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# MEASUREMENTS OF VERY LARGE DEFORMATIONS IN "POTASH SALT" IN CONJUNCTION WITH AN ONGOING MINING OPERATION*

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## ABSTRACT

Room and pillar deformation were measured in conjunction with a relatively new type of mining operation in a southeastern New Mexico potash mine. The extraction ratio was approximately 90 percent in a first mining operation. Due to severe deformations encountered, instrumentation had to be developed/modified for these measurements. This paper concentrates on experiment design, design of special instrumentation, field installation of equipment, and presentation of the data. Measurements made include extensometers in the pillar, in the floor and ceiling in the room between pillars, "absolute" level measurements, floor ceiling closure, and stress (strain) measurements. Associated laboratory rock mechanics measurements of samples from the mine are being done separately.

Two separate room pillar complexes were instrumented. In the first complex, floor-ceiling deformations of approximately 1 inch/day and pillar deformations around 1/2 inch/day were measured. In the second complex, instrumentation was installed while the pillar was a part of a long wall and the subsequent sequential mining (long wall-pillar with only one adjoining room on one side - pillar in the middle of room pillar complex) was observed. Data return from this operation was good.

## INTRODUCTION

Sandia National Laboratory has implemented an interrelated matrix of experiments performed in salt in support of the Waste Isolation Pilot Plant (WIPP). The goals of the overall program are to obtain scientific and engineering data applicable to the design of emplacement and containment systems for radioactive waste disposal in bedded salt formations in southeastern New Mexico and to acquire information to resolve generic technical issues relevant to isolation of high-level waste in salt formations.

The work reported herein is one phase of this overall program and involves the measurement of room and pillar deformations in a Southeastern New Mexico Potash mine. The work was a joint effort between Sandia and Mississippi Chemical Company (MCC) to monitor pillar deformations at ambient temperature conditions in an ongoing mining operation. The relatively new mining system employed by Mississippi Chemical Company involves 90 percent extraction of ore in a first mining operation. The remaining 10 percent is left in the form of a symmetric array of small pillars which undergo severe deformations over relatively short periods of time. This mining approach provides a unique opportunity to monitor large deformations all the way to failure, to document the failure mechanisms, and to provide detailed data on large deformations due to mining for subsequent comparison with numerical techniques.

An agreement was made with the MCC which allowed Sandia personnel to instrument two rooms and adjacent pillars along the advancing mine face. The mining engineering department of Mississippi Chemical Company provided support in this effort. Deformation measurements were taken for a number of weeks following each installation.

Large rock samples from appropriate horizons were taken for laboratory determination of material properties. These measured material properties are now being used in computer modeling. Both the laboratory data and the modeling work will be reported separately.

Two separate room-pillar complexes were instrumented and the instrumentation concentrated on measuring the following:

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(1) Pillar deformation.

(2) Roof-floor closure between rows of pillars and the pillars themselves.

(3) Extensometers in the floor and ceiling in the center of the room to measure separation of strata due to mine deformation.

(4) Stress measurements in pillars (Cook and Ames (1978)).

Sandia designed the overall experiment with additional inputs from the mine. Sandia provided and installed the transducers (in part Sandia-designed and modified) and recorded the data. All phases of the work were cooperative in that both Sandia and the mine staff made inputs in all areas of the operation. Transportation of men, material, and equipment, early preparation of a recording alcove (away from the mining face in a quiet, stable portion of the mine), drilling of extensometer holes, and survey work were mainly done by mine personnel.

The instrumentation design required that the very large (2-4 feet) deformations to be measured be recorded by automated transducers. Deformations of the pillars with associated roof collapse and floor heave occurred rapidly, on the order of inches per week, and severe deformations occurred within a few weeks. Multipoint extensometers were constructed from commercially available, single channel potentiometer readout gates coupled together with special brackets. Relative floor-ceiling room closure was easy to measure with extensometers, but floor and/or ceiling motion had to be determined separately. A hydraulic level gage was developed and installed, which permitted separating motions of floor and ceiling.

Implementing this activity involved problems associated with instrumentation of an experimental area in proximity to an ongoing mining operation and the aspect of mine safety due to the rapid deformation. In order to record the data at a distance of approximately 1000 ft. away from the instrumented pillars, long cable runs, cable jumpers, and junction boxes were necessary. Automated readouts, using potentiometers (vs. dial gages) were necessary for personnel safety.

This paper reports on highlights of the experiment design, design of special instrumentation, field installation of equipment and presentation of representative data. Space limitations preclude presentation of all details and data. A more extensive report is in preparation with a detailed accounting of all aspects of the program (Sattler and Christensen (1980)).

## DISCUSSION OF EXPERIMENTS

Two major experiments were planned and executed--Small Pillar Experiments One and Two. A plan view of the mine where experiments were performed is shown in Figure 1. The experiments centered on measuring the deformation of one of the small pillars which remains behind during the mining operation, recording the deformations which take place in the rooms on each side of the pillar and evaluating the instruments designed for these tasks. The layout and sequence of the mining operation can be seen in Figure 1, with a geologic profile of the horizons mined shown in Figure 2.

In each room-pillar complex, the pillar chosen for instrumentation was as close to the center of the room as possible to minimize the effects of barrier or abutment pillars or other boundaries. For the same reason, rooms selected for instrumentation were chosen well away from barrier or abutment pillars. The area remaining after mining consisted of runs of 8-foot x 20-foot pillars, 10 feet apart, 60 feet between rows.* The minimum distance between an instrumented area and any boundary or area differing in mining was about 150 feet for the first room instrumented and about 200 feet for the second room instrumented.

In the second of the two experiments, Mississippi Chemical Mine personnel agreed to mine a long pillar by omitting two cuts between standard pillars, providing a pillar whose dimensions were 80-feet long x 10-feet wide x 6-feet high. This provided a more favorable aspect ratio which allowed a two-dimensional plane strain configuration for subsequent computer modeling comparisons instead of three-dimensional calculations. Further, it provided more space along its length for installation of instrumentation.

## INSTRUMENTATION UTILIZED

It became clear in the design phase of these experiments that, because of the high extraction

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*Such extraction of approximately 90 percent of the ore indeed causes immediate measurable deformations. Floor-ceiling closure starts at about an inch per day and continues at about this rate for a few weeks until floor and ceiling touch or are only a few inches apart.

ratio in the mining operation with the attendant large and rapid deformations, there would be problems not normally encountered in field rock mechanics measurements. As with most mining operations, the transducers had to be installed as soon as possible after mining as the early deformation data are very important. Manually read (dial) gages were not an option because instrumented areas became inaccessible due to mine safety considerations within a few days as the mining operation progressed. Also relative floor-ceiling motion, measurable by a floor-ceiling gage, would have to be further analyzed so that ceiling collapse and floor heave can be differentiated. The above instrumentation and recording constraints were met as follows:

Extensometer Development/Modification

Multipoint extensometers with automatic readouts capable of measuring very large deformations were not available on a time frame consistent with the mining schedule. However, single channel potentiometer readout deformation gages useful as floor-ceiling displacement gages capable of measuring large deformations on the order of one foot are commercially available.* These gages were directly utilized for recording relative floor-ceiling deformations with minor modifications (See Figure 3). A complete measurement of the displacement field in the floor and ceiling was accomplished by designing a bracket which utilized several of these individual potentiometer gages in combination, also shown in Figure 3. A more detailed view of the constructed multipoint extensometer is presented in Figure 4. This multipoint extensometer was then inserted in the floors and ceilings of the instrumented rooms as well as in instrumented pillars, resulting in deformation-time measurements at given distances above the roof and below the floor of the room.

Hydraulic Level Gage

In order to determine absolute displacement of roof and floor, a hydraulic level gage accurate to approximately 0.1 inch was used. Use of this gage allowed roof and floor motion to be distinguished. This level gage was on the floor in the middle of the instrumented rooms in each of the two experiments, while the reference reservoir was in a more stable area of the mine (about 500 feet away). A reading of floor motion heave was obtained by observing the level of the reference reservoir.

Ceiling motion was also obtained at one point by optical survey methods using a reflecting prism on the ceiling above the level gage. This was done in each of the two room-pillar complexes.

Installation of Instrumentation

Because the initial pillar deformations were up to two inches per day and safe access could be maintained only until an adjoining room was mined, detailed planning of the gage installation had to be made prior to actual installation of rock mechanics equipment in the two room-pillar complexes. Cable runs from the data logger to the mining face (approximately 2000 ft.) had to be made, a junction box connected at the end of the cable run and a preliminary check of channels made. When permission was given by Mississippi Chemical Company to actually enter the newly-mined room-pillar complex, transducer installation began immediately and was virtually completed in two to four days with the exception of floor-ceiling gages which would go on the far (unmined) side of the mine face as the mining advanced.

A data acquisition system was installed in a room prepared in a conventionally-mined room and pillar area of the mine. This room was on the other side of a barrier pillar separating the new mining and the rest of the mine (See Figure 1). It was also reasonably far from other mining activity to be suitable for a base station for recording, and a staging area for installation of transducers.

Cables (twisted shielded pair)** were run between the base station and locations one room behind the rooms which were mined and instrumented. The cable was fastened to the wall and ceiling, tying onto staples set in the mine with a RAM Set staple gun. Adequate slack was left between ties so the cable would not be snapped by ensuing deformation. A junction box was connected to the cable and checked out.

When the room to be instrumented was made accessible by Mississippi Mine personnel, the junction

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* Units utilized in this program were manufactured by Celesco and Research Incorporated.

**Chosen for strength and convenience in recording.

box was brought into the room and all transducer connections were made through that box. The local cable runs between the junction box and the transducer runs were made using a four conductor shielded cable.* Upon retreating from a room after the instrumentation was installed, a steel table was placed over each of the two junction boxes. These precautions were adequate to prevent loss of data due to crushed or ruptured cable.

Instrumentation utilized in Small Pillar Experiment One was as follows:

(1) Eight (8) Floor/Ceiling Convergence Gages
(2) One (1) 3-point Floor Extensometer at -27', -20', -10'
(3) One (1) 3-point Ceiling Extensometer at +30', +20', +10'
(4) Two (2) 2-point Wall Extensometers at (2',4') and (5', 10')
(5) Two (2) Irad Stress Gages
(6) Ten (10) Break Wire Gages
(7) Three (3) Micro Seismic Detectors
(8) One (1) Leveling Gage
(9) Two (2) Roof Bolt Matrix Installations

Instrumentation utilized in Experiment Two consisted of:

(1) Eight (8) Floor/Ceiling Convergence Gages
(2) One (1) 3-point Floor Extensometer at -27', -20', -10'
(3) One (1) 1-point Ceiling Extensometer at +20'
(4) Three (3) 2-point Wall Extensometers, 2 at (6', 4') and 1 at (6', 12')
(5) Ten (10) Irad Stress Gages
(6) Two (2) Strain Gage Stressmeters
(7) Six (6) Break wire gages
(8) Three (3) micro seismic detectors
(9) One (1) leveling gage
(10) Two (2) roof bolt matrix installations.

Locations of placement of the various convergence, extensometer and breakwire gages are indicated in Figure 5 for Small Piller Experiment 1 and in Figure 6 for Experiment 2. Note particularly the long ("plane strain") wall instrumented in Experiment 2.

Information on the data logger was recorded every hour for two weeks after installing each of the two groups of instrumentation and every three hours until the end of the recording period. Access to the instrumented rooms after installation (mainly for photography) lasted only for about a week due to mine safety considerations. The base station, which contained the data acquisition system and associated circuitry, was visited twice weekly to remove data and maintain the recording system. Long-range photography of the instrumented areas was continued for approximately two months from a main accessway to that area until even the accessway to the mined-out panels was barred to entry.

## RESULTS

### First Experiment

In the first experiment, Small Pillar Experiment 1, where the panels and room were mined two to three days prior to experiment installation, the floor-ceiling closures were about an inch per day for thirty days and slower thereafter. Ceiling motion accounted for about two-thirds of the motion and floor heave accounted for the rest. The closure was fairly uniform in the room. The pillars provide some local support for the ceiling at later stages of deformation. The closure at the center of the room was similar to the closure between pillars. Floor-ceiling convergence data from the eight convergence gages are plotted schematically from a computer printout in Figure 7 for various times, showing the spatially uniform closure rate. (See Figure 5 for gage identification.)

The pillars themselves bulged out as seen schematically from a computer printout in Figure 8. The extensometer through the width of the pillar showed an elongation of one-half inch per day for 30 days on the outer quarter of the pillar and the half width of the pillar increased about 2/3 of an inch per day for 30 days. The elongation of this instrumented pillar was about two-thirds of an inch per day for 30 days with most of this coming in the outer three-fourths of the pillar and virtually none coming from the center portion (1/4) of the pillar.

The data from extensometers in the floor and ceiling showed that up to 30 ft. into the rock in each direction vertically there is no appreciable separation of the strata (Figure 9).

The level gage and survey data show that in 30 days the floor heave amounts to about eight inches out of a total floor-ceiling closure of 30 inches. The floor-ceiling convergence data correlate well

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*Chosen for strength and convenience in recording.

with the separate floor (level gage) and ceiling (survey) measurements.

Breakwire gages installed to detect gross slabbing gave ambiguous data as pillar slabbing occurred virtually on a continuous basis.

Only two channels out of about twenty were damaged and gave spurious readings after the first fifteen days. After 30 days more of the channels gave ambiguous readings, probably due to the effects of severe deformations on the extensometer mounts. The signal was lost from only one channel (after 40 days) during the monitoring period.

### Second Experiment

In the second experiment, the mining operation was such that the sequence in mining could be better observed by the instrumentation. The panels were only 9 hours old when installation was made into the portion of the long wall which was not to become a pillar until three days later. Floor ceiling closure transducers and extensometers into the floor and ceiling were installed within two days. Only the one adjoining room beyond the 80 ft. by 20 ft. wall was mined until about 50 days later. During this time, the floor-ceiling closure rate was slower than in the first experiment. After 50 days, additional rooms were mined beyond the long wall pillar. Each data channel (floor-ceiling closure, pillar deformation and floor heave) showed a distinct inflection (increase) in the deformation rate when this additional mining was initiated after three days and 50 days. A typical floor-ceiling convergence gage recording is shown in Figure 10. The two inflections present corrrespond to the times when additional mining operations were initiated. These inflections are also visible in Figure 11, which shows data from a representative wall extensometer recording taken near the outside of the long wall in Figure 6. (These inflections were seen in virtually all floor-ceiling, leveling gage and extensometer channels. All channels recorded for 70 days.)

## CONCLUDING REMARKS

The large deformations in rooms and pillars resulting from the new high extraction mining method used at Mississippi Chemical Company were successfully measured. The installation of instrumentation was able to begin promptly after mining the room and pillars especially in the second experiment. The experiment was conducted with no interruption in the mine production schedule. The sequence of mining was observed very clearly in the extensometer and closure data observed in the second experiment.

The Sandia modification, adaptation, and fabrication of transducers which measure large deformations worked satisfactorily.

The hardening techniques used to protect extensometer anchors, signal cables, cable runs, junction boxes, etc., were adequate. Signals from virtually all critical channels were recorded without ambiguities during the course of the monitoring period. Laboratory rock mechanics tests to determine material properties and the comparative analyses are currently underway (Senseny, Pfeifle and Klasi, (1980)).

## ACKNOWLEDGEMENTS

(1) The authors and Sandia Laboratories are grateful for the cooperation and participation of the Mississippi Chemical Company in this work. A special acknowledgement is given to Timothy Hall, Mine Superintendant, and the mining engineering staff who devoted a great deal of time and effort in ensuring the success of this venture.

(2) The transducer design/modifications were made by E. S. Ames and C. W. Cook of Sandia Laboratories. J. T. McIlmoyle, Sandia, was in charge of data acquisition.

(3) This report and the attendant experimental results were reviewed and edited by T. A. Duffey, Los Alamos Technical Associates, Inc.

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(3) Senseny, P.E., Pfeifle, T.W., and Klasi, M.L., "Laboratory and Numerical Studies in Support of the Sandia Small Pillar Experiment Two", RE/SPEC Inc. Report RSI-0012 (1980). (First Interim Report).

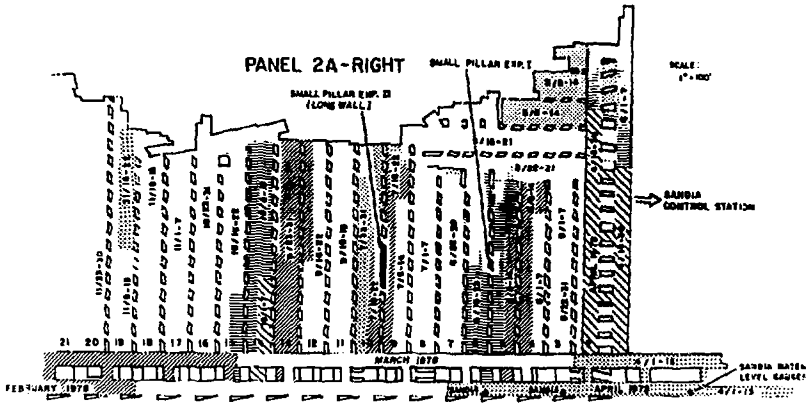


FIGURE 1. PLAN VIEW SHOWING EXPERIMENT IN MISSISSIPPI CHEMICAL CO. MINE

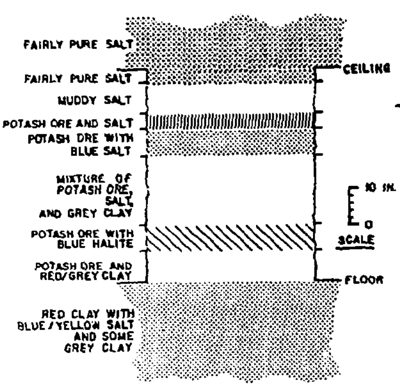


FIGURE 2. GROSS STRATOGRAPHIC CROSS SECTION THROUGH MINED AREA

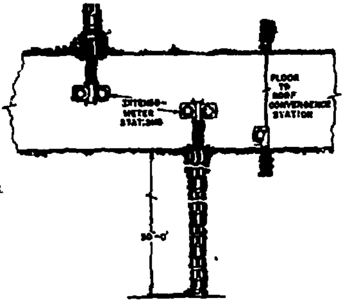


FIGURE 3. VIEW OF TYPICAL EXTENSOMETER AND CONVERGENCE STATIONS

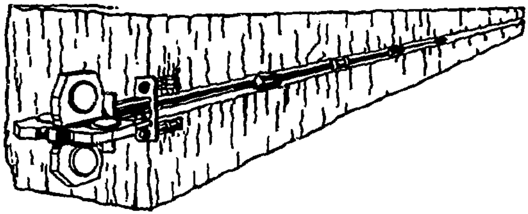


FIGURE 4. MULTIPOINT EXTENSOMETER DESIGN

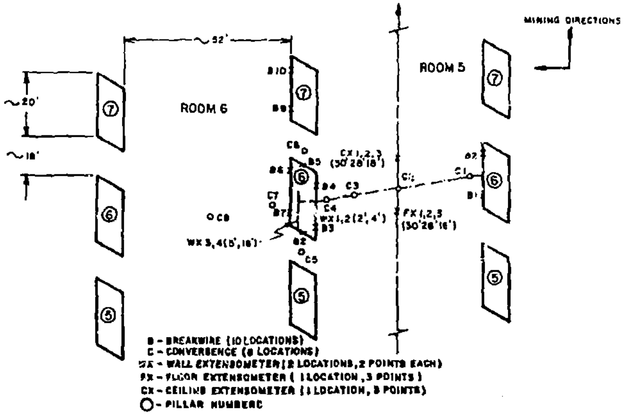


FIGURE 5
SMALL PILLAR EXPERIMENT 1
MISSISSIPPI CHEMICAL CO.
16-22 JUNE 1978 INSTALLATION

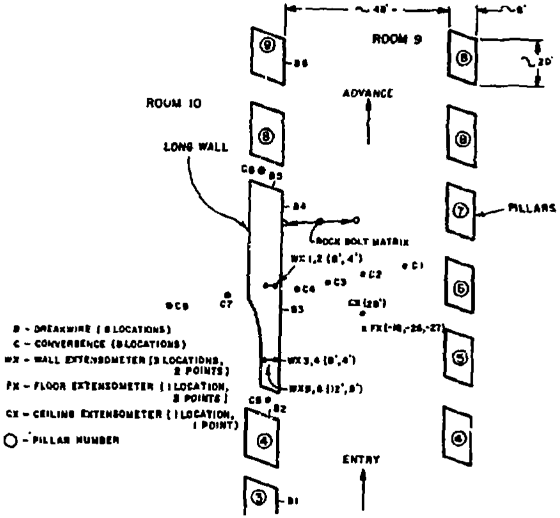


FIGURE 6. SMALL PILLAR EXPERIMENT 2
MISSISSIPPI CHEMICAL CO. 17-24 JULY 1978 INSTALLATION

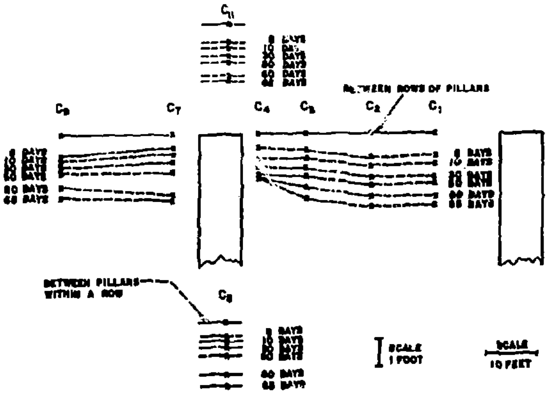
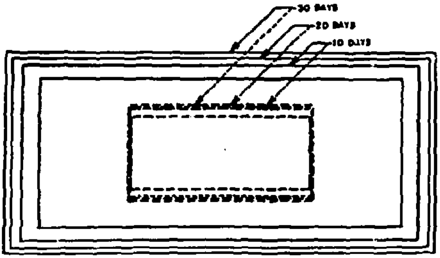
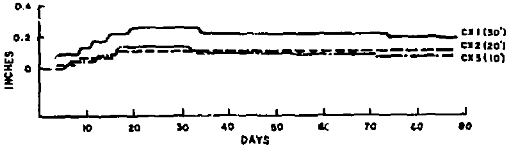


FIGURE 7. SCHEMATIC OF FLOOR-CEILING CONVERGENCE
*EXPERIMENT I*



- FIGURE 8. SCHEMATIC OF PILLAR EXPANSION EXPERIMENT I

SCALE
8 FEET



— FIGURE 9a. CEILING EXTENSOMETER DATA -- SMALL PILLAR EXPERIMENT I

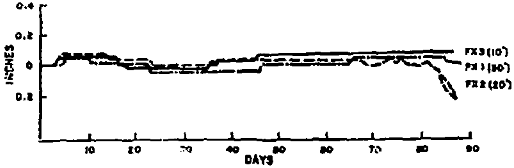


FIGURE 9b. FLOOR EXTENSOMETER DATA -- SMALL PILLAR EXPERIMENT I

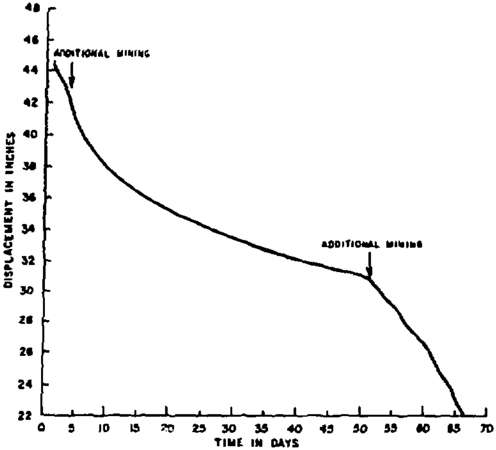


FIGURE 10. TYPICAL FLOOR/CEILING CONVERGENCE RECORDING
(EXPERIMENT 2, GAGE C2)

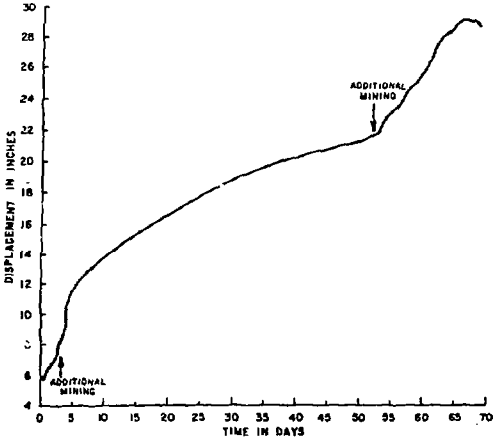


FIGURE 11. TYPICAL WALL EXTENSOMETER RECORDING
(EXPERIMENT 2, GAGE WX 2)