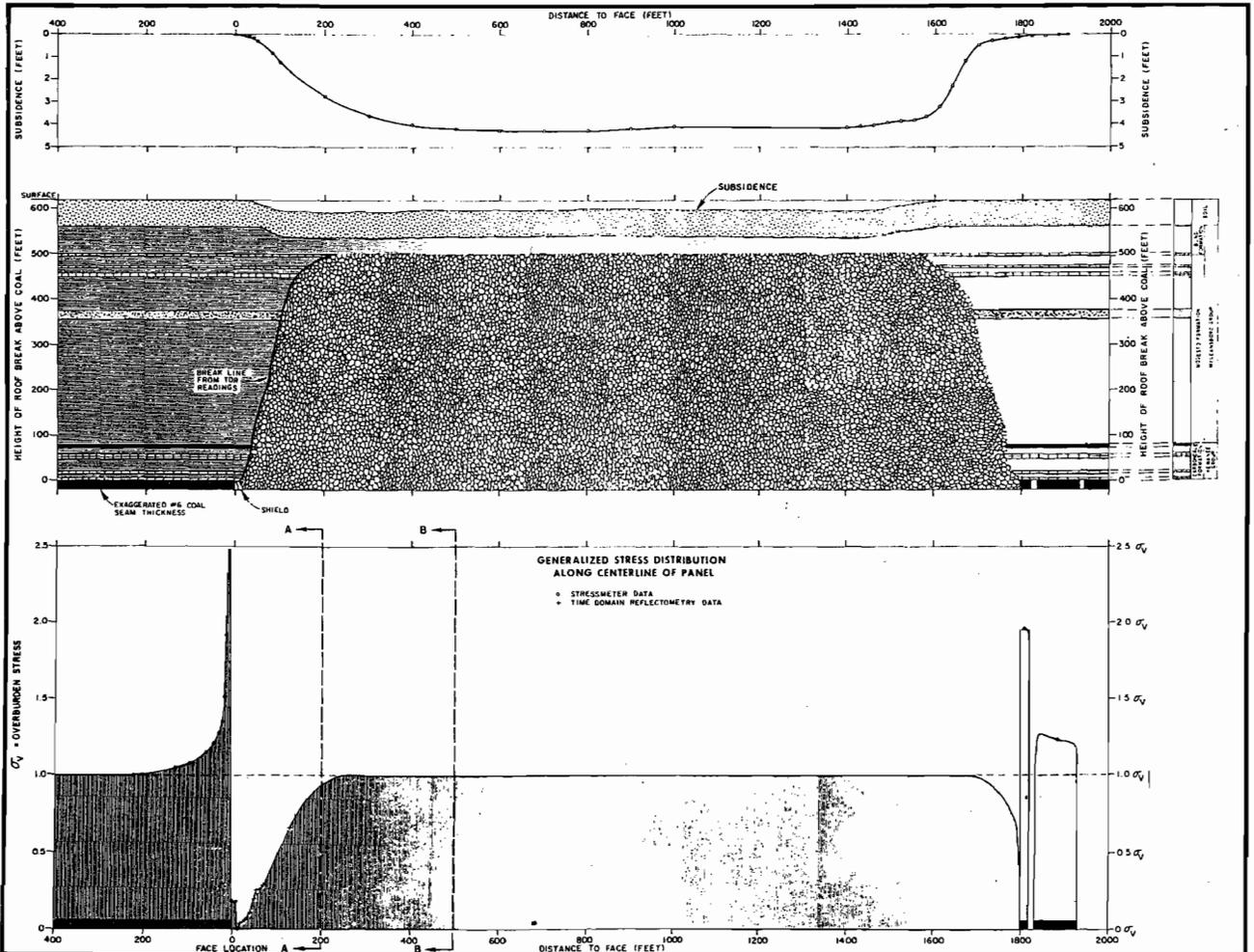


Fig. 11— Generalized stress distribution along panel center-line.

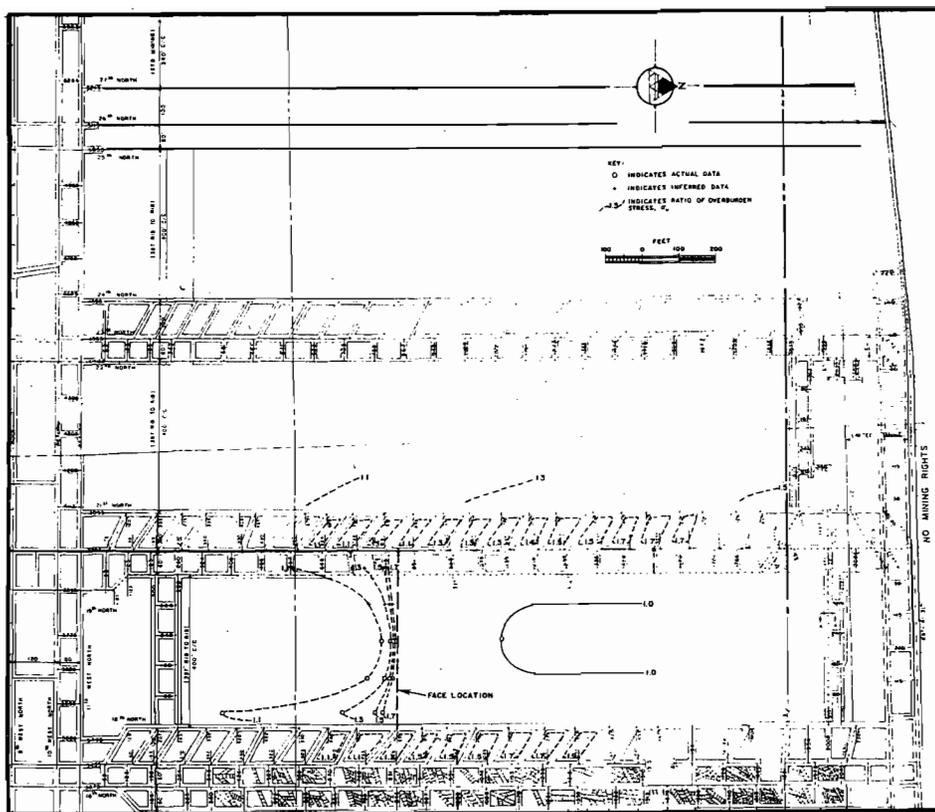


Fig. 12— Generalized stress contours.

the period of the wire at its resonant frequency. The readout value (period of the wire) must then be converted to the change in stress; this is accomplished by using a calibration curve developed for the type of rock in which the stressmeter is installed.

The stressmeters were used to monitor pressure changes in the coal seam, in the longwall panel and the pillars surrounding the panel, and in the siltstone floor under the longwall panel. The stressmeters were placed in 38.1-mm (1½-in) diam boreholes drilled both horizontally and at an incline into, around and under panel 1. The setting distances ranged from 7.3 to 84.7 m (24 to 278 ft). The locations of the stressmeter installations are shown in Fig. 8.

Each stressmeter installation consists of one vibrating wire stressmeter set in the borehole to monitor vertical stress changes. The stressmeters measure the change in stress from their initial value.

Representative plots of stress change as a function of face advancement are shown in Figs. 9 and 10.

## Conclusions

The conclusions presented here are based on observations and analyses of data collected during the mining of the first longwall panel. These conclusions are preliminary and may be revised after additional analysis or upon analysis of data collected during mining of panel 2.

Fig. 11 was developed from stressmeter, TDR, and subsidence data to show generalized stress distribution along the panel centerline. This figure shows that at a distance of approximately 76.2 m (250 ft) loading on the gob has resumed overburden pressures. At a distance of approximately 91.44 m (300 ft), most of the subsidence is the result of consolidation of the gob. Fig. 12 was developed from stressmeter data and shows the generalized distribution of stresses in the panel and adjacent pillars.

The time domain reflectometry (TDR) study was particularly

valuable in analyzing the behavior of the rock strata above the mine after removal of the coal. The analysis permitted observation of the strata failure with respect to face advance and stratigraphy. By examination of the TDR records, it was possible to observe initial strata separation and development of the separation until failure occurred. Correlation of strata failure, as seen on TDR records, to surficial subsidence was difficult since the majority of strata failure occurred between monthly subsidence surveys.

Maximum surficial subsidence observed over panel 1 was 1.34 m (4.39 ft). This is approximately 62% of the extracted seam height of 2.1 m (7 ft). The angle of draw was calculated to 0.003-m (0.01-ft) subsidence. This angle was computed to be 0.24 rad (14°) at the south end of the panel, 0.52 rad (30°) at the north end of the panel, and 0.4 rad (23°) at the west end of the panel. The draw angle was not calculated over the east side since this area was subject to subsidence from conventional mining operations in an adjacent section.

The performance and reliability of the vibrating wire stressmeters was very good. Only one gage malfunctioned although several gages were replaced after their lead wires were cut during installation.

Stressmeter data indicates that stress in the panel begin to increase when the face is approximately 60.9 m (200 ft) away. The rate of increase accelerates when the face is approximately 30.5 m (100 ft) away and reaches a maximum rate 15.24 m (50 ft) from the face. The maximum stresses occurred in the panel approximately 2.7 to 3.0 m (9 to 10 ft) in front of the face.

Stressmeters (SMC 1-2 and SMC 1-3) installed in pillars at the bleeder entries showed a marked increase in stress  $2.7 \times 10^6$  to  $4.1 \times 10^6$  Pa (400 to 600 psi) when the face was advanced to approximately 45.7 m (150 ft). At that point, stress reduced sharply and then increased to exceed  $4.1 \times 10^6$  Pa (600 psi) above initial stress. The sharp stress reduction was accompanied by large roof falls behind the shield and by failure of the underclay beneath the bleeder entry pillars. A similar failure of the underclay was observed at pillars in the recovery area when pillar stresses reached  $4.1 \times 10^6$  to  $5.5 \times 10^6$  Pa (600 to 800 psi) above overburden stress.

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# New Method of Satellite Imagery Analysis Applied to Underground Mining

David K. Hylbert and Thomas F. McLoughlin

**Abstract**—A new method of satellite imagery analysis has been developed during underground mine roof research. Landsat positive film transparencies were projected onto topographic base maps to scale and lineaments enhanced with a Ronchi grating (method A). Thirty-five millimeter slides of video-enhanced scenes were also projected onto base maps (method B). Both methods permit direct plotting of lineaments to scale and direct correlation with surface and subsurface data using transparent overlays.

## Introduction

The use of Landsat imagery in the detection of some zones of structural weakness that may cause unstable roof conditions has been reported by several investigators (Rinkenberger, 1979; McCabe, 1976; Rinkenberger, 1977; Sullivan, 1978; Wier, et al., 1973). The imagery has been successfully used to delineate "lineaments," or topographic and/or tonal alignments that may reflect structural anomalies such as faults or joint systems.

Imagery analysis is appealing because it permits a relatively rapid evaluation of a mining area on both a local and regional scale. Also, inaccessible (or forested) areas may be analyzed and imagery lineaments correlated with known structural features in the area so that subsequent field work is greatly reduced. Additionally, geographic coverage by Landsat imagery is essentially complete and available to the general public.

The procedure discussed herein was developed during the past year as a consequence of research directed toward coal mine roof falls in eastern Kentucky. Satellite imagery analysis has been used to develop methods of determining roof stability in advance of mining.

## Development of Procedure

Satellite imagery was obtained from the USGS-EROS Data Center, Sioux Falls, SD. The imagery obtained consisted of 1:1,000,000-scale positive film transparencies and prints of black-and-white infrared band 7 imagery recommended for

geologic studies (Wier, et al., 1973). Winter scenes were selected to avoid excessive vegetation and to obtain scenes with a low-sun elevation which enhances topographic elements. Black-and-white prints at a scale of 1:250,000 were also obtained for reference purposes and for possible direct plotting of lineaments.

A review of current literature indicated that the detection of linear features on Landsat imagery has been accomplished by at least four methods: (1) inspection of imagery-film transparencies on a light table with hard magnifiers; (2) stereoscopic viewing of pairs of transparencies and/or positive prints using

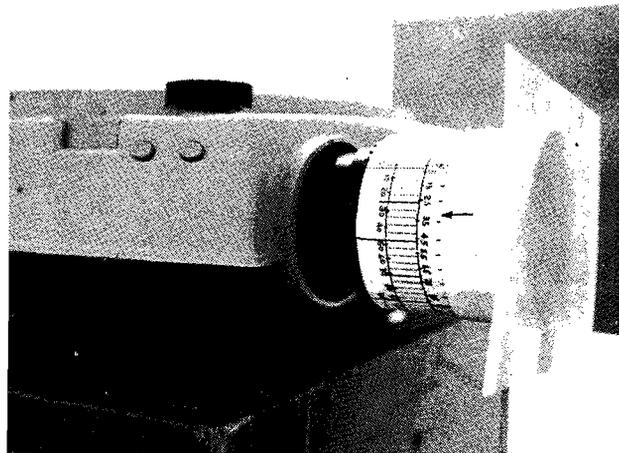


Fig. 1— Photograph of Ronchi grating and indexing device. The index is divided into four 90° quadrants and labelled according to compass directions.

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D.K. Hylbert and T.F. McLoughlin are professor of geosciences and research assistant, respectively, Morehead State University, Morehead, KY. TP 79-220. Manuscript, July 28, 1979. Discussion of this paper must be submitted, in duplicate, prior to Feb. 28, 1981.

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