RI 8811

Bureau of Mines Report of Investigations/1983

Experimental Drift Linings in a Block-Caving Operation— A Field Demonstration

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UNITED STATES DEPARTMENT OF THE INTERIOR

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James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

McLaughlin, William C

Experimental drift linings in a block-caving operation—a field demonstration.

(Bureau of Mines report of investigations ; 8811)

Supt. of Docs. no.: I 28.23:8811.

1. Ground control (Mining). 2. Caving mining. I. Thomas, L. A. (Lloyd A.). II. Harasha, J. L. (James L.). III. Title. IV. Series: Report of investigations (United States. Bureau of Mines) ; 8811.

TN23.U43 [TN288] 622s [622'.28] 83-600128

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	min	minute
cu m	cubic meter	MPa	megapascal
cu yd	cubic yard	mV	millivolt
°C	degree Celsius	pct	percent
°F	degree Fahrenheit	psi	pound per square inch
ft	foot	rpm	revolution per minute
g	gram	sq cm	square centimeter
hr	hour	sq ft	square foot
in	inch	sq in	square inch
kg	kilogram	sq m	square meter
km	kilometer	V	volt
kPa	kilopascal	wt pct	weight percent
lb	pound	yr	year
m	meter		

EXPERIMENTAL DRIFT LININGS IN A BLOCK-CAVING OPERATION—A FIELD DEMONSTRATION

By W. C. McLaughlin,[1] L. A. Thomas,[2] and J. L. Harasha[3]

ABSTRACT

Under a cooperative agreement, the Bureau of Mines, Magma Copper Co., and ASARCO, Inc., tested backfilled ground support systems at two elevations in Magma's San Manuel, AZ, mine. The tests were mainly for guidance in designing the loading crosscuts of the new ASARCO Sacaton underground mine.

Two-piece, wide-flange steel sets for 8- by 8-ft (2.44- by 2.44-m) and 11- by 11-ft (3.36- by 3.36-m) openings were designed. Set spacing was 3 ft (0.91 m) and 5 ft (1.52 m), respectively. After erection, the sets were lagged with various test materials. The void between the lining and the ground was backfilled with sand and pea gravel. Instruments measuring strain (used to determine changes in stress) were placed beneath the sets and in the backfill. Results indicate the backfilled sets in the smaller drift (2315 grizzly level, panels 6 and 7) of 8- by 8-ft (2.44- by 2.44-m) cross section are a viable permanent support system, lower in cost than the standard formed concrete.

Results are inconclusive in 2615 grizzly level, panels 5 and 6, where wide-flange steel sets were used with 5-ft (1.52-m) long concrete gob lagging of T-design.

[1]Mining engineer, Spokane Research Center, Bureau of Mines, Spokane, WA (retired).
[2]Chief planning engineer, Magma Copper Co., San Manuel, AZ.
[3]Project engineer, ASARCO, Inc., Sacaton Unit, Casa Grande, AZ.

INTRODUCTION

The San Manuel Mine of the Magma Copper Co. is located 50 miles (80.5 km) northeast of Tucson, AZ. Mining, milling, and smelting methods are described by Dale (4).[4] The San Manuel ore body is a deposit of chalcopyrite disseminated throughout a structurally weak, highly fractured, strongly altered quartz monzonite host rock. A full-gravity caving system is used to mine the ore body. The ore body is divided into parallel 140-ft (42-m) wide panels along its axis. Typical development of openings within a panel is shown in figure 1. Haulage drifts are driven parallel to the panel, grizzly drifts are driven at right angles to the haulage drifts, and undercut drifts are driven perpendicular to the grizzly drifts.

Preconcrete support in fringe drifts usually is 4-in (10.2-cm) wide-flange (WF) sets with arched cap and battered posts, and wooden lagging as needed. Grizzly drifts are driven using 6-ft (1.83-m) rockbolts and wire mesh for preconcrete support. Grizzly drifts are driven to allow a minimum of 18 in (0.46 m) of concrete on the sides and 2 ft (0.61 m) in the back. A concreted grizzly drift is 4 ft (1.22 m) wide by 6-1/2 ft (1.98 m) high. Further information on concrete mixing, transportation, forming, and pouring is given by Seaney (17).

[4] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

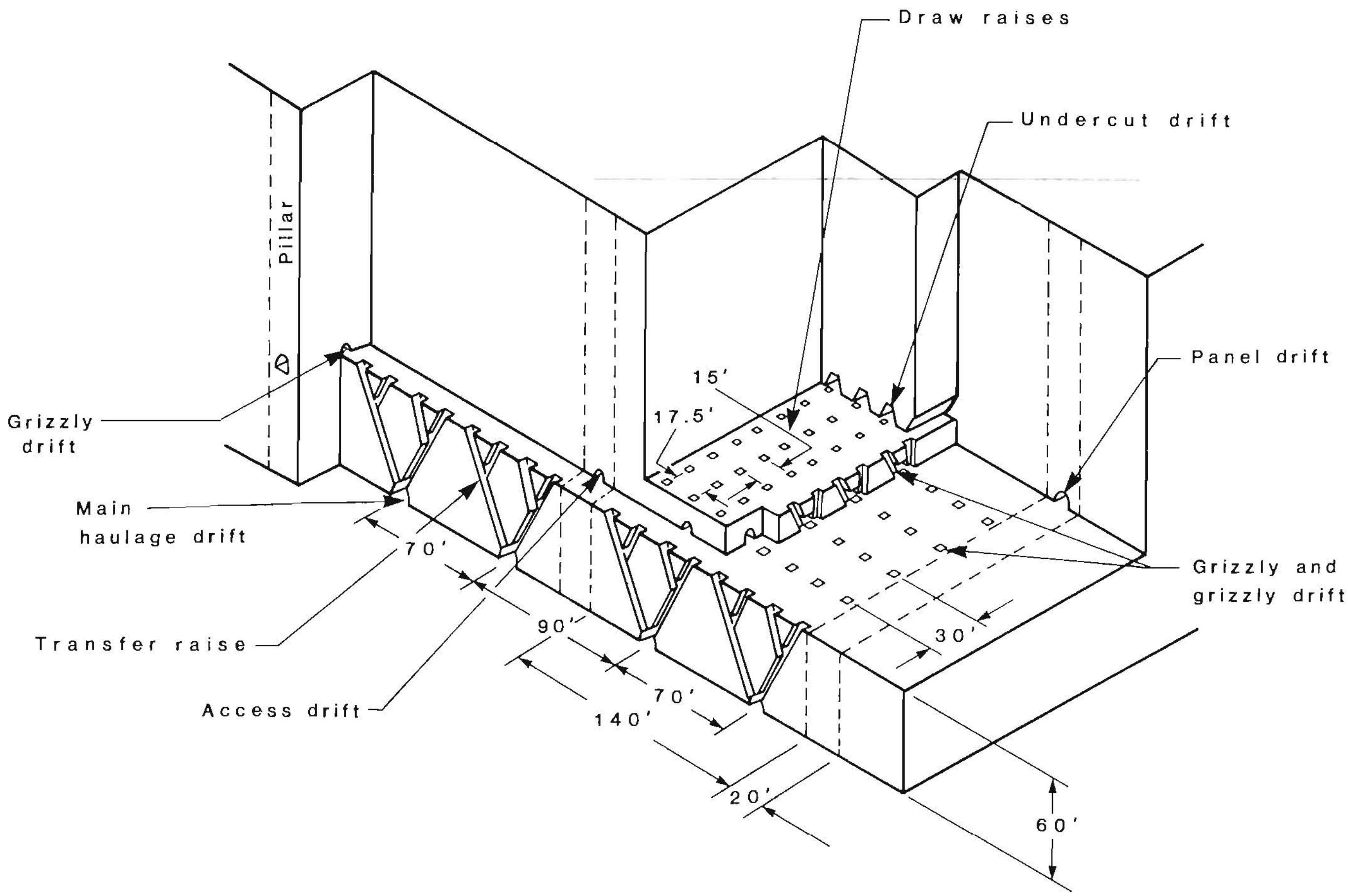

FIGURE 1. - Isometric view of panel.

Fifteen feet (4.57 m) above the grizzly level, the cave is started by drilling and blasting out pillars between undercut drifts. Although undercutting can start at any position in the block, it must be started against an older caved block and retreat diagonally to a solid corner. Over the length of several panels, mining expands diagonally. This undercutting sequence is known as "diagonal retreat panel caving by block" (19-20).

The complicated system of openings and the progressive mining of each undercut level and adjacent panel blocks impose a complex and everchanging state of stress on the openings below the undercut level. Current production comes from the 2015, 2315, and 2615 grizzly levels. Formed concrete is costly to repair and in some cases gives inadequate support to maintain the drifts.

After discussing these problems with Magma Copper Co. and with ASARCO personnel (who were planning a block-caving operation at Sacaton, AZ), the Bureau of Mines, in May 1978, entered into a cooperative study of an alternate support system with the two companies.

ACKNOWLEDGMENTS

ASARCO's technical and conceptual input and financial assistance are especially acknowledged. Magma furnished the test sites, labor, and supplies; and its geological department took the instrument readings, which are gratefully acknowledged.

The guidance of Dow Chemical Co. in the manufacture of latex-modified concrete lagging at a local site is also acknowledged.

PREVIOUS WORK

Previously, the Bureau had made several analytical studies of unreinforced-concrete tunnel linings. Dixon (7) made a finite-element analysis of freestanding (not influenced by the surrounding rock media foundation) circular and horseshoe shapes used in production access drifts of the San Manuel copper mine. In total, nine concrete-lined tunnel configurations were subjected to 22 biaxial load conditions. Structural design data were developed from these calculations. Bending, axial shear, boundary stresses, moments, thrusts, shear forces, and structural deflection at any point on the lining can be calculated from these data.

In a sequel, Dixon (6) analyzed these structures under conditions where the linings were simultaneously forced to comply or interact with the rock mass around the drift. When the support-rock interaction is accounted for, the distribution and magnitude of rock reactions due to this interaction depend on the deformable properties of both the lining and rock mass, and the type of connection between them. Structural design data were developed for circular, horseshoe, and rectangular concrete linings, each with two thicknesses and subjected to eight loading conditions for drifts excavated in hard and soft rocks. A comparison of data from these two investigations shows that the stresses, loads, and deformations of the linings are substantially influenced by such factors as the deformation modulus of the rock media and the thickness, or stiffness, of the lining.

Physical properties of San Manuel rock have been investigated. Work on determining the geometry of fractures and their influence on the cavability of the San Manuel Mine is reported by Mahtab (11-12). While that work did not determine a modulus of deformation for the mine rock, it did show that the complicated rock jointing greatly influenced the mechanical behavior of the rock. Mechanical properties determined in the laboratory are given by Kendorski (10). He points out that a small amount of confining stress will improve the elastic modulus of a fractured rock mass at the San Manuel Mine.

From this previous work and field observations of failed grizzly drifts, it was determined that a support system must satisfy the following criteria. It must be stiff enough to--

1. Allow rock displacement, permitting a redistribution of stress concentrations in the rock mass.

2. Apply some confining stress on the rock mass, so as to improve the rock mass mechanical and strength properties.

3. Allow only small closures of the grizzly and haulage drifts. In addition, the support system must be strong enough to carry heavy loads.

CRITERIA FOR SELECTION OF TEST SITES

The cooperators selected test sites to meet the following conditions:

1. The adjacent rock was to be friable, altered, jointed quartz monzonite and was to be traversed by major faults.

2. Test panels were to be adjacent to unmined panels so that abutment loads could be expected near the test drifts during block undercutting and subsequent mining.

3. After undercutting the test blocks, a major part of the ore draw would be in hard, consolidated quartz monzonite.

4. Locate at least one site in a drift using temporary rock support of wood posts, steel caps, rail sets, and lagging. Thus, point loading would be expected on the permanent lining.

5. The above conditions would present a severe mining test and would approximate mining practice in heavy ground at San Manuel.

This set of criteria led to the selection of a steel-supported system backfilled with sand and/or gravel. A finite-element analysis of this support design was not possible because of the largely unknown values needed to describe the physical behavior of the backfilled gravel, the in situ stresses and mining-induced loading conditions, and the short time schedule. Rather, an empirical and observation approach to design was undertaken. Magma Copper Co. offered a test site and technical support to the Bureau and ASARCO. The initial test site was on grizzly level (GL) 2315 in a connecting drift between grizzly drifts (figs. 1-3). The second test site was on GL 2615 in a panel drift (figs. 1-3).

DESIGN OF PROTOTYPE SUPPORT

Over the past 10 to 15 yr, research on backfilled flexible liners has been conducted by the Bureau. This has been both theoretical and experimental (2, 5, 14-15). Advantages are shown to be a reduction of stress in the lining and a more uniform distribution of stress transmitted from the surrounding rock mass. This is one of the potentially better support systems that has been examined. It is essentially a continuous liner, with backfilling that cushions the liner from the rock.

One lining included in the test was latex-modified, steel-reinforced concrete lagging, developed under contract to the Bureau of Mines. This was locally manufactured by a concrete firm, with Dow Chemical Co. supervision. Lagging was cast in 4- by 6-in (10.2- by 15.2-cm) rectangular sections with three No. 6 rebars near the bottom of the lagging; length was 34 in (0.89 m).

In the laboratory, this type of concrete tested to 23,500 lb (10,660 kg) in

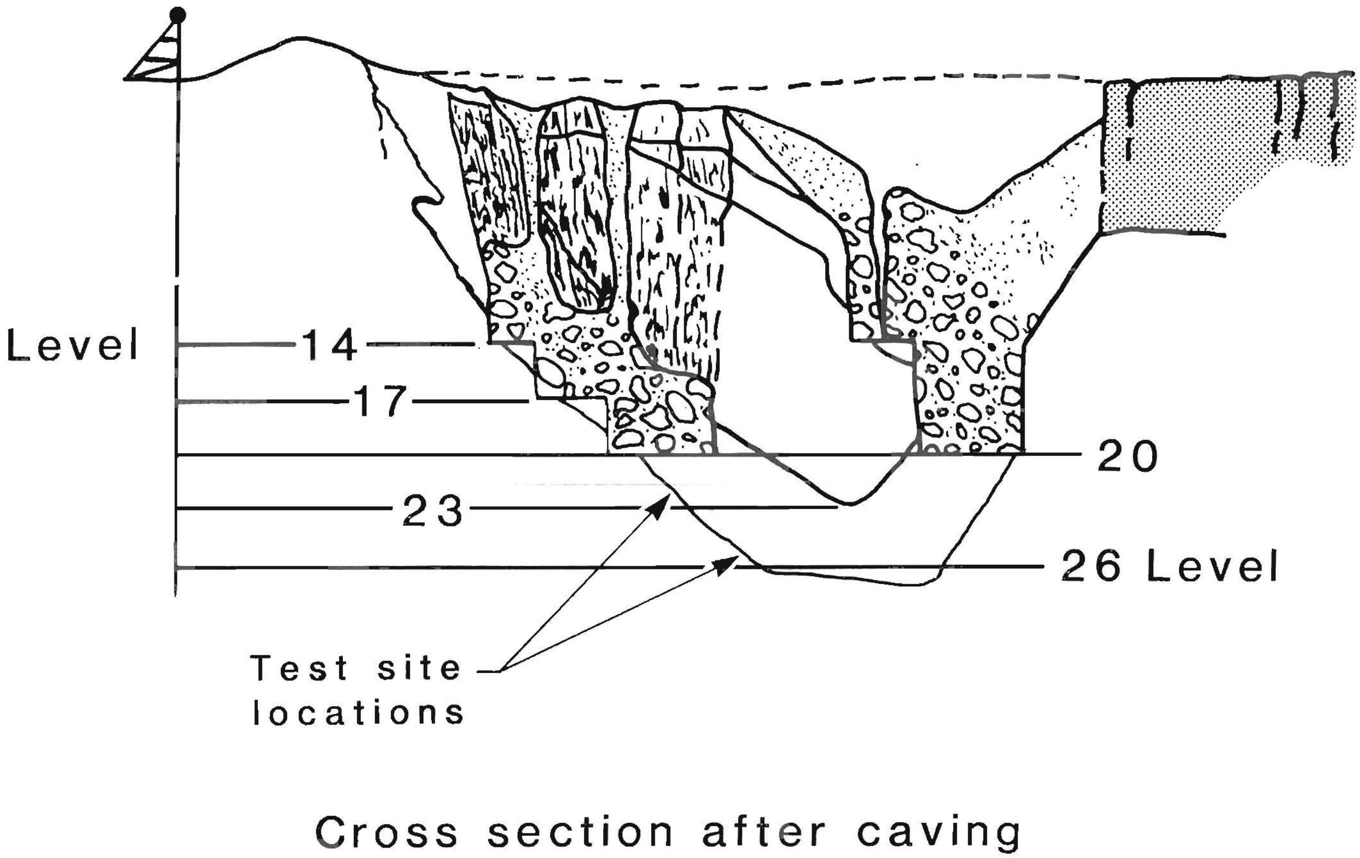

FIGURE 2. - Test site locations.

compressive strength at four-point loading; dry fir lagging of like section tested 11,000 lb (4,990 kg).

Table 1 and figure 4 show test results of the prototype concrete lagging. Water is critical in the mixing of latex concrete, hence a variation in breaking strength. The laboratory failure (fig. 4) with cracks at a low angle to the long axis indicates that the three No. 6 rebars are more than adequate. Even after cracking of the concrete, deflection continues; lagging 3 initially failed at 18,500 lb (8,392 kg), but the steel rebars continued to support 4,850 lb (2,200 kg) after concrete failure. The concrete is more expensive than wood but has the advantage of fire resistance, and it is not susceptible to dry rot.

TABLE 1. - Concrete lagging test (four-point loading)

4- by 6-in beam, 34 in long	Load at failure, lb	Remarks
Fir.......	11,160	From Lakeshore Mine.
Concrete 1	14,800	3 No. 6 rebars.
Concrete 2	18,500	Do.
Concrete 3	23,500	Do.[1]

[1]Supported 4,850 lb after the concrete failed.

NOTE.--Concrete was aged 5 months. Latex-modified portland cement and regular aggregate were used. Steel rebar was not galvanized. Test lagging were from 3 separate pours, 1 test per concrete.

CONSTRUCTION IN 2315 GRIZZLY LEVEL, PANELS 6 AND 7 TEST DRIFT

DRIFT SUPPORT AND INSTRUMENTATION

In April 1978, a test drift was excavated in a wide shear zone between two grizzly drifts (parallel to and 20 ft (6.1 m) away from the access drift). Figure 3 shows the initial test drift location. The opening was about 11 by 11 ft (3.35 by 3.35 m) in cross section and 25 ft (7.62 m) long; the back was only 4 ft (1.22 m) below the undercut. Overbreak was considerable. After excavation, the back and ribs of the test drift and the adjacent grizzly line were instrumented with vibrating-wire stress meters (9) and rockbolt (RB) load cells (4) in the back and ribs for measurement of strain changes in the pillars during mining. Temporary ground support was rockbolts and wire mesh.

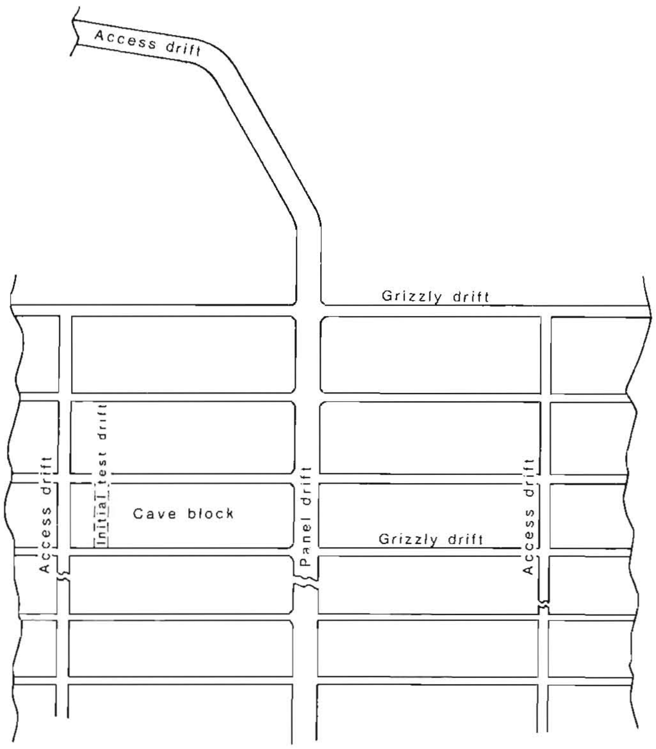

FIGURE 3. - General plan of grizzly level.

WF 8- by 6-1/2-in (20.32- by 16.5-cm) by 24-lb (10.8-kg) steel sets were installed in the drift. The sets were fabricated with an arch and tapered sides in two pieces that bolted together at the top of the arch. Overall height is 7-1/2 ft (2.29 m), and width is 6 ft 5-1/2 in (1.99 m). The sets were placed on 3-ft (0.91-m) centers. They were drilled for 1/2-in- (1.27-cm) round by 44-in (1.12-m) threaded connector rods for ease of erection and for greater stability of the structure.

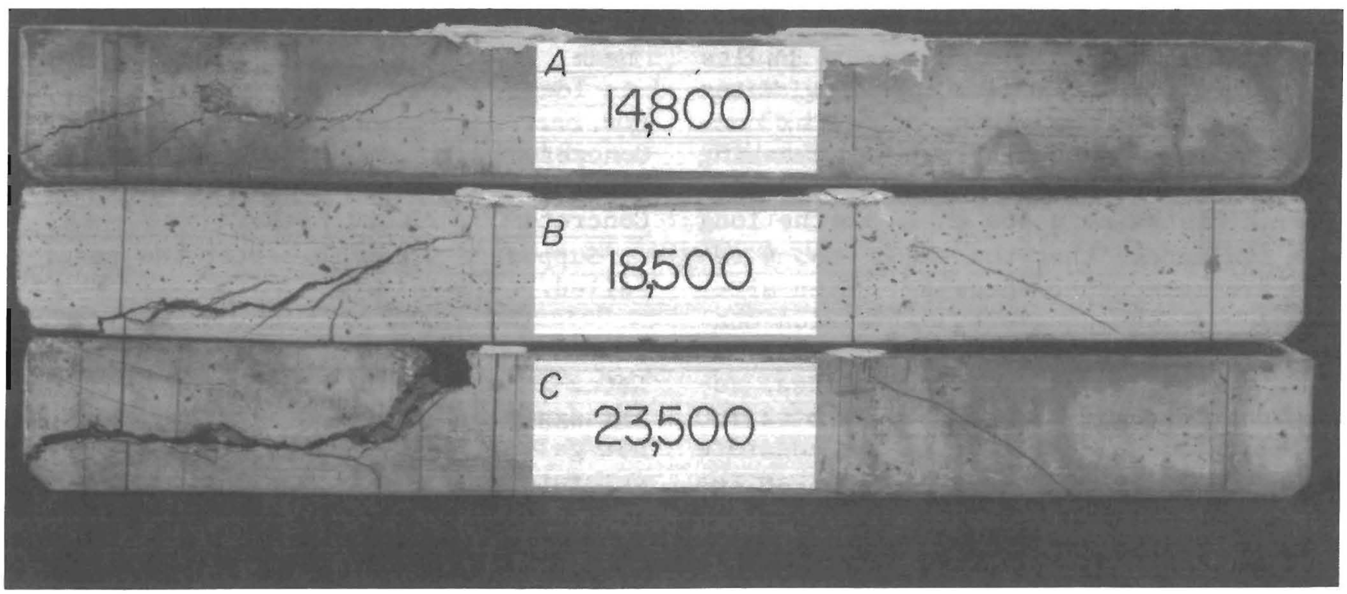

FIGURE 4. - Concrete lagging flexure test showing failure weight, in pounds. *A*, Concrete 1; *B*, concrete 2; *C*, concrete 3.

Various types of lagging were used because the loads to be supported were not known and a comparison of different cost and strength materials was important. Straight-grain fir pieces, 4 by 6 by 34 in (10.2 by 15.2 by 86.4 cm), latex-modified reinforced concrete (8) in pieces 4 by 6 by 34 in (10.2 by 15.2 by 86.4 cm), and steel channel, C6 by 1-7/8 by 34 in (15.2 by 4.8 by 86.4 cm) were selected for testing. The fir weighs about 7 lb (3,175 g) per foot, latex-modified concrete with three No. 6 rebars weighs about 20 lb (9,072 g) per ft, and the steel channel weighs 8.2 lb (3,720 g) per ft.

Concrete forming on the ends of the drift held the sets and backfill material and reinforced the ground at the four drawpoints. Seven steel sets were placed on 3-ft (0.91-m) centers, and the eighth set (on the north end) was on a 2-ft (0.61-m) center to match up with the formed wall. Sections of fir, latex concrete, and steel channel were placed between the sets.

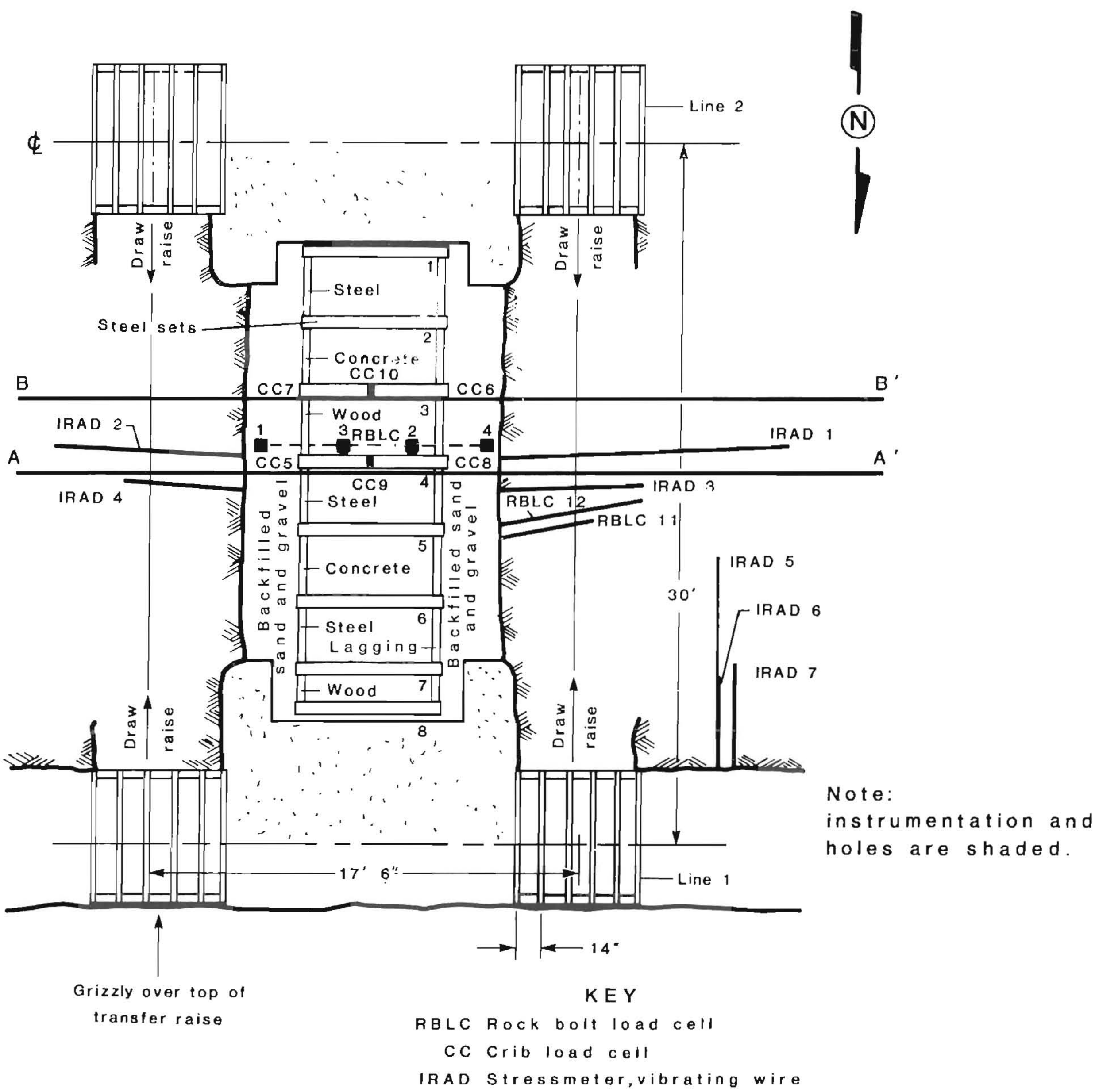

FIGURE 5. - Instrumentation plan for test drift, 2315 grizzly level.

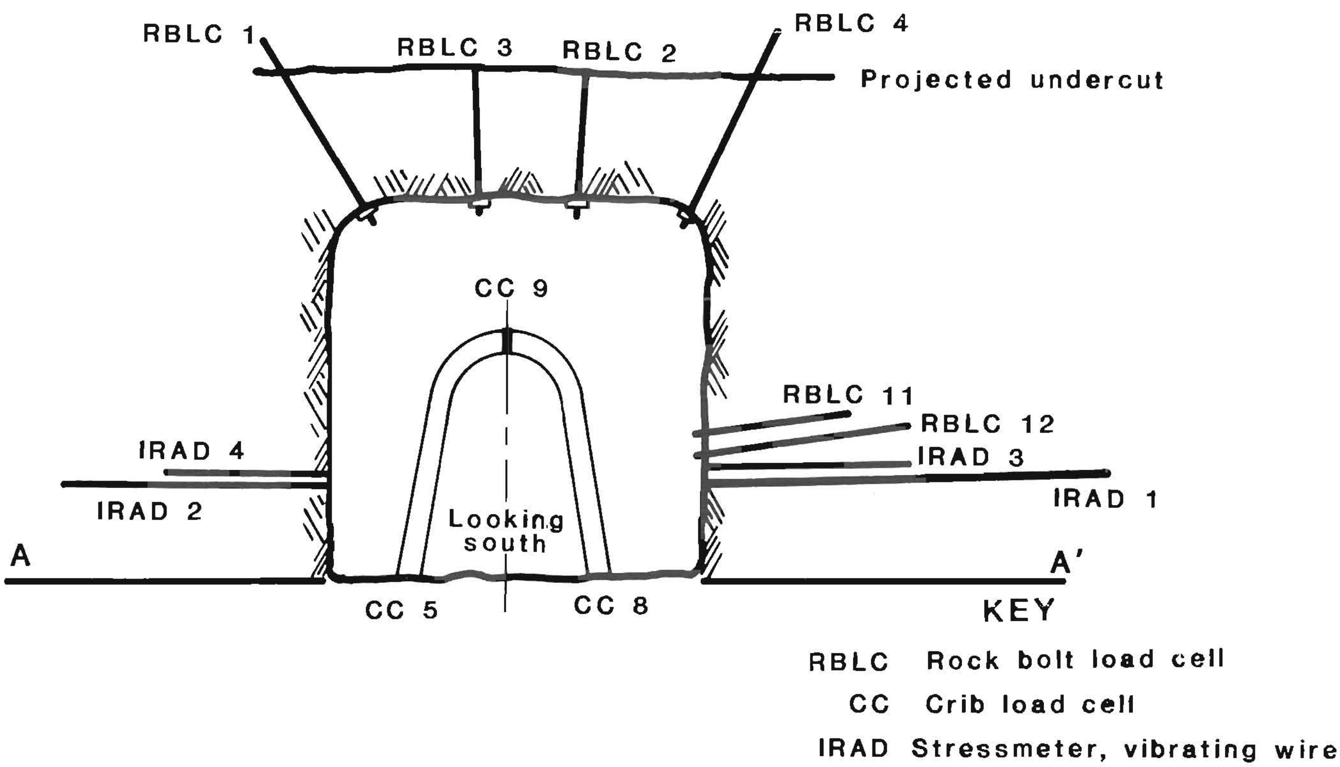

FIGURE 6. - Vertical section A-A' of instrumentation plan, 2315 grizzly level.

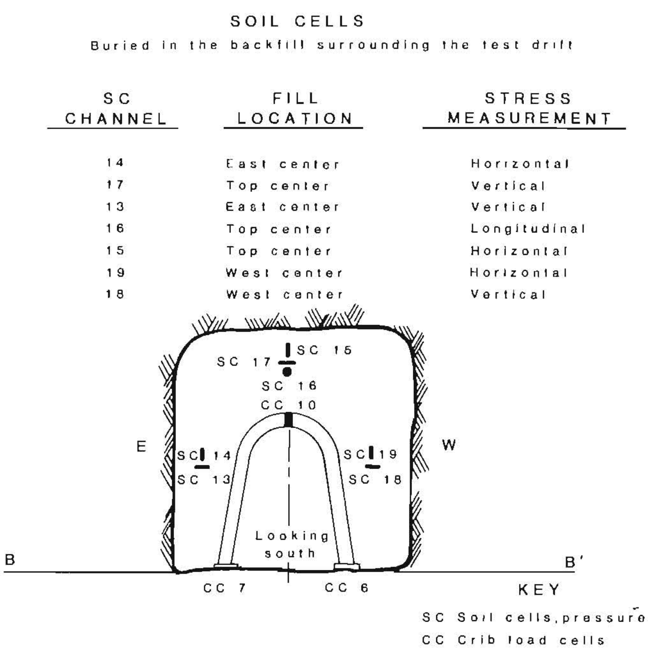

FIGURE 7. - Vertical section B-B' of instrumentation plan, 2315 grizzly level.

During the installation, load cells (3) were placed between set segments and beneath the legs to measure load changes as the panel was mined (fig. 5). Also, soil pressure cells (2) wired to fencing were buried in the backfill to measure load changes in it. The instrumentation layout is shown in figures 5, 6, and 7.

Fill pressure (loading) was measured with the Bureau-developed soil cell. The unit is 1.812-in (4.60-cm) OD and 0.340-in (0.86-cm) thick with a 0.100- (0.25-cm) by 1-in (2.54-cm) diam strain-gauged diaphragm. The unit is customarily built with either a 100-psi (689 kPa) or 1,000-psi (6.9 mPa) range and an accuracy of ±0.25 pct. Sensitivity at 5-V excitation is approximately 1.5 mV/V or about 8 mV for a full-bridge, full-scale signal. The water-blocked polyethylene electrical cable is brought into the unit through a 3.75-in (9.50-cm) stainless steel tube to reduce the inclusion effects.

The steel set loads were measured with 12-in (30.48-cm) titanium load cells having a 9-in (22.90-cm) diam, 0.080-in (0.20-cm) thick strain-gauged titanium ring diaphragm placed between two steel plates. The load cell had a dynamic range of 0 to 100,000 lb (0-45.360 kg) with 50 pct overrange. Five-volt excitation was usually used, giving an approximate 1.5 mV/V sensitivity and 8-mV full-scale output.

Figure 8 shows placing of the sets and lagging. Figure 9 shows the temporary support of rockbolts and wire mesh. Figure 10 indicates dimensions of the steel sets in the test drift.

BACKFILLING

On completion of the drift lining and instrumentation, the entire structure was backfilled with a mixture of sand and pea gravel.

Initially, an Aliva[5] dry-type shotcrete placer was tried for placing the filling; however, because of materials-handling problems and lack of operating experience with the Aliva, the operators decided to use the Flocrete placer pots of about 1-cu yd (0.765-cu m) capacity each. The latter are standard transporting and placing units used for concreting the blocks. Though designed for concrete placing (with about 16 wt pct cement), the pots worked reasonably well by using sand in the pea gravel and by adding larger amounts of water. Some cement was added to improve the flow characteristic. Cement has an adverse effect on uniform stress distribution. In filling, 72.7 cu yd (55.6 cu m) of gravel and sand was used.

INSTRUMENTATION

The IRAD vibrating wire stress meters, RB load cells, and crib load cells (CC 9 and 10) were of little value; the IRAD (9) meters and RB load cells lost their anchorage soon after blasting started and the CC 9 and 10 cells were destroyed by movement of the two segments of the steel set before meaningful readings could be taken. However, readings from the soil pressure cells oriented at different directions in the backfill, and the crib load cells beneath the steel sets could be correlated and appeared to be valid.

DISCUSSION OF DATA RECORDED

Data are plotted versus time, in days, beginning with the installation day and ending on day 340. Various mining events are then correlated with the data by noting that (1) undercutting of the panel began on day 253, (2) the pillar over the test drift was shot on day 279, and (3) undercutting of the panel was completed by day 291.

Soil Pressure Cells

Soil pressure cells SC 13, 17, and 18 measured vertical stress change in the backfill. Readings are plotted in figure 11. Soil pressure cells SC 14, 15, and 19 measured horizontal stress change in the backfill. Readings are plotted in figure 12. SC 16 measured longitudinal stress change; readings were not plotted because of erroneous data. In general, stress changes in the horizontal direction were greater than those in the vertical. This kind of behavior could be caused by the rib pillar yielding and losing shear rigidity with increasing lateral displacement. It indicates the pillar acts plastically or has failed. Also the vertical stress increases in the backfill after undercutting is complete. The backfill stiffens as it reacts to increasing confining pressure from the surrounding rock.

Crib Load Cells

Data from crib load cells CC 5, 7, and 8 are shown in figure 13. CC 6 was erratic and its data are not shown. These curves show a significant increase in load beginning with the undercutting and a leveling off shortly after undercutting is complete.

The total vertical pressure area supported by instrumented sets 3 and 4 is 60 by 72 in (1.52 by 1.82 m), or 4,320 sq in

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[5]Reference to specific trade names or manufacturers is made for identification purposes only and does not imply endorsement by the Bureau of Mines.

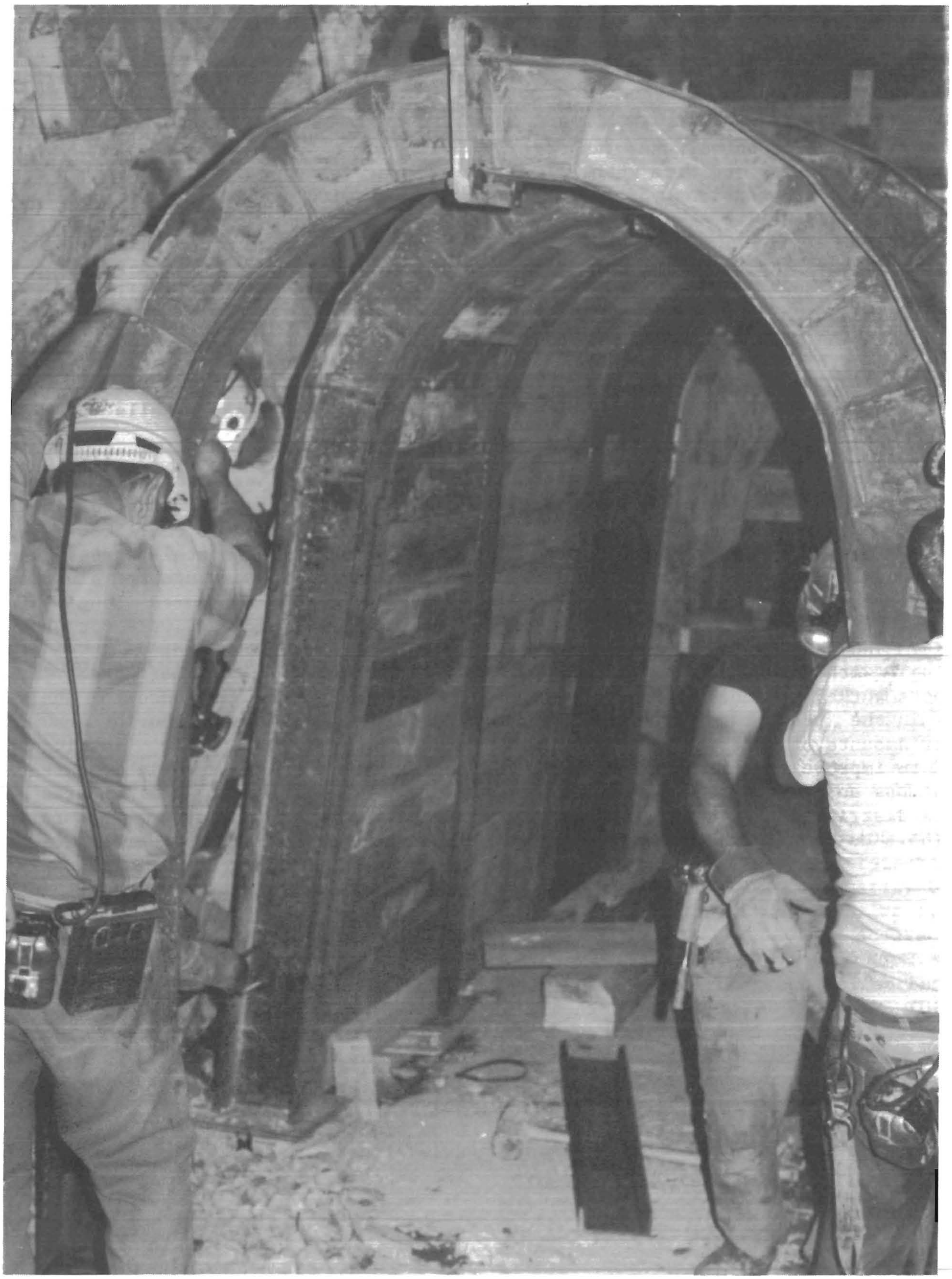

FIGURE 8. - Steel set and lagging installation, 2315 grizzly level.

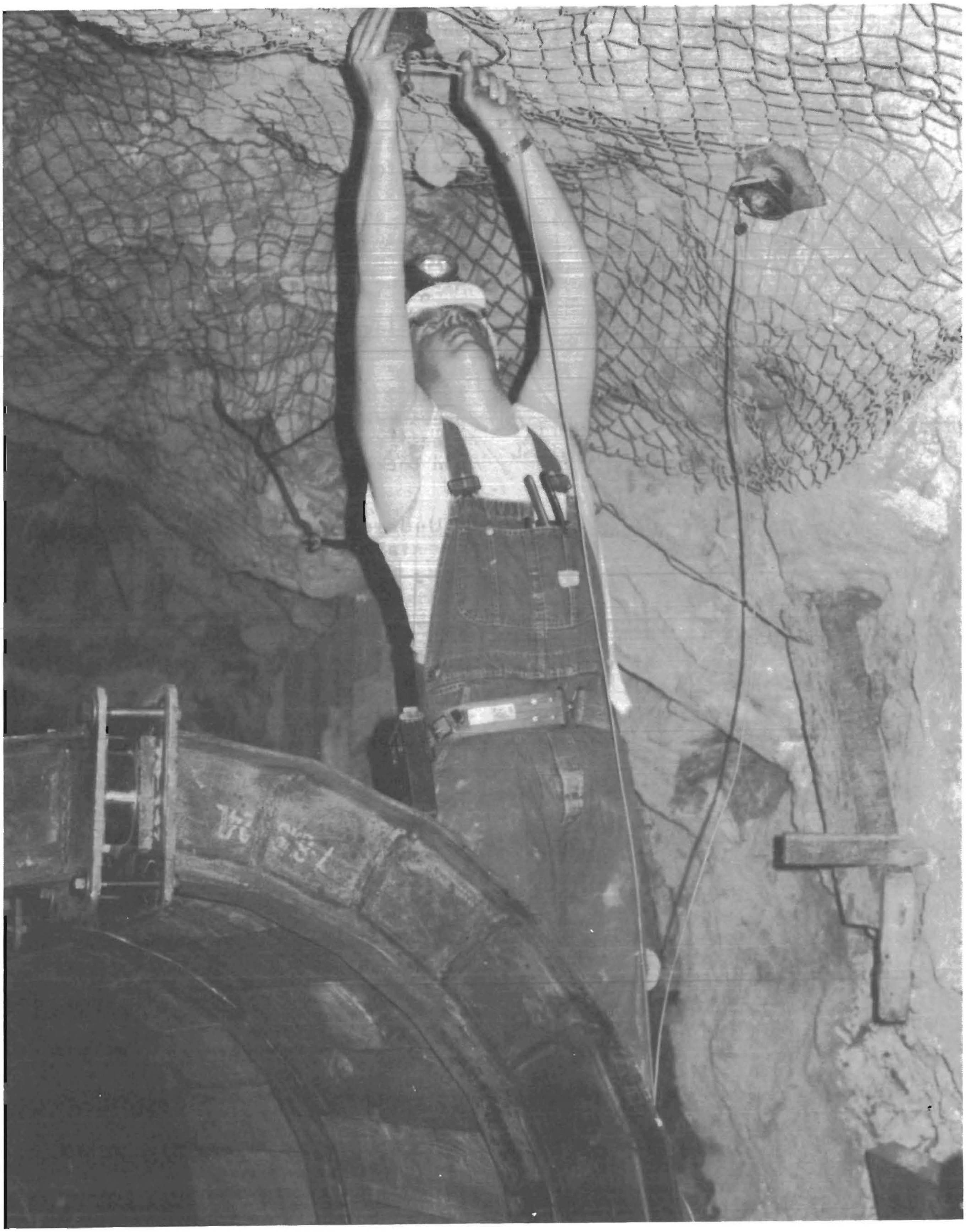

FIGURE 9. - Temporary support, rockbolts and wire mesh, 2315 grizzly level.

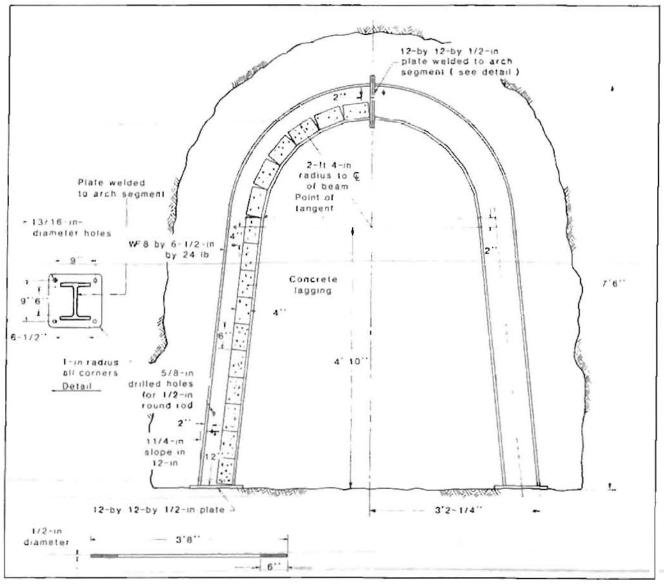

FIGURE 10. - Steel set dimensions, 2315 grizzly level.

(2.77 sq m). The average vertical pressure in the backfilled material between gauges SC 13 and 18 on day 315 is 32.9 psi (230.3 kPa); between gauges SC 18 and 17 it is 51.2 psi (358.4 kPa). This calculates to a total load on the sets of 181,656 lb (82,398 kg). The measured load for that same day is 197,854 lb (89,745 kg) (assuming the value of CC 6 to be equal to CC 8). Thus, the steel set loads calculated from the backfill pressure cells compare reasonably well with the load measured on the sets.

Similar calculations in horizontal directions are less certain because the legs of the steel sets displaced inward about 2 in (5.08 cm), owing to lateral pressure. This lateral movement of the steel set legs caused eccentric loading and buckling of load cells CC 9 and 10.

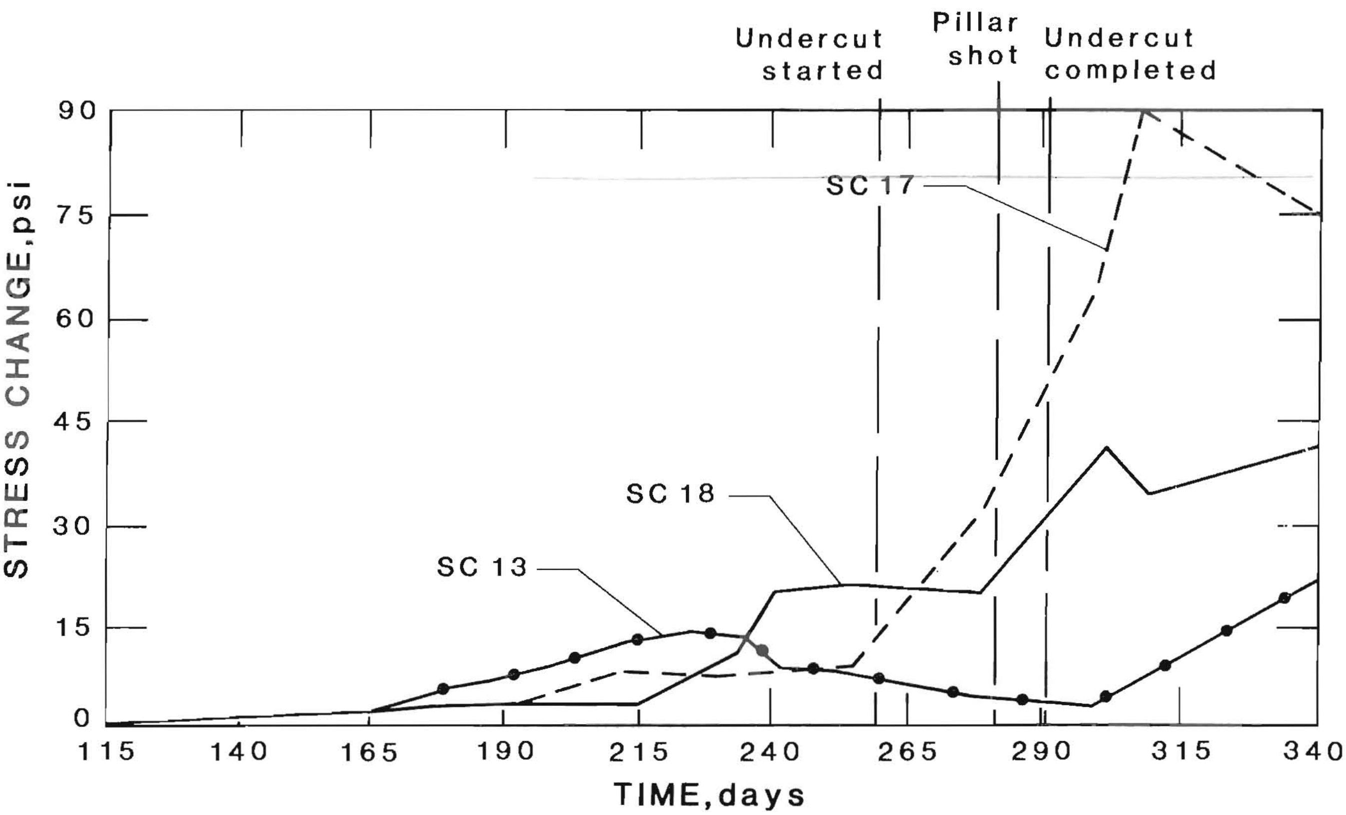

FIGURE 11. - Vertical stress changes in backfill, measured by soil pressure cells (SC), 2315 grizzly level.

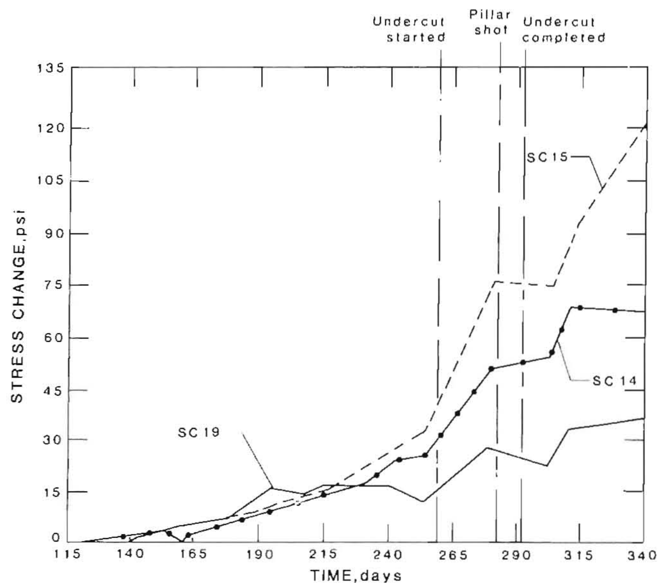

FIGURE 12. - Horizontal stress changes in backfill, measured by soil pressure cells (SC), 2315 grizzly level.

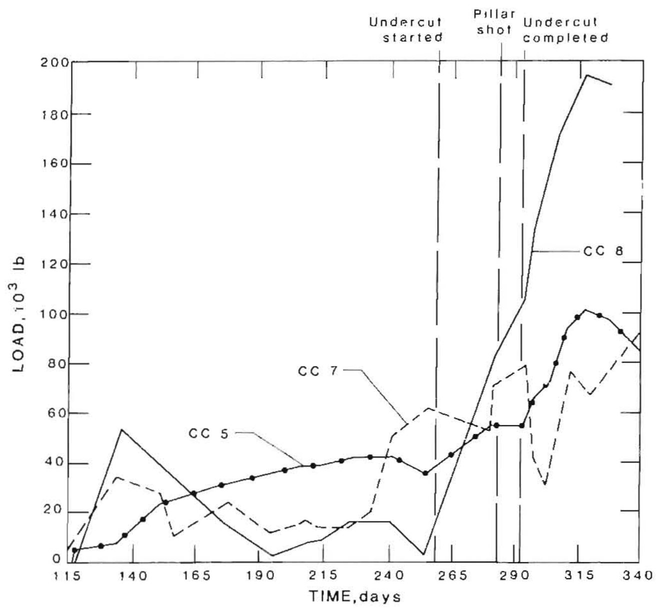

FIGURE 13. - Load in steel sets, measured by crib load cells (CC), 2315 grizzly level.

RESULTS

The initial installation of WF steel sets, various lagging, and pea gravel backfill was made in 2315 GL test drift in May 1978. This block was completely undercut in October, and caving progressed through the balance of 1978 and most of 1979 until drawing was completed. Based on stress measurements in and adjacent to the test drift (2315 GL) and on field observations, it was concluded that the initial support installation was correctly sized for the stresses encountered. The taper of the steel-set legs contributed to the stability of the test section.

After measurement of the stress in the backfill, about 40 psi average (277 kPa), it is possible to calculate the theoretical maximum horizontal deflection of the steel sets using the following formula (16) for a simple beam:

$$\text{Max } y = \frac{5 \ w \ l^4}{384 \ E \ I}, \tag{1}$$

where Max y = horizontal deflection at the middle, in inches,

w = uniformly distributed load per unit length, in pounds per square inch,

l = the span of the vertical segment, in inches,

E = Young's modulus for steel beams,

and I = moment of inertia of the section at the center.

For comparison, l is the vertical height and curvature is not considered in the calculation, as stress is assumed to be normal to the beam at all points; l is taken to the nearest foot.

For the test conditions, WF 8 by 24-lb (10.3-kg) sets, 7 ft (2.14 m) long on 3-ft (0.9-m) centers with 34 in (0.86 m) of lagging bearing on each set, and assuming an average stress of 40 psi (277 kPa), the calculation shows

$$\text{Max } y = \frac{5 \times 40 \times 34 \times (84)^4}{384 \times (29 \times 10^6) \times 21}$$

$$= \frac{6{,}800 \times 50 \times 10^6}{8{,}100 \times 29 \times 10^6}, \quad (2)$$

$$\text{Max } y = \frac{34 \times 10^{10}}{23.5 \times 10^{10}}, = 1.45 \text{ in},$$

and 2 Max y = 2.90 in--this is the total horizontal closure.

Actual closure was measured at just under 3 in (7.62 cm). No failure of the lining occurred during undercutting nor subsequent drawing of the block. Figure 14 shows the lining in good condition after the block was mined; figure 15 shows adjacent concrete damage.

CONSTRUCTION IN 2615 GRIZZLY LEVEL, PANELS 5 AND 6 PANEL DRIFT

DRIFT SUPPORT AND INSTRUMENTATION

For the second phase of the experiment, a panel haulage drift of larger cross section was selected (fig. 3). The cooperators selected a site and used WF 6 by 20-lb (9.1-kg) steel sets fabricated specifically for the drift support and charged to ASARCO costs for the project. Also, to conform to the mine standard, the sets were spaced on 5-ft (1.52-m) centers. Dow Chemical Co. furnished experimental gob lagging of latex-modified concrete (reinforced). Construction of the lagging of a T-design was adopted to reduce the weight, and details are shown in figure 16. These were tested to 11,000 psi (76 MPa) compressive strength. This strength is about that of the fir lagging.

One set of corrugated aluminum was ordered from Kaiser. This consisted of two 58-in (1.48-m) wide plates of 9- by 2-1/2-in (22.8- by 6.3-cm) aluminum-corrugated sheet 0.25 in (0.63 cm) thick. Each plate was 146 in (3.70 m) long. These were designed for 40-psi (276-kPa) stress in the backfill, and curved to the 57-in (1.42-m) crown radius. One edge of the horizontally lapped seam was of standard round and the other edge was notched to facilitate alignment and bolting. The assemblage could free stand between the ribs, but was in this case bolted to the web of the WF steel sets with clips. Reinforcing plates were bolted on the back of the corrugated sheets.

Stress meters (IRAD) and RB load cells were not installed in 2615 GL fringe drift, as previous data obtained in 2315 GL were not usable because of slippage in the soft rock. However, the soil pressure cells (SC) and crib load cells (CC) were again installed in 2615 GL, as the prior test indicated valid readings from these instruments. See figures 17 and 18 for instrumentation plan and section. Insufficient clearance between the temporary support and the WF steel sets precluded soil cell installation on the east side. Strain gauges were welded to the inside of the WF 6 by 20-lb (9.1-kg) steel sets (as a check against readings in the crib load cells). Early distortion of the steel sets affected these readings and they were of no value.

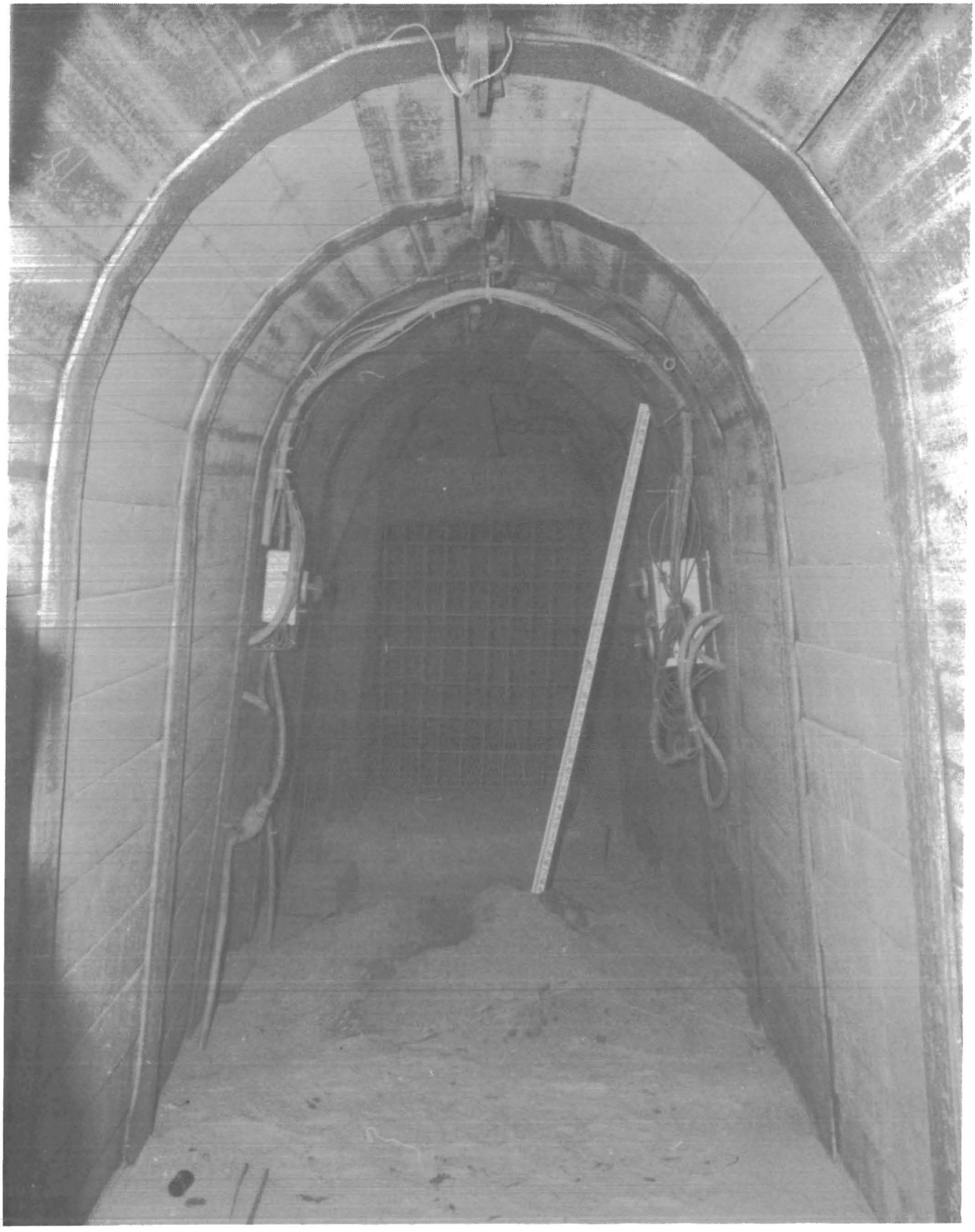

FIGURE 14. - 2315 grizzly level test drift after block was mined.

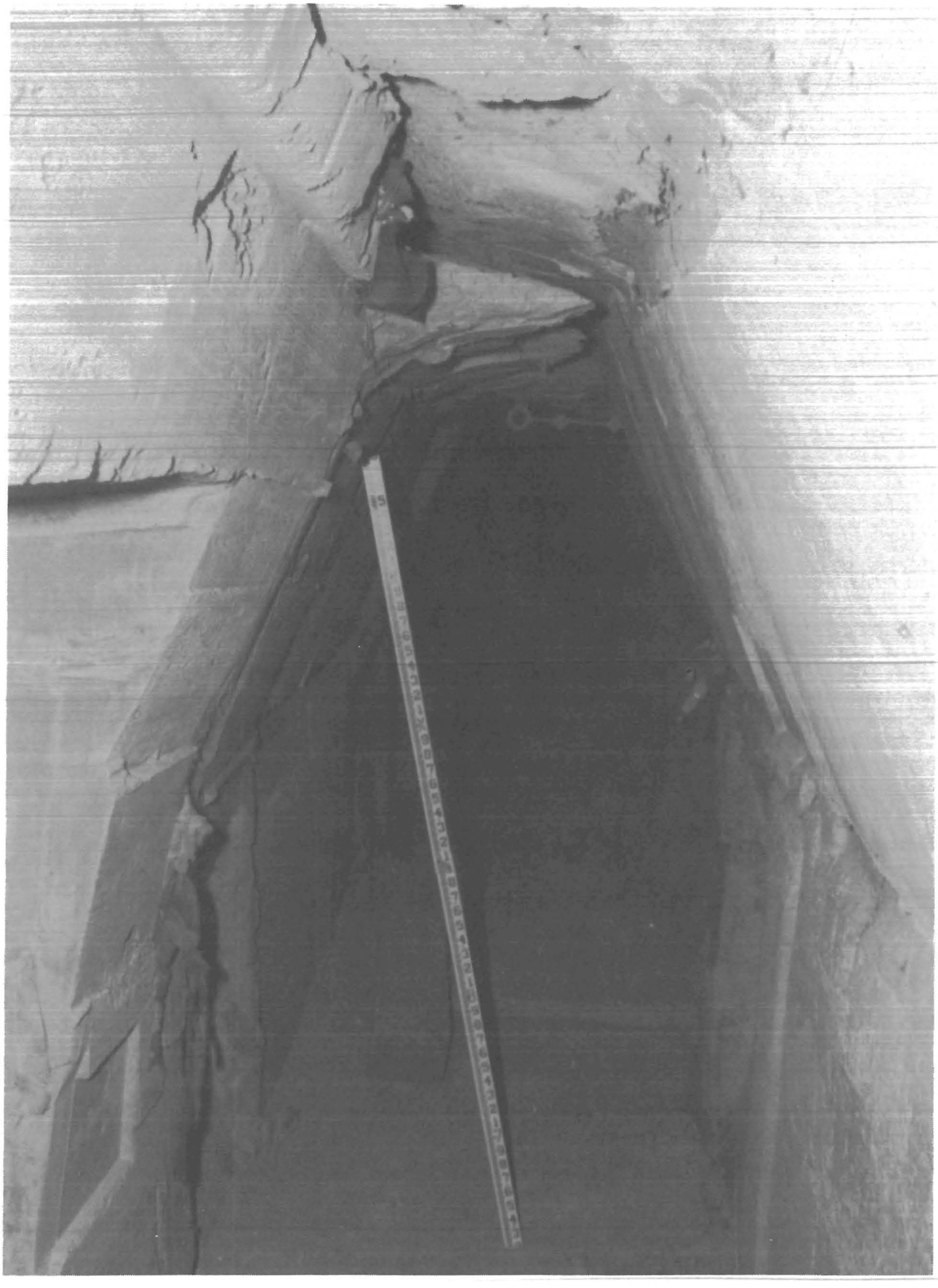

FIGURE 15. - Monolithic concrete failure adjacent to 2315 grizzly level test drift.

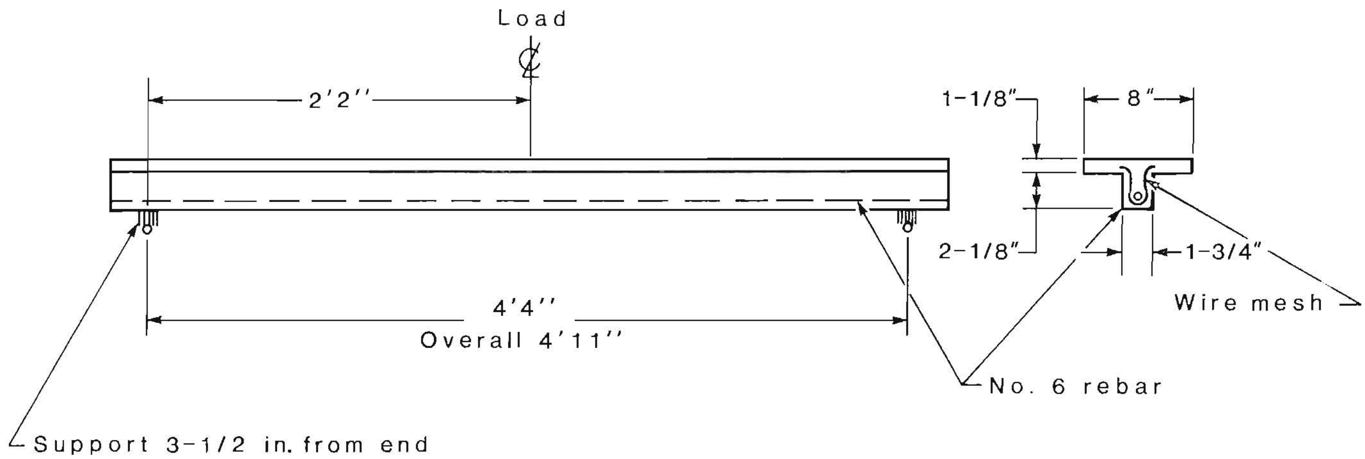

FIGURE 16. - Gob lagging construction and testing, 2615 grizzly level.

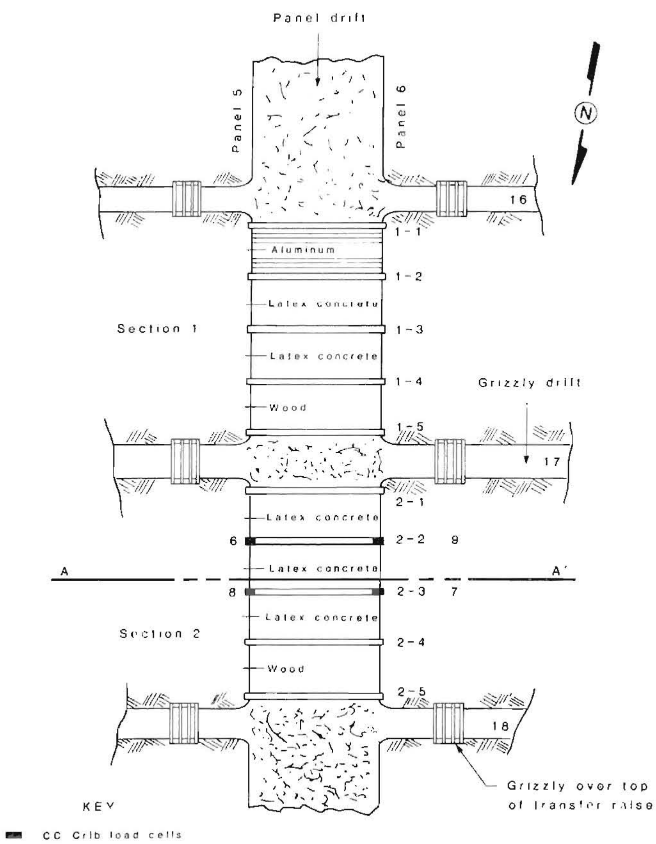

FIGURE 17. - Instrumentation plan for test drift, 2615 grizzly level.

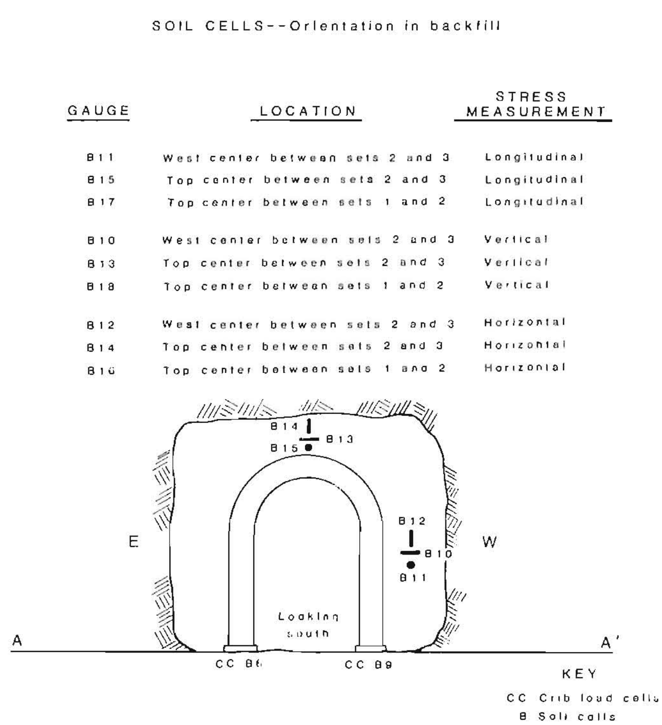

FIGURE 18. - Vertical section A-A' of instrumentation, 2615 grizzly level.

Dimensions of the WF steel sets are sketched in figure 19. An artist's conception of an isometric view of the installation with instruments is shown in figure 20.

BACKFILLING

A modified Reed shotcrete machine was leased for stowing the sand and pea gravel behind the permanent support and was

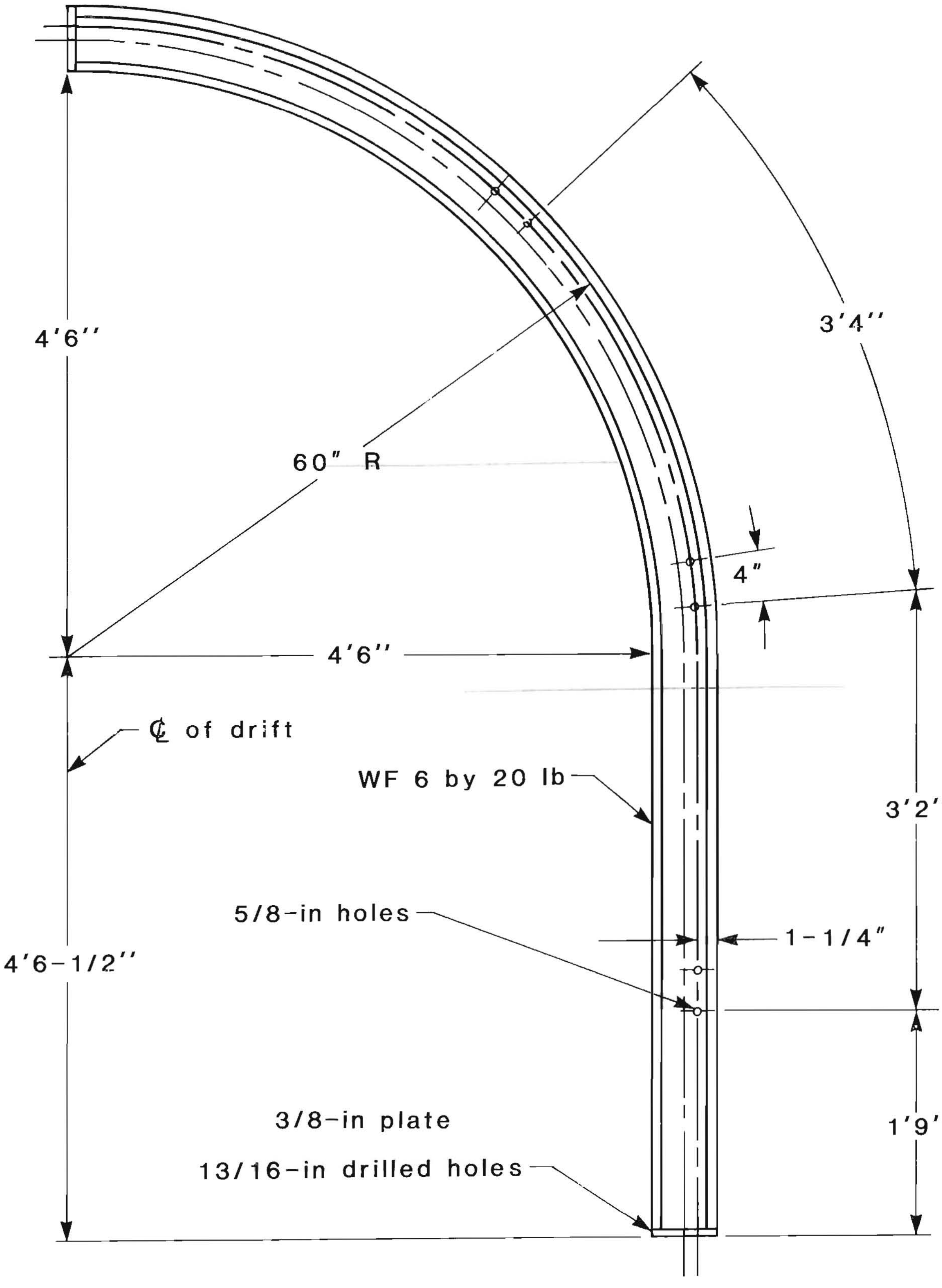

FIGURE 19. - Steel set dimensions, 2615 grizzly level.

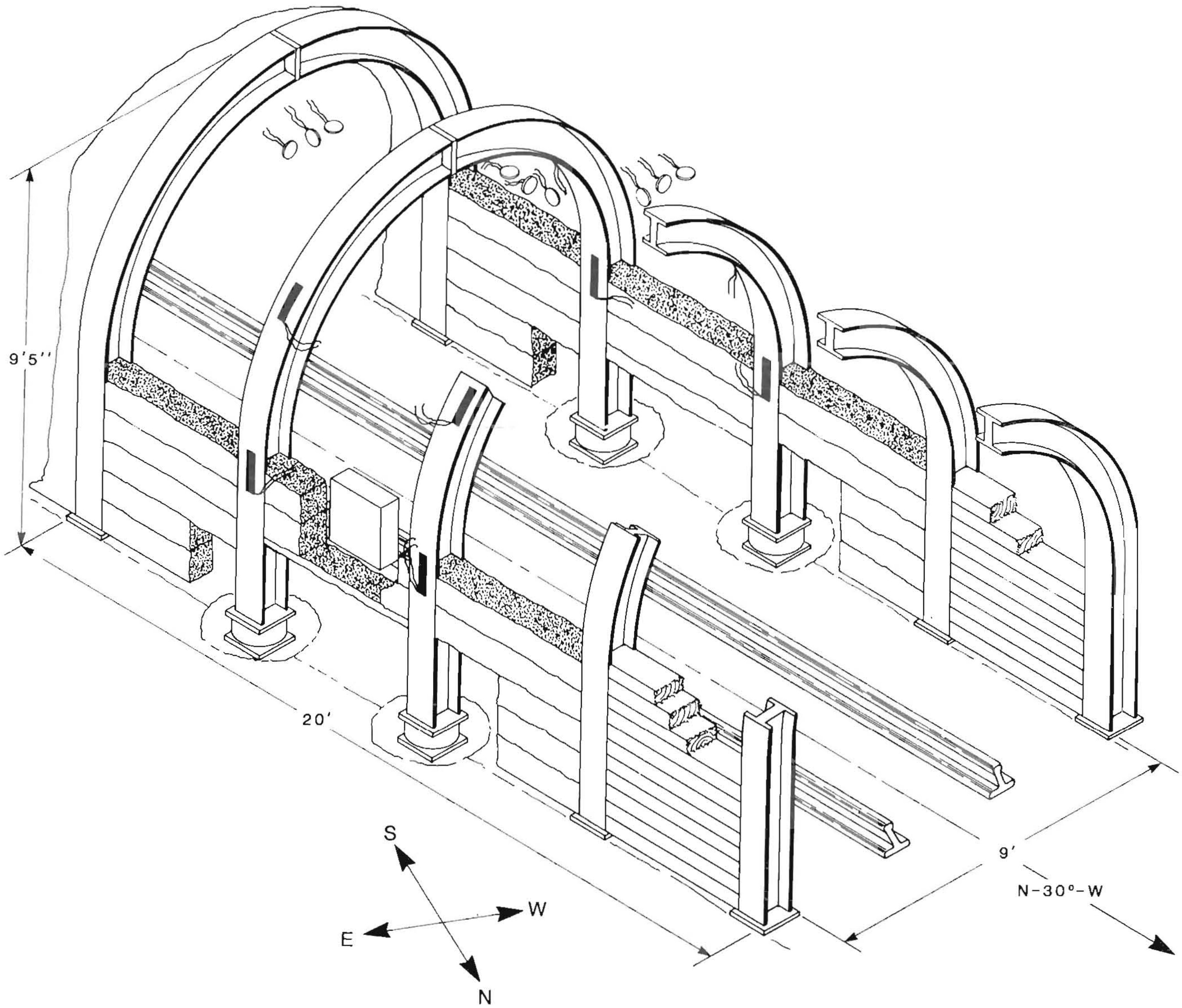

FIGURE 20. - Isometric view of test installation, 2615 grizzly level.

tested on surface before being sent underground. However, a mine fire delayed stowing for a month and this was followed by a 4-month strike. The idle shotcrete machine was returned to the factory in the meantime.

On resumption of mining, the Flocrete placer pots (as in the prior test) were used to complete placing of the backfill. To increase the fluidity of the sand and gravel, 6.5 wt pct cement was added.

However, because cement increases the modulus of the backfill, it has an adverse effect on stress transmission from the rock.

DISCUSSION OF RECORDED DATA

The time lapse between instrument installation and the start of mining in the block was 5 months (the delay noted previously). Initial readings were taken May 1, 1980, and this is the zero point on the time, days. During the idle time, two of the load cells beneath the sets (B6 and B7, fig. 21) became inoperative. However, the other two load cells (B8 and B9, fig. 21) appear to give valid readings. At 400 days, B8 read 236,000 lb (107,050 kg) and B9 read 136,000 lb (61,690 kg). The calculated vertical load on the set was

$$\text{Weight} = \frac{236{,}000 + 136{,}000}{2}$$

$$= 186{,}000 \text{ lb},$$

Area = 5 by 9 ft (45 sq ft), or 45 by 144 sq in (5,480 sq in),

$$\text{Average stress} = \frac{186{,}000}{5{,}480}$$

$$= 34 \text{ psi (234 kPa)}.$$

Figure 22 (vertical stress changes in backfill) at 400 days shows a B10 to B18 range of 45 psi (310 kPa) and B13 to B18 of 30 psi (207 kPa) or an average of 37 psi (255 kPa). Note that B10 and B13 are between sets 2 and 3, and B18 is between sets 1 and 2. Figure 23 (horizontal changes) approximates the load on the steel sets as measured by the crib load cells (fig. 21). Figure 24 (longitudinal stress changes in backfill) shows values that are lower. The vertical stress is that shown by the stress in the steel sets and that in the backfill--or about 35 psi (241 kPa).

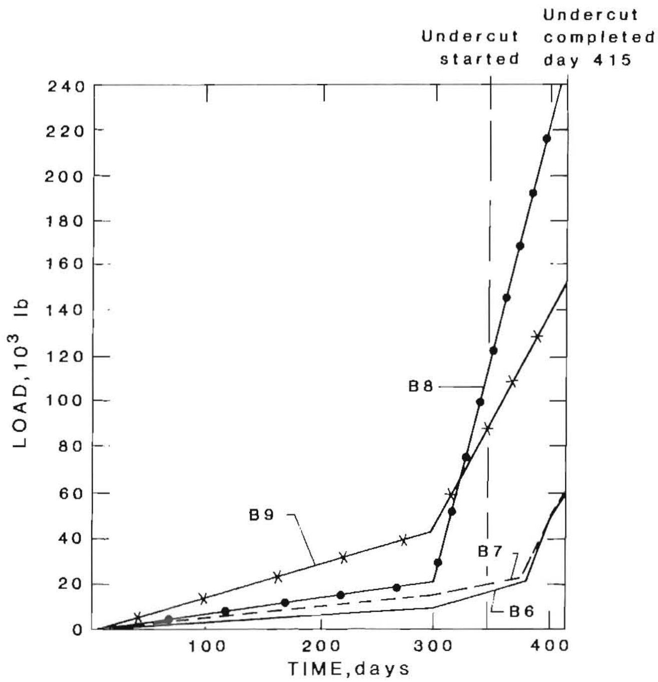

FIGURE 21. - Load in steel sets, measured by load cells (B), 2615 grizzly level.

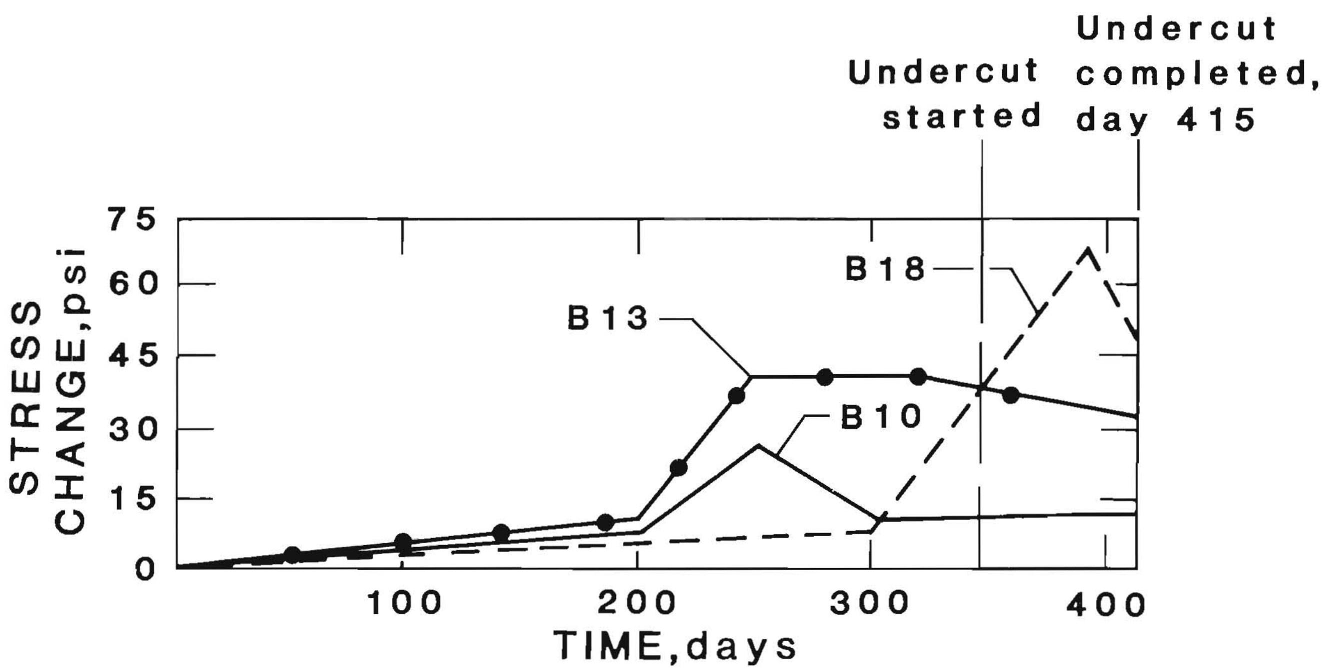

FIGURE 22. - Vertical stress changes in backfill, measured by soil cells (B), 2615 grizzly level.

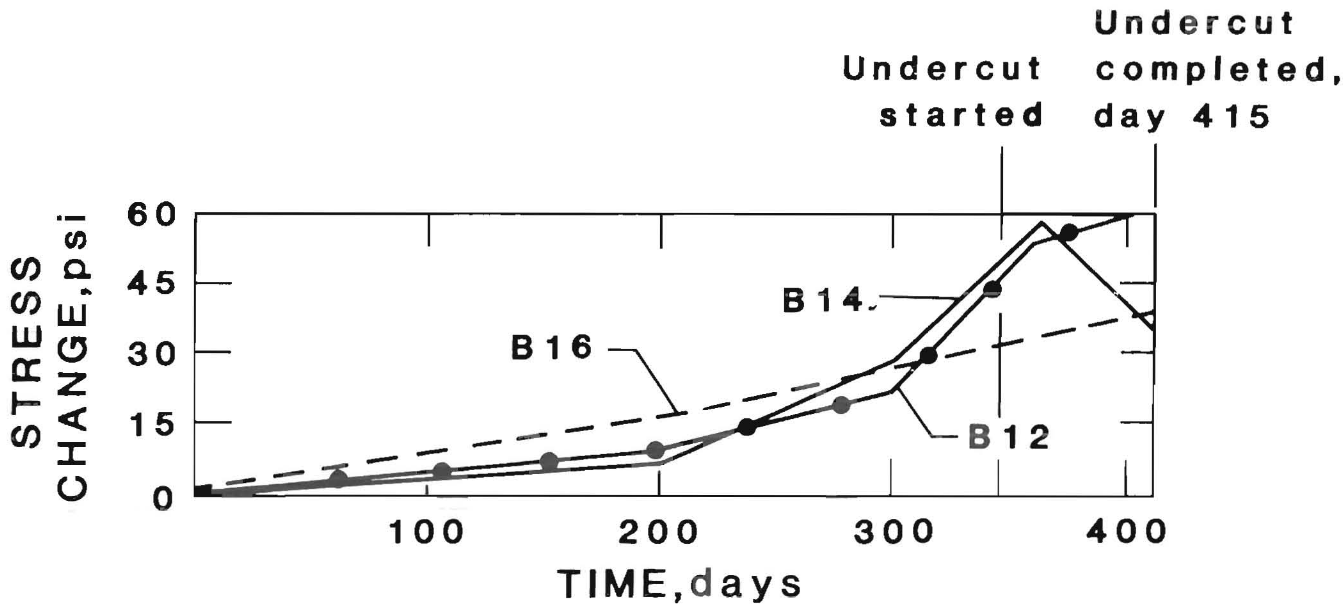

FIGURE 23. - Horizontal stress changes in backfill, measured by soil cells (B), 2615 grizzly level.

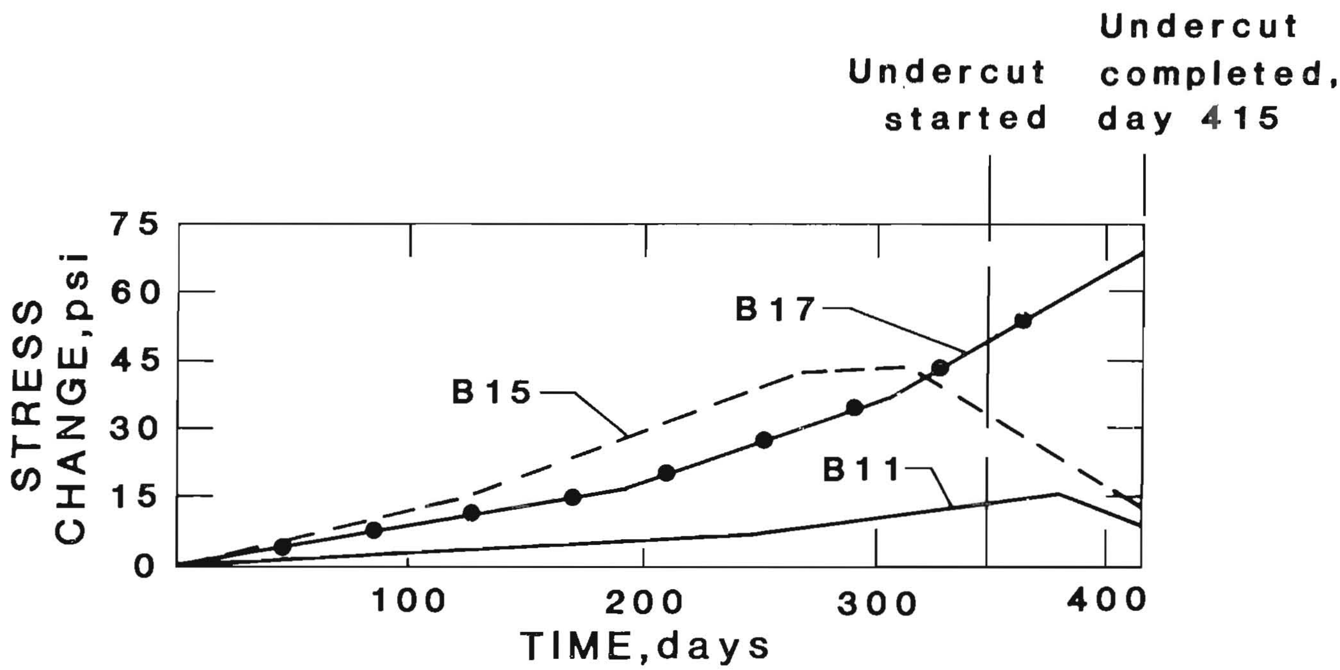

FIGURE 24. - Longitudinal stress changes in backfill, measured by soil cells (B), 2615 grizzly level.

Figure 25 shows progress of undercutting 2615 GL, panel 6, lines 10 through 19. Note the location of the test site termed "ASARCO drift" on the map, which is the boundary between solid rock to the east and the block that is undercut to the west. Undercutting started April 11, 1981 (day 345) and was completed June 20, 1981 (day 415). Readings beyond day 415 were not taken because of failure of the drift lining and instrumentation.

RESULTS

For the severe conditions encountered in 2615 GL panel drift, the corrugated aluminum gave the best results. This support was designed for 40 psi (276 kPa) in the backfill. No failure had occurred as of January 1982.

Closure of the steel sets was determined by a modified triangular configuration method of cross-tunnel measurements developed by Panek (13). Measurements were made with an extensometer horizontally across the top of the vertical legs, and at about 30° from the top of each leg to the arch. This gave the generalized deformation of the drift, which was adequate for the study. All measurements were on the inside of the set. Figure 26 shows a typical deformation at day 400 in section 2 with almost 5-in (12.7-cm) closure. Deformation in test section 1 (fig. 17) was less than the deformation in section 2, approximately a ratio of 3:5, indicating greater weight on section 2, which contained the stress-measuring instruments.

Assuming 35-psi (241 kPa) average stress in the backfilled material, horizontal deflection calculates (WF 6 by 20-lb (9.1-kg) beam, 9 ft (2.75 m) long, on 5-ft (1.52-m) centers, 59 in (1.50 m) of lagging bears on the steel set) as

$$\text{Max } y = \frac{5 \times 35 \times 59 \times (108)^4}{384 \times (29 \times 10^6) \times 13}$$

$$= \frac{10{,}325 \times 136 \times 10^6}{5{,}000 \times 29 \times 106}, \qquad (4)$$

$$\text{Max } y = \frac{1{,}400 \times 10^{10}}{14.5 \times 10^{10}} = 9.75 \text{ in},$$

Total horizontal closure (2 Max y)

= 19.5 in (49.30 cm).

Failure occurred during undercutting and continued during subsequent mining of the block. When closure approached 6 in (15.24 cm), failure of the steel sets and concrete lagging took place, and the calculated value of 2 Max y therefore was not reached.

In the formula, Max y varies as l^4. Steel set spacings over 3 ft (0.91 m) are not compatible with required strength of the lining.

A better design is WF 8 by 35-lb (15.9-kg) steel sets on 3-ft (0.91 m) centers

$$\text{Max } y = \frac{5 \times 35 \times 36 \times (136 \times 10^6)}{384 \times (29 \times 10^6) \times 31}$$

$$= \frac{6{,}300 \times 136 \times 10^6}{11{,}900 \times 29 \times 10^6} \qquad (5)$$

$$\text{Max } y = \frac{86 \times 10^{10}}{34.5 \times 10^{10}} = 2.5 \text{ in},$$

and $\quad 2 \text{ Max } y = 5.0$ in.

Wood lagging or steel channel would be suitable, and end failure probably would not result with either type. Concrete lagging is very questionable because of its brittleness.

The monolithic concrete in 2615 GL panel drift adjacent to the test site failed (fig. 27) and was reinforced with 90-lb (40.8-kg) steel rail sets on 5-ft (1.52-m) centers. Likewise, rail sets were placed in the test section, after lagging and set failure, to stop further drift closure.

Figure 28 is a surface mockup of the steel sets installed in 2615 GL with aluminum structural plate and latex concrete lagging. Figure 29 shows bolting of the

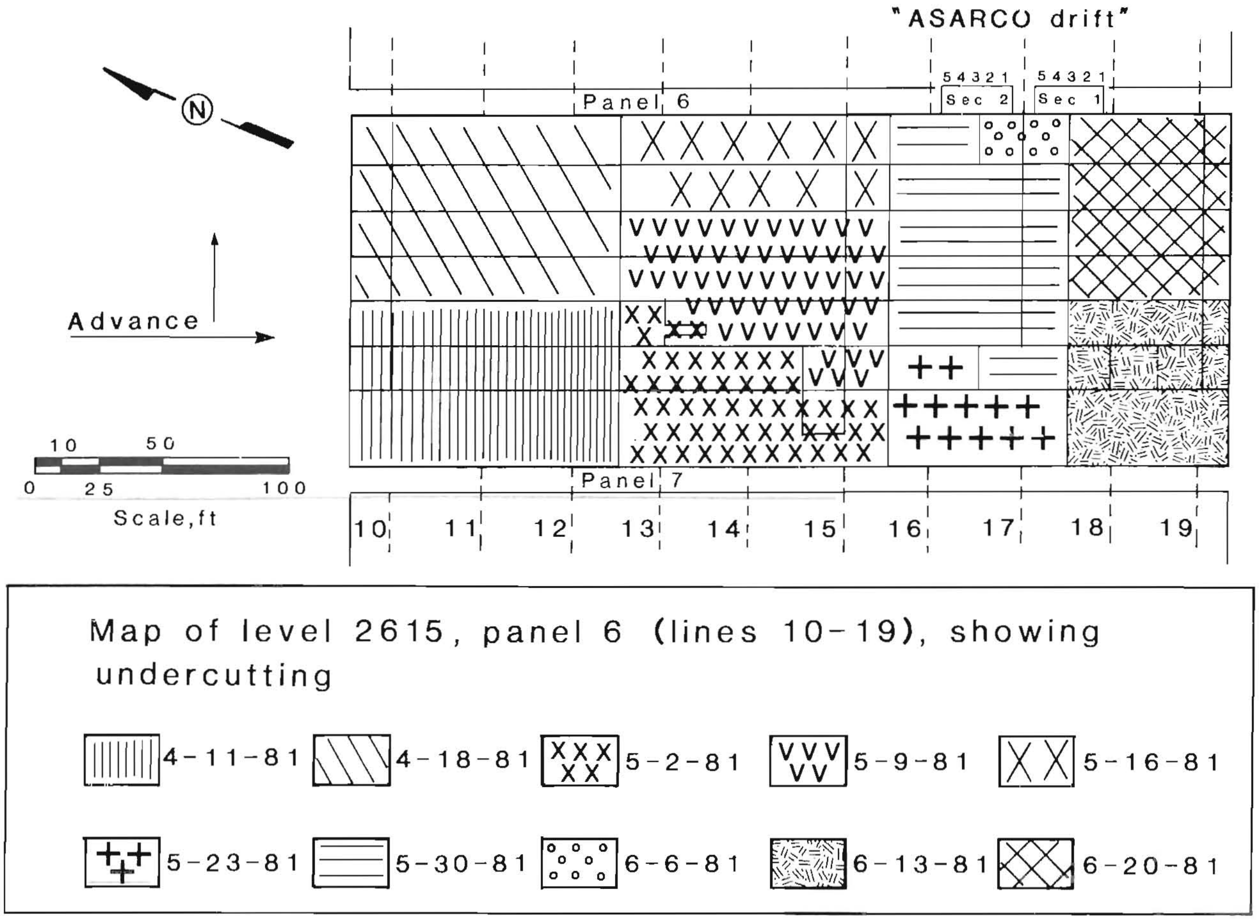

FIGURE 25. - Undercutting, 2615 grizzly level.

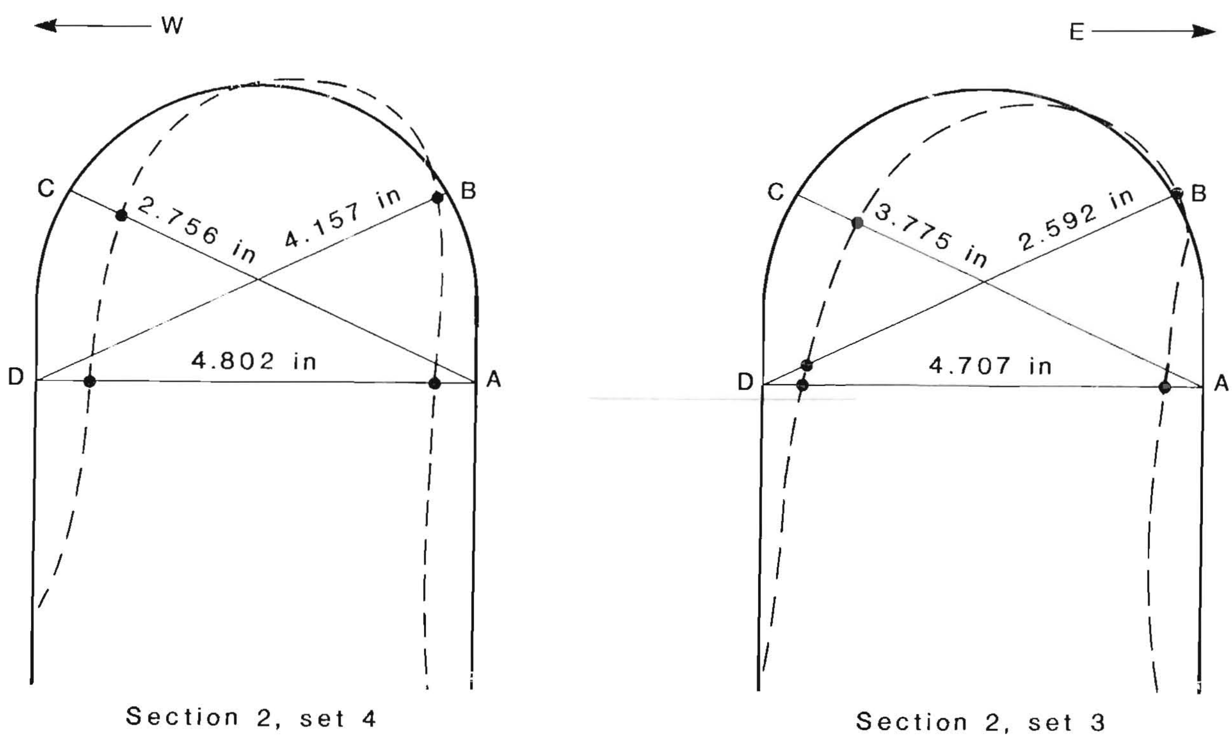

FIGURE 26. - Typical deformation in steel sets, 2615 grizzly level—example.

FIGURE 27. - Monolithic concrete failure in 2615 grizzly level.

two aluminum plates at the top in 2615 GL; note the temporary support of wood posts with steel cap and rail set with wood lagging.

ESTIMATED LINING COSTS

There is an apparent savings in lining an 8- by 8-ft (2.44- by 2.44-m) grizzly-connecting drift using WF 8 by 24-lb (10.8-kg) steel sets on 3-ft (0.91-m) centers with various laggings, and back-packing with pea gravel and sand; 50 pct overbreak is assumed. See table 2 for detailed costs.

TABLE 2. - Estimated lining costs, 8- by 8-ft drift

	Fir	Steel channel	Latex concrete
7.5- by 6.5-ft arched WF 8 by by 24-lb steel sets..........	$225	$225	$225
Lining (32 pieces)...........	[1]120	[2]400	[3]225
Installation labor...........	150	150	150
Backpack labor and material[4]..	150	150	150
Total per set............	645	925	750
Total per linear foot.....	215	308	250

[1]6 by 4 by 34 in; $3.75 per piece; 25 lb.
[2]6 by 1-7/8 by 34 in; $12.50 per piece; 40 lb.
[3]6 by 4 by 34 in; $7.00 per piece; 50 lb.
[4]Pea gravel; 7.5 cu yd per set; $20.00 per cubic yard in place.

NOTE.--Estimated cost of formed concrete is $300 per linear foot (comprised of concrete, rail sets, and lagging for temporary support).

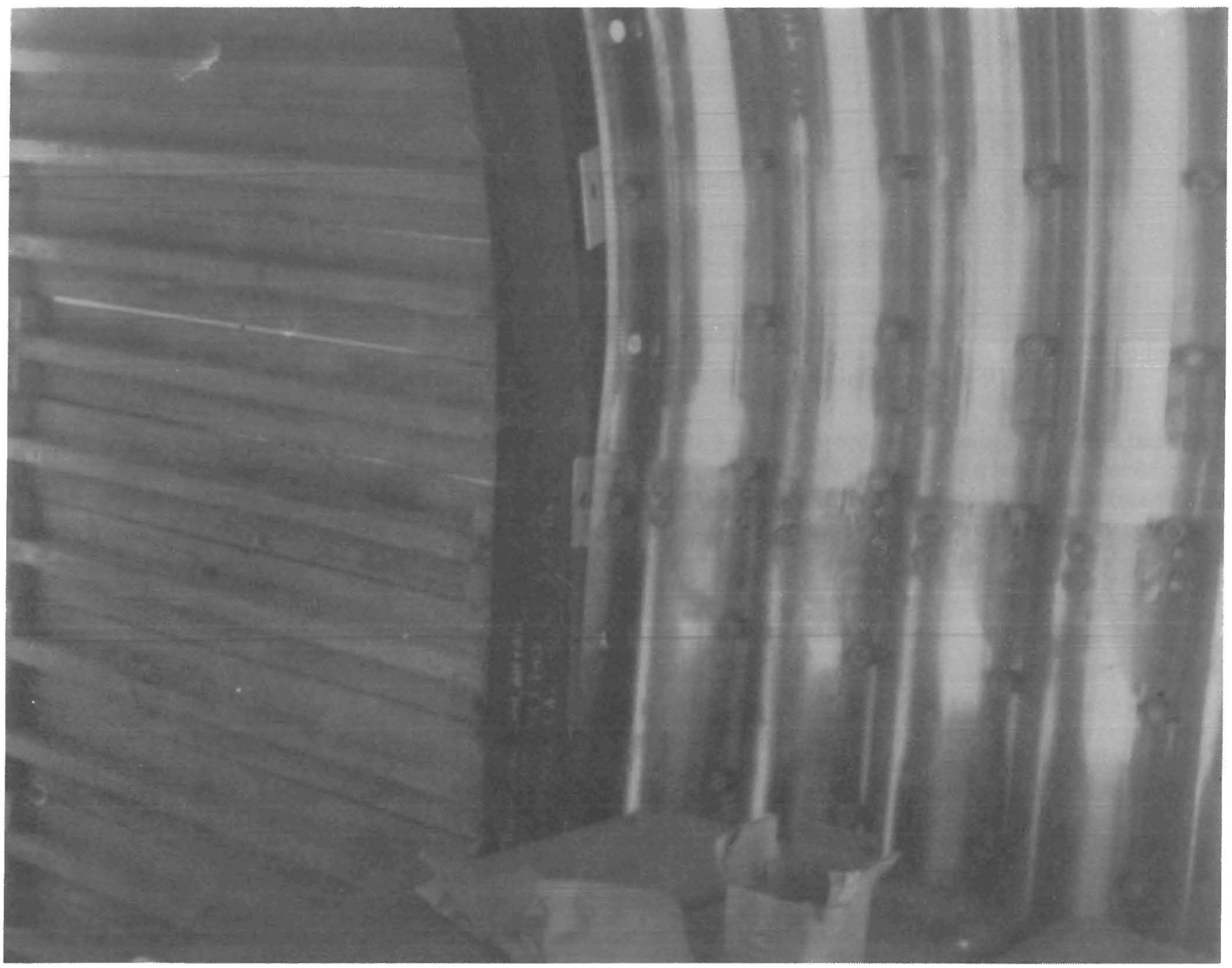

FIGURE 28. - Surface mockup of aluminum sheets and latex concrete lagging for 2615 grizzly level.

FIGURE 29. - Bolting two aluminum sheets at the top, 2615 grizzly level.

Costs of lining an 11- by 11-ft (3.36- by 3.36-m) opening with WF 8 by 35-lb (15.9-kg) steel sets on 3-ft (0.91-m) centers with fir or steel channel lagging or 5-ft (1.5-m) sheets of aluminum are given in table 3. A savings here is not established, and further testing could determine the service life and ultimate cost.

TABLE 3. - Estimated lining costs, 11- by 11-ft opening

	Fir	Steel channel	Aluminum[1]
9.5- by 10-ft WF 8 by 35-lb steel sets.	$400	$400	$400
Lining (45 pieces)....................	[2]170	[3]562	[4]2,000
Installation labor....................	200	200	200
Backpack labor and material[5]..........	200	200	200
Total per set......................	970	1,362	2,800
Total per linear foot.............	323	454	560

[1]Consists of two 58-in-wide, 146-in-long, 0.25-in-thick panels. Vertical corrugations are 9 by 2.5 in, formed to 57 in. in the crown radius. Reinforcing plates are bolted to the back.
[2]6 by 4 by 34 in; $3.75 per piece; 25 lb.
[3]6 by 1-7/8 by 34 in; $12.50 per piece; 40 lb.
[4]Would be reduced on a production basis.
[5]Pea gravel; 10 cu yd per set; $20.00 per cubic yard in place.

NOTE.--Estimated cost of formed concrete is $350 per linear foot.

FUTURE TESTING

Possibly the next step in testing wide-flange steel sets, lagging, and back-filled material in small drifts would be in the grizzly drifts, proper. One test arrangement is shown in figure 30.

The Kaiser aluminum corrugated sheets were experimental, and it is suggested that a test be made of aluminum structural plate with WF steel sets versus standard bolted aluminum structural plate (unsupported) to show which is the better design. Previously, in 1972, the Bureau installed an 8-ft (2.44-m) diam circular aluminum liner in the Burgin Mine at Eureka, UT. This was backfilled with sand; present day total cost would be about $225 per linear foot ($738 per linear meter) (1).

The Bureau also installed, in 1969, an Armco multiplate steel arch lining, 12-ft (3.66-m) span by 11-ft (3.36-m) rise in the tertiary gravels of Badger Hill, Nevada County, CA. This was placed near the portal of the tunnel and was back-filled with stream gravel, and had about 100 ft (30.5 m) of overburden. Present total cost is about $300 per linear foot ($984 per linear meter) (18). After more than 10 yr, these linings are still in fair condition although mine production has not been continuous.

It is suggested that if considerable quantities of backfill are to be placed, use of a pneumatic stower be considered (18).

CONCLUSIONS

In drifts 8 by 8 ft (2.44 by 2.44 m) in section, it was demonstrated that steel sets and lagging with backfill have the potential to reduce overall lining costs, as compared with formed concrete. However, in the larger panel drifts, 11 by 11 ft (3.36 by 3.36 m) in section, a savings potential was not apparent. For the larger openings, further testing should be done on backfilled multiplate steel and/or corrugated aluminum.

Temporary ground support of rockbolts and wire mesh is preferred wherever this can be safely used. Point loading on the permanent lining is practically prevented by this type of support.

Latex-modified, steel-reinforced concrete lagging, 4 by 6 by 34 in (15.24 by 10.16 by 86.4 cm), is suitable for the small drifts; however, the lagging of T-design developed for gob application

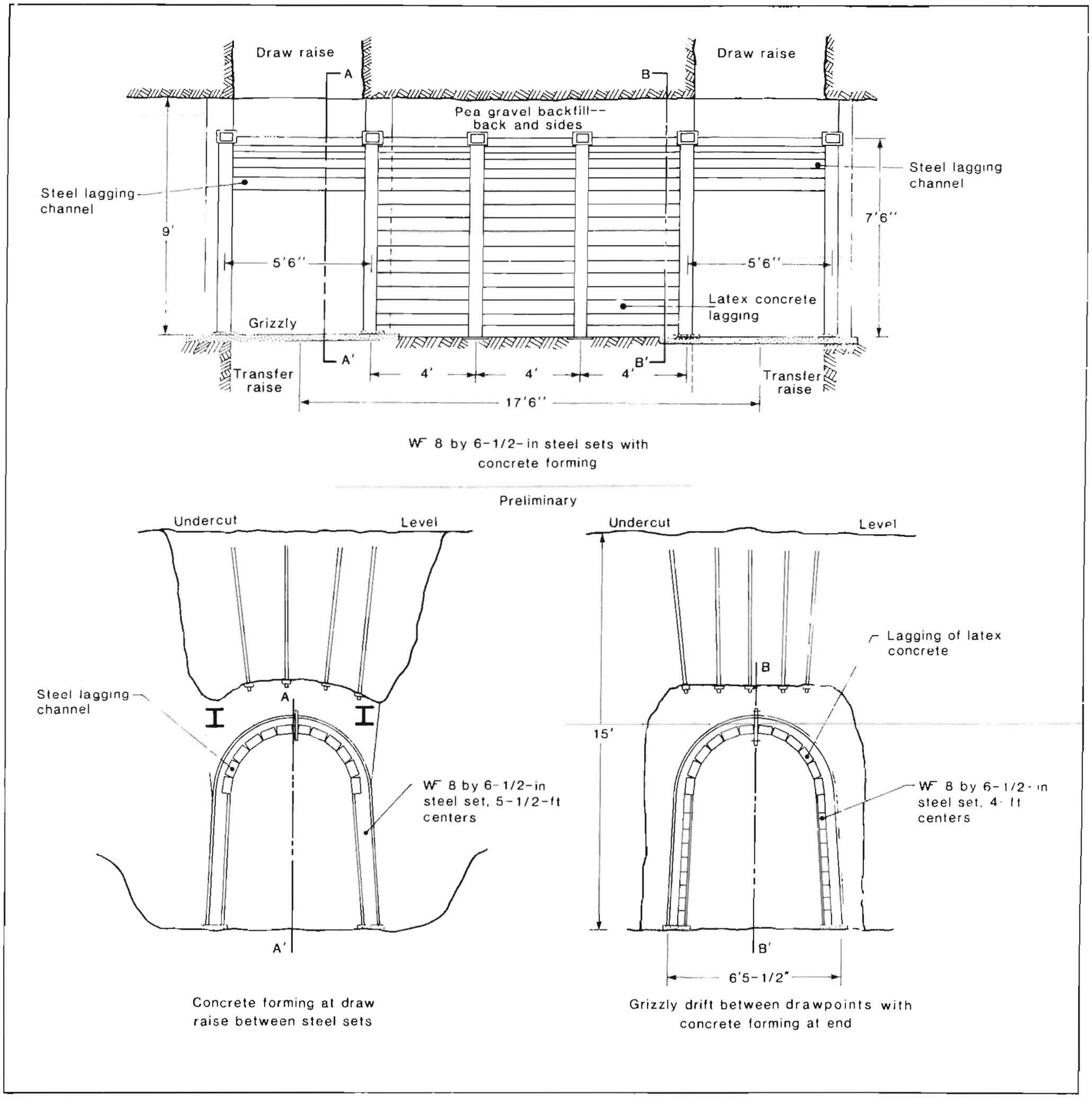

FIGURE 30. - Possible lining test in grizzly drifts.

should not be considered on the grizzly level. Failure of gob lagging in 2615 GL test drift is shown in figure 31. The steel channel is a valid lining for high-stress conditions and, like the concrete lagging, is fire resistant.

One advantage of using sand and gravel backfilling is that it is more economical than is placed concrete for filling the void caused by overbreak. Taper of the legs of the WF steel sets adds to the stability of the structure.

Stress measurement in the backfill (with soil pressure cells) correlated with the load on the steel sets (measured with crib load cells). After measurement at two separate test sites (2315 GL and 2615 GL); it was assumed with some

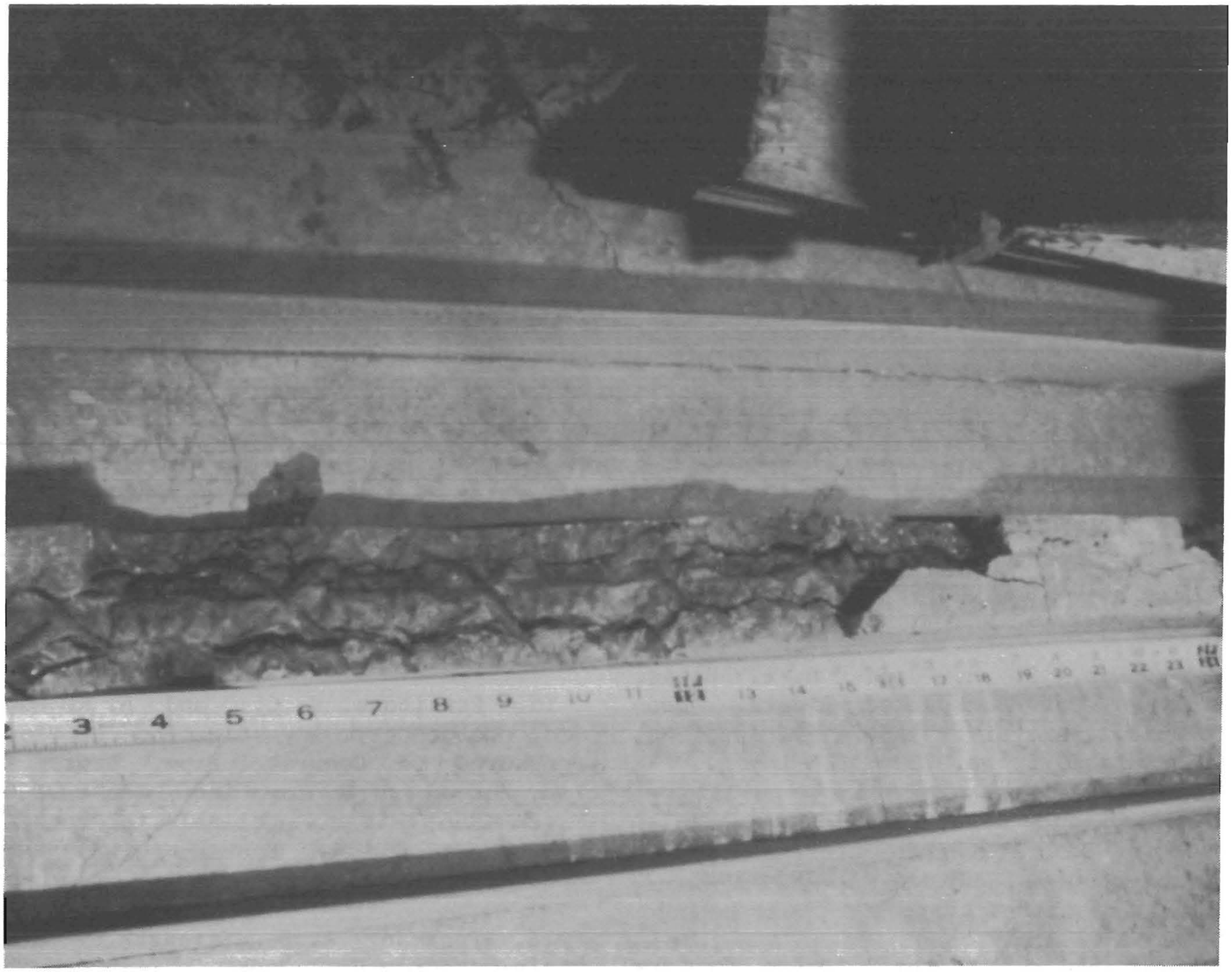

FIGURE 31. - Gob lagging failure in 2615 grizzly level.

confidence, that the average stress is 40 psi (276 kPa) and 35 psi (241 kPa), respectively. Calculated closure of the steel sets agreed with the measured closure.

For the panel drift, WF steel sets can be selected to withstand the high stresses that develop; probably steel channel, backfilled with sand and gravel, is the best lagging. The question to be yet decided is: Can the increase in cost be justified? This would be determined by the ultimate life of the lining.

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APPENDIX.--PRELIMINARY STUDY OF MASS PRODUCING LATEX-MODIFIED, REINFORCED CONCRETE LAGGING

The following costs are estimated for manufacturing rectangular, latex-modified, steel-reinforced concrete lagging, 4 by 6 by 36 in (10.2 by 15.2 by 91.5 cm). Three No. 6 rebars are cast in the lagging. As previously reported, a test of the Dow T-design concrete gob lagging in 2615 GL panel showed that this is not sufficiently strong for grizzly or haulage drift application.

The proposed plant will produce 100 rectangular-section concrete lagging per day or 500 per week, with a three-person crew (table A-1).

TABLE A-1. - Estimated cost for one 50-lb lagging

	Cost
Labor:	
Daily	$300
Weekly	1,500
Per lagging	3
Material	[1]4
Total	7

[1]Breakdown: concrete ($1.75) and 3 No. 6 rebars ($2.25).

The proposed design includes belts supporting the molds, with endless rubber or wire-rope-supported belts or light apron feeders, and gravity dump from the molds. A transverse rubber-belt conveyor would carry the lagging from the mold belt to storage pallets for curing. One hundred molds total, either steel or fiberglass, on two belts is required to produce a like number of lagging. The turnaround time is about 24 hr.

The molds can be filled by a 3-cu yd (2.30-cu m) transit-mix truck or other type of concrete mobile unit. Plant workers would place the No. 6 rebars in mold, and pour and vibrate the concrete.

The dumping from the molds would be automatic, but hand-stacking on pallets would be required. A forklift truck would transfer pallets on the curing-room floor to the outside of the building. An alternative to the transit mix is a small bin-and-batch plant and a 3-cu yd (2.30-cu m) stationary mixer installed near the tail pulleys of the mold-supporting belts.

A schematic (fig. A-1) outlines a plant that includes two 65-ft (19.8 m) belt conveyors to which are fastened the molds, head and tail pulleys, and a reversible crossbelt conveyor.

Curing space for about 2,500 lagging should be provided. Head pulleys on the 65-ft (19.8-m) conveyors could be the self-cleaning, spoked type which would undulate the belt and expedite dumping.

ELEMENTS THAT SHOULD BE CONSIDERED

The recommended manufacturing procedure for latex-modified concrete includes vibrating in the mold for 1 to 2 min, followed by hand troweling. The mold is then covered with a damp cloth and the concrete sets for 24 hr. The lagging is dumped from the mold, conveyed to pallets, and cured for 27 days at 109° F (43° C) and 50 pct relative humidity.

An alternate curing is 4 days with dry heat at 187° F (86° C), followed by 9 days at 109° F (43° C) and 50 pct relative humidity. While still in the mold, the concrete should be at 109° F (43° C) and 100 pct relative humidity.

Mold-conveyor travel would be slow--about 2 rpm with a 36-in (91.44-cm) diam pulley. Estimated weight on the 65-ft (19.8-m) conveyor is only 7,500 lb (3,402 kg) including steel molds and concrete on the 4-ft (1.22-m) wide belt; therefore, medium-duty design would suffice.

The building would be about 10,000 sq ft (925 sq m). In the Sun Belt, curing could be done in the building under 50 pct humidity control, and 109° F (43° C)

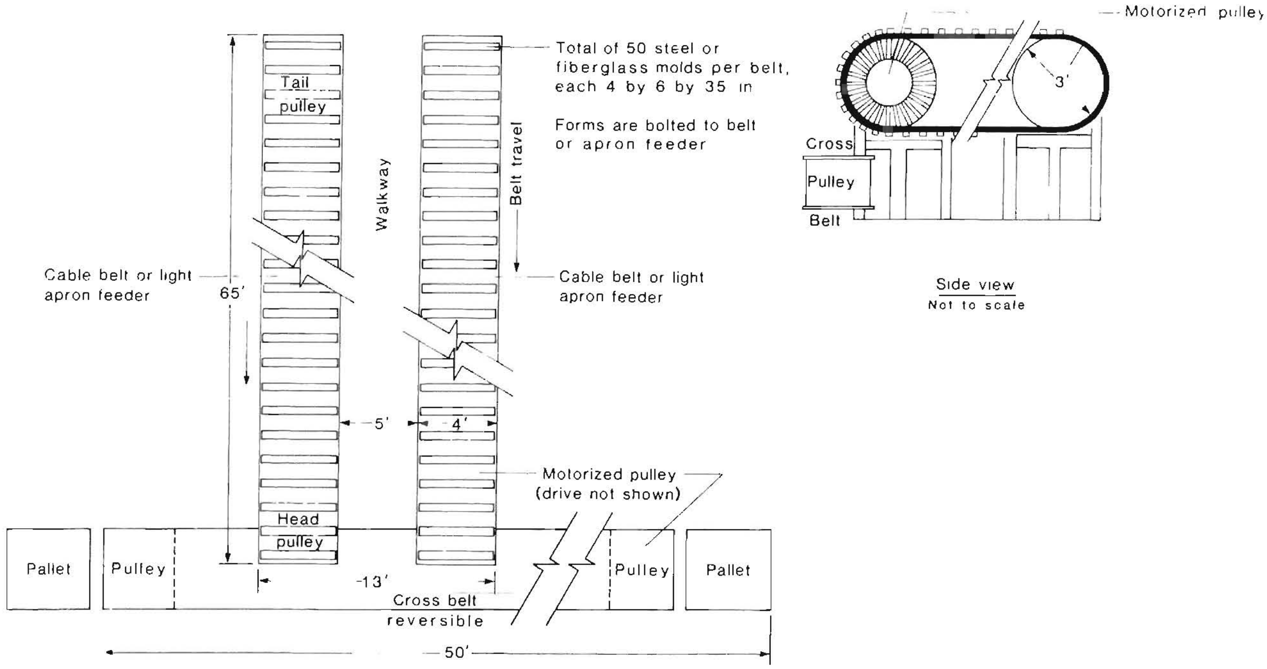

FIGURE A-1. - Mold support plan.

for part of the 27 days, and then the lagging moved outside and kept damp under plastic pallet covers, as storage will be a problem. A drying oven may be unnecessary in Tucson or Casa Grande, AZ.

As space is required for the transit-mix to load the molds, it is anticipated that outside storage will be used during part of the curing time. Although the total plant cost has not been worked out, an investment of $200,000 could be amortized in about 4 yr by adding $2 to the price of each lagging. If a large mining company built such a plant, then the investment could be minimized by using present transit-mix and forklift trucks, and possible surplus conveyors, building, etc. Likewise, a large concrete supplier or contractor could utilize its equipment and space.