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# Field Measurement of Rock Displacement During Sinking of a Deep Rectangular Shaft

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UNITED STATES DEPARTMENT OF THE INTERIOR



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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F degree Fahrenheit

h hour

ft foot

in inch

gpm gallon per minute

pct percent

# FIELD MEASUREMENT OF ROCK DISPLACEMENT DURING SINKING OF A DEEP RECTANGULAR SHAFT

By J. K. Whyatt<sup>1</sup> and M. J. Beus<sup>2</sup>

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## ABSTRACT

The Bureau of Mines, under a cooperative agreement with Callahan Mining Corp., measured rock displacement at the 4,750-ft level of the 5,100-ft-deep rectangular, timbered Caladay Shaft in northern Idaho. Displacements were measured with multiple-position borehole extensometers (MPBX) installed 4 ft above the face and timber extensometers (TE) installed with the timber sets. This report presents the displacement data along with preliminary, qualitative observations of rock behavior. The measured displacements showed an instantaneous response to shaft sinking and significant time dependency. The relative magnitudes of displacement measured at the shaft walls were heavily influenced by local geologic structure and distance from the shaft bottom.

## INTRODUCTION

For many years, the Bureau of Mines has conducted research to evaluate the in situ stress field and to develop structural guidelines for designing shafts in deep vein-type mines. Much of this work has centered on evaluating the in situ conditions that affect the structural stability of shafts in the Coeur d'Alene Mining District of northern Idaho (1).<sup>3</sup> Recent work on field monitoring of actual rock and support behavior includes a preliminary study of half-scale test shafts (2) and instrumentation of Hecla's Silver Shaft (3).

The test site is situated in the new Caladay shaft recently completed by the Callahan Mining Corp. The rectangular shaft extends a total length of 5,100 ft in virgin ground, providing an ideal opportunity to measure the geomechanical response of a rock mass to construction of a deep mine opening without the extraneous effects of adjacent excavations.

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<sup>3</sup>Underlined numbers in parentheses refer to items in the list of references at the end of this report.

## ACKNOWLEDGMENTS

The authors express their gratitude to officials and personnel of Callahan Mining Corp., particularly Doug England, project manager, and Monty Iten, shop foreman. Gratitude is also expressed to the shaft sinking contractor, Fausett International, particularly Lavonne Fausett, president, and Marty Ewell, project foreman, for assistance with installation of the instruments. The sinking crew did a tremendous job during instrumentation

and while working around the instrumentation cables, etc., resulting in an unusual extensometer survival rate. Terry Stephenson, mining technician, formerly of Hecla Mining Company, and Bill Hand and Gene Stone, Spokane Research Center (SRC) technicians, provided assistance with instrument preparation and installation, and data acquisition system construction and operation.

## SITE DESCRIPTION

The Caladay Shaft (fig. 1) is located in the Coeur d'Alene Mining District near Wallace, ID, on the south side of the west-northwest striking Osburn Fault, the

dominant structural feature in the district. Existing development at the project site included a main adit, several short crosscuts, a shaft station,

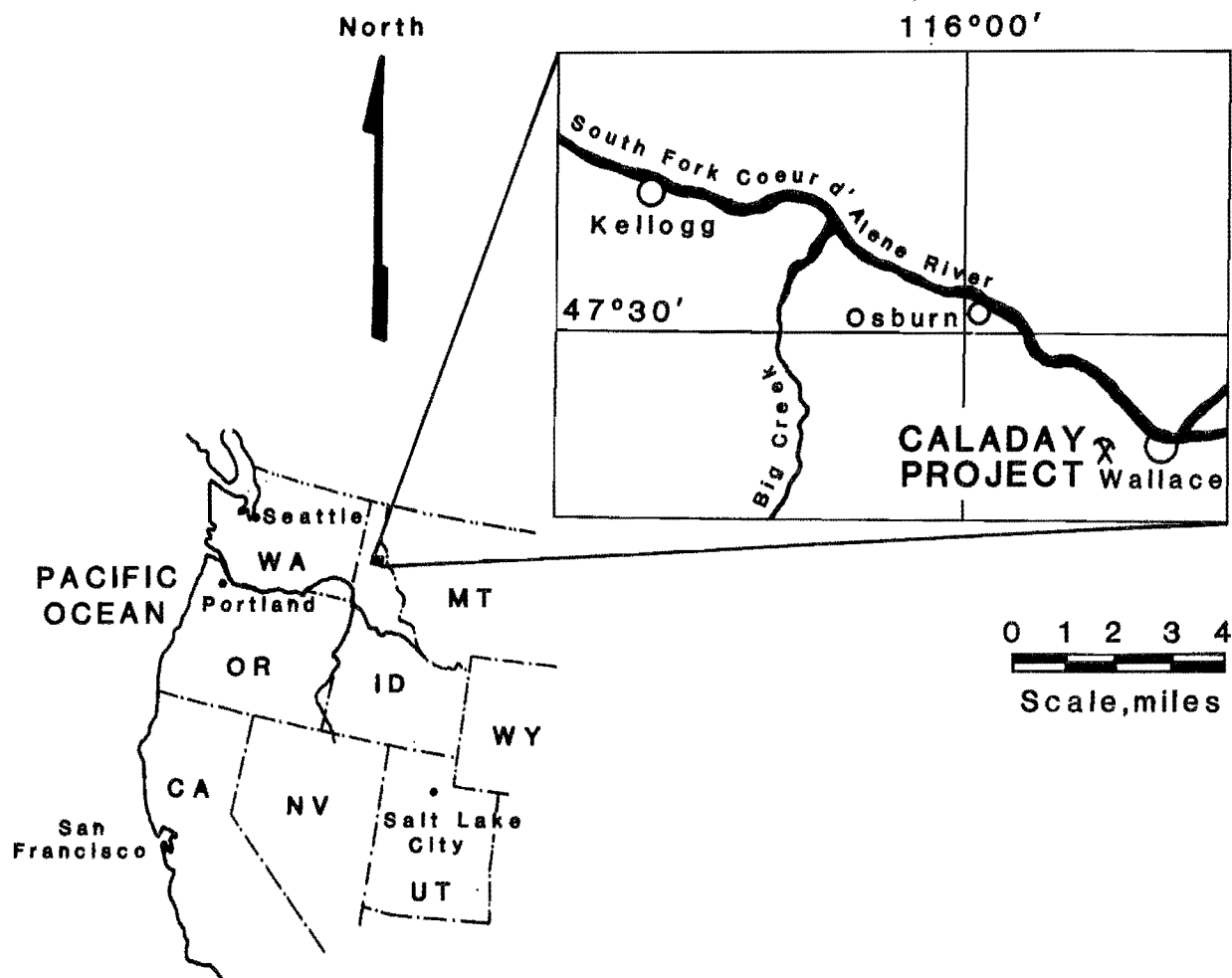


FIGURE 1.—Location of the Caladay project in the Coeur d'Alene Mining District of northern Idaho.

and related service excavations. The shaft-collar station was located 5,200 ft inside the portal of the main adit under 1,200 ft of overburden (fig. 2). The instruments were installed at the 4,750-ft level of the shaft, under 5,950 ft, of overburden, between the 4,600- and 4,900 ft stations. The rock at this

depth is part of the Revett Formation (Precambrian age) and consists of thinly bedded (1- to 6-in thick) argillaceous quartzite with interbedded argillaceous material. In addition, there are numerous gouge-filled joints, partings, and minor faults. The shaft endwalls were parallel to the strata, which strike

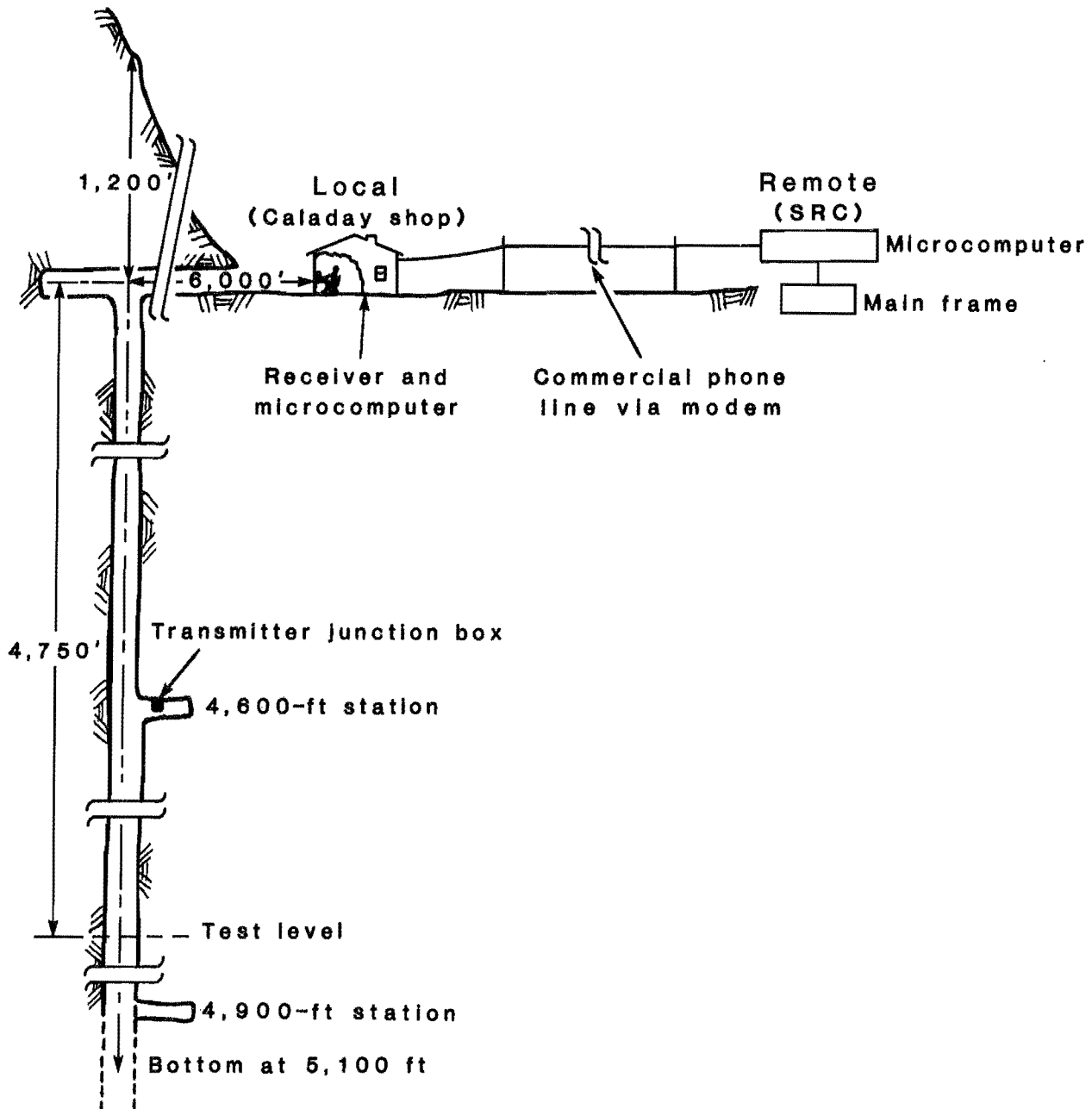


FIGURE 2.—View in cross section of the Caladay adit-shaft system with the test level and data-line routing.



northwest at 35° to 45° and dips 65° to 75° to the northeast.

The shaft was approximately 22 by 11 ft in cross section, although an additional foot or so of overbreak was common, particularly on the endwalls. Conventional drill-and-blast sinking practices were followed using handheld sinkers, bench blasting, and a Cryderman mucker mounted in the center compartment. Initial support at the face consisted of 5-ft split sets and 6-ft grouted rebar on 4-ft centers with wire mesh and matting. Timber sets on 6-ft centers were extended, three sets at a time, to within 20 to 25 ft of the shaft bottom. The 2 by 12-in timbers were blocked and wedged into place using cedar or fir blocking, depending on location (fig. 3). Cedar, which yields at lower pressure than fir, was used to preserve set alignment despite distortional shaft squeeze.

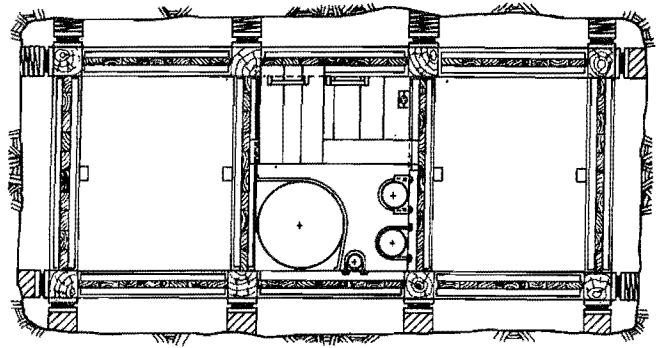


FIGURE 3.—Plan view of Caladay shaft showing blocking and compartment layout.

#### INSTRUMENTATION

Measurements of shaft closure, timber set movement, and the distribution of displacements within the rock mass were sought to provide data on rock-mass behavior and the reaction of timber sets to shaft sinking. The distribution of displacements in the rock mass reflected the progressive fracturing of rock around the shaft, a poorly understood mechanism that is a major contributor to closure in deep mines. However, overall shaft closure, especially closure rate, indicated shaft stability and the adequacy of ground support. Some shaft closure after set installation is necessary to develop timber support loads, but excess closure damages shaft timber and guide alignment, increasing shaft maintenance and repair costs. Set deformation can be somewhat controlled by adjusting the time between shaft excavation and timber installation.

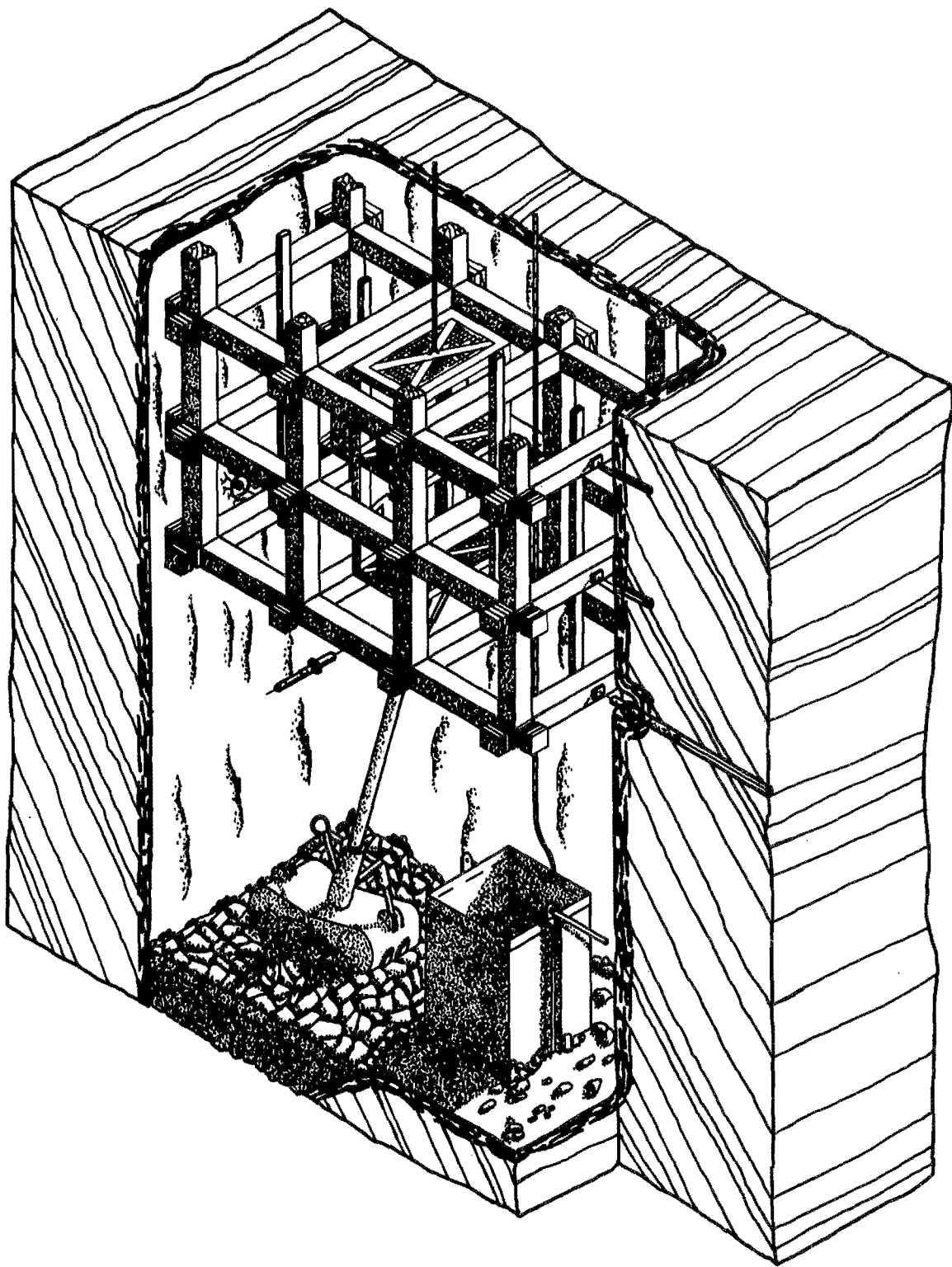
Preliminary planning of the Caladay instrumentation project focused on installing instruments near the bottom of the 5,100-ft-deep shaft. In order to simplify data interpretation, a section of shaft was sought that was outside the influence of shaft stations, ore passes, and structural features. The 4,750-ft

depth between the 4,600-ft and bottom (4,900-ft) stations was chosen, with the exact depth left to construction and scheduling considerations.

MPBX's were placed in the middle of each shaft wall to measure shaft closure and the distribution of rock displacement with depth. TE's were used to measure closure between the timber sets and shaft walls. All instruments were installed in and around three sets (fig. 4). Access to the instruments was limited, prompting use of a remote data acquisition system (RDAS).

#### INSTRUMENT SPECIFICATIONS

Four 4-position MPBX's were chosen to give a profile of rock displacements with distance into the shaft wall and an estimate of total shaft closure. They were located at the midpoints of each shaft wall (fig. 5). Each MPBX was equipped with four, 4-in range, linear potentiometers connected to respective hydraulic anchors by 5-, 10-, 25-, and 50-ft lengths of stainless steel rod. The 50-ft maximum depth was considered "stable" for estimation of total shaft-wall displacement.



**FIGURE 4.**—Artist's concept of the Caladay shaft showing the overall layout of the instrumentation. (See also figure 5.)

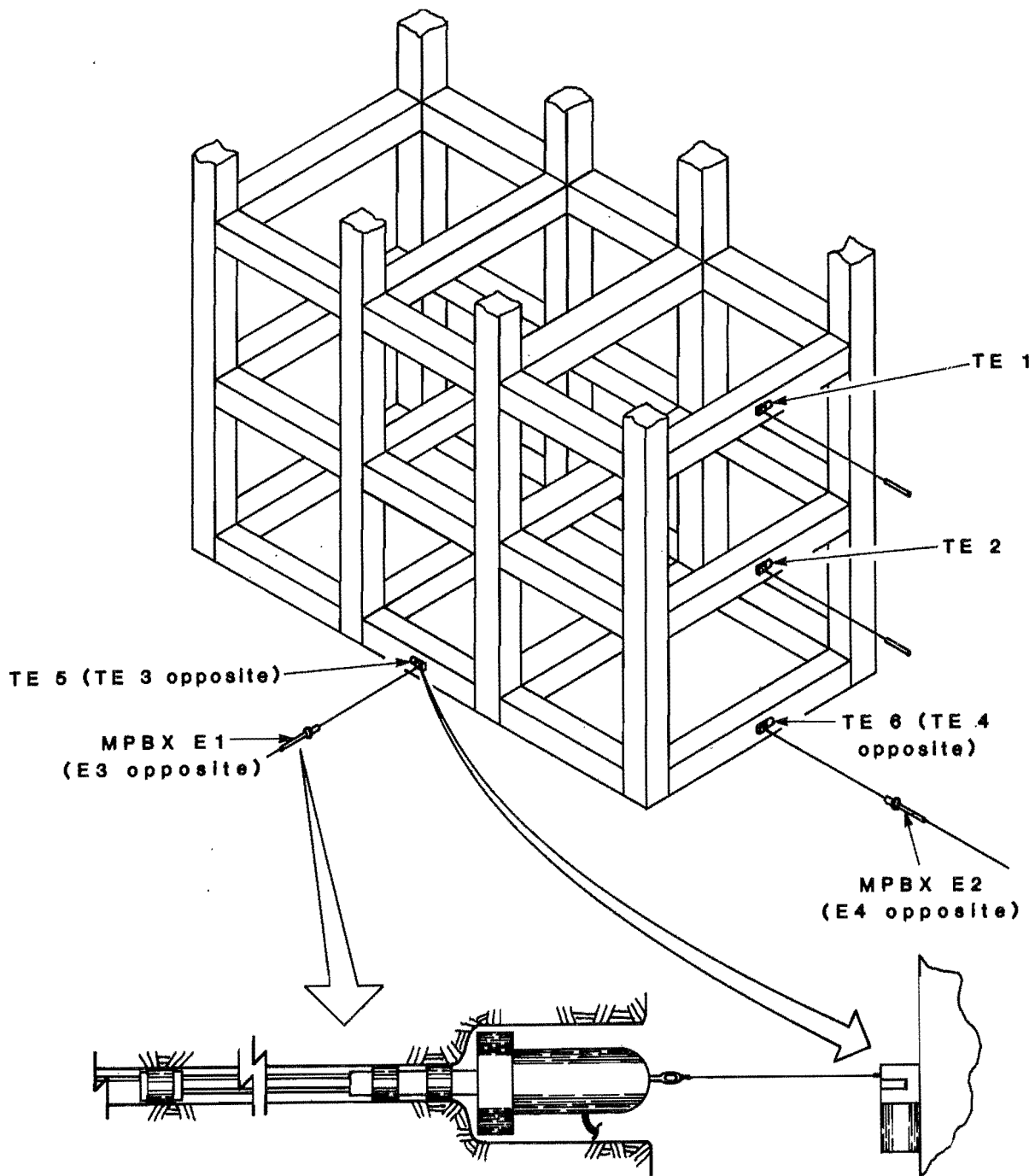


FIGURE 5.—Detailed layout of the instrumentation in the Caladay shaft.

This estimation was based on experience from a similar project during sinking of the Silver Shaft in the same mining district.

Six TE's were used to measure movement between the timber set and the rock wall at the four MPBX locations and at the end of the upper two sets, as shown in figure 5. Each TE consisted of a 10-in range rotary potentiometer connected via stainless steel cable to an anchor in the rock. Eyebolts were attached to the ends of the four MPBX heads to serve as anchor points for the bottom set TE's, providing a direct measurement link between MPBX's and the timber set. Hydraulic anchors were installed in 1-3/8-in holes for TE's on the two upper sets.

#### ENVIRONMENTAL PROTECTION

Environmental conditions at the shaft bottom were difficult to work in and hostile to electronic equipment. A substantial inflow of ground water resulted in standing water on the shaft bottom, falling water, mist, and 100-pct humidity. The geothermal gradient raised ground water temperature to about 108° F and shaft bottom air temperature to over 90° F. Installation, especially of the MPBX's, was also hampered by limited work space at the shaft bottom. After installation, bench blasting resumed only 4 ft below the MPBX's, subjecting them to shock and flyrock.

To prevent damage, the MPBX heads were recessed in the shaft walls and protected by 3-ft-square, 3/8-in-thick aluminum plates. The 9-in square panels in the middle of each plate allowed access to the extensometer heads for anchoring the TE's after timber set installation. Signal cables, placed in waterproof conduits with waterproof connectors, were covered with compressed air hoses and steel channels and bolted to the shaft walls. They were routed from the aluminum cover plates to the first timber set. The TE's were protected by an aluminum mounting box, which included a telescoping tube for protection of the anchor cable.

#### DATA ACQUISITION SYSTEM

The Bureau's MDAP85-RDAS (4) was used for data collection. The system consisted of an underground subsystem that collected and transmitted data to the surface through mine phone lines, and a microcomputer at the mine office to receive, reduce, and store the data. Underground components included instrumentation power supplies, voltmeters, analog to digital converters, and digital transmitters, all protected from shaft conditions by a sealed, stainless steel junction box (J-box). A phone link and SRC-based microcomputer allowed continued remote data collection.

#### INSTALLATION

SRC personnel began on-site preparations at the Caladay shop in late May 1984. The data acquisition system J-box was installed on the 4,600-ft level, establishing data transmission. The MPBX's were preassembled in 12-ft sections, packaged, and transported to the 4,600-ft station.

Drilling of the boreholes began on June 9, 1984. Each MPBX borehole was begun by drilling and blasting a 1-ft diam, 1-ft deep "doghole," 4 ft above the shaft bottom, for recessing the MPBX transducer head. Then, 3 ft of 3-in hole were drilled for the MPBX standpipe. The remainder of the hole was drilled 2-1/4-in diam to total depths of 38, 48, 48, and 50 ft for MPBX's E1, E2, E3, and E4, respectively. The short depth of hole MPBX-E1 was caused by a fault at 42 ft that released 50 gpm of 108° F water into the shaft. The combination of water and ravelly ground around the fault prevented deeper placement of the anchor. Total drilling time for all four holes was 16 h.

Each MPBX was installed immediately upon completion of the drill hole. Final assembly of the MPBX's was completed on the 4,600-ft station. Each MPBX was equipped with a sling for suspension beneath the sinking bucket for traversing

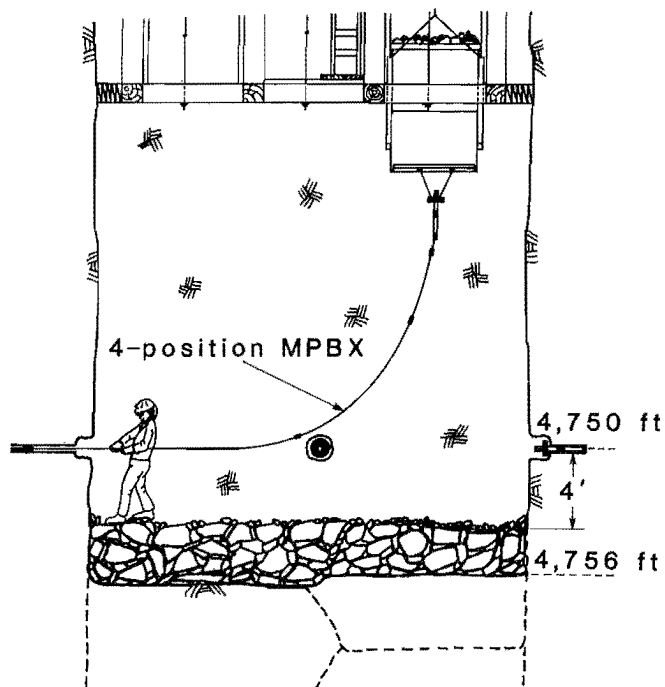


FIGURE 6.—Technique for installing MPBX's in shaft wall boreholes.

the final 150 ft to the shaft bottom. The sling protected the displacement transducers from the weight of the anchors and rods, while preserving the flexibility required for bending from the shaft into the horizontal boreholes. The sling consisted of a steel cable attached to the head of the MPBX and a polypropylene rope along the length of the instrument tied off to each anchor and the head to support the rods and anchors. The assembly was slowly lowered to the shaft bottom and the extensometer installed in the borehole, as shown in figure 6. The anchors were then pressurized, starting with the deepest and working back towards the collar standpipe. Prior to setting the standpipe anchors, the MPBX head was

adjusted to allow an approximately 3-in closure over the 4-in range of each transducer.

The flex conduit housing the extensometer signal cable was lowered down the manway compartment and tied to the wire mesh on the shaft walls below the timber. The cables were connected to the J-box at the 4,600-ft station, and data collection initiated on June 11th.

The TE's were installed June 15th, after the shaft bottom was sunk an additional 18 to 22 ft below the extensometers. The timbering work platform (battleship) was lowered for timbering, drilling of the TE hydraulic anchor holes, and instrument installation. After installation of the hydraulic anchors, the TE stainless steel cables were extended and tied to the anchors with piano wire. All instruments were installed, cabled to the data-acquisition system, and operating satisfactorily by the end of the day.

#### OPERATION

THE MPBX's performed remarkably well, despite being submerged during a pump failure, June 11th (shortly after installation). The TE anchor cables on the bottom set were vulnerable to blasting, and three of the four were destroyed almost immediately. The fourth failed after the first timber and excavation cycle. In contrast, the upper TE's were protected by the bottom set and performed well. The data-acquisition system worked exceptionally well, except for problems with a loose connection in the telephone line and overheating of the J-box. A portable compressed air blower cooled the J-box sufficiently to prevent loss of data.

#### RESULTS

Displacement data collected from the shaft instruments were combined with blasting records in a single data base on SRC's computer. MPBX displacements were calculated with respect to the deepest anchor, which was assumed stable. This was a valid assumption for MPBX's E2, E3, and E4, but any displacement across the

E1 borehole fault was not measured. As deep anchors went off range or were damaged, all subsequent displacements were rereferenced to the deepest existing anchor. "Rereferenced" data suffered a minor decrease in accuracy of total displacements, but good estimates of displacement trends were obtained.

The first timber and excavation cycle after instrumentation extended into the shaft bottom 18 ft and extended shaft timber by three sets in less than a week (fig. 7). Combined plots of MPBX displacement data and bench blasting over the first 5 days after instrumentation (fig. 8A-D) showed significant rock displacement response to blasting. The alternating large and small jumps in MPBX E2 and E4 plots reflected the first eight blasts on alternating benches, directly below the respective MPBX's.

Detailed plots of the displacement response to blasting (fig. 9) showed a change in character with successive blasts. The time-dependent displacement decay curves observed after each blast, flattened with shaft advance and approaches a constant creep rate while the displacement "jump" disappeared. By the ninth blast, at the beginning of the second excavation cycle, nearly all displacement was time dependent.

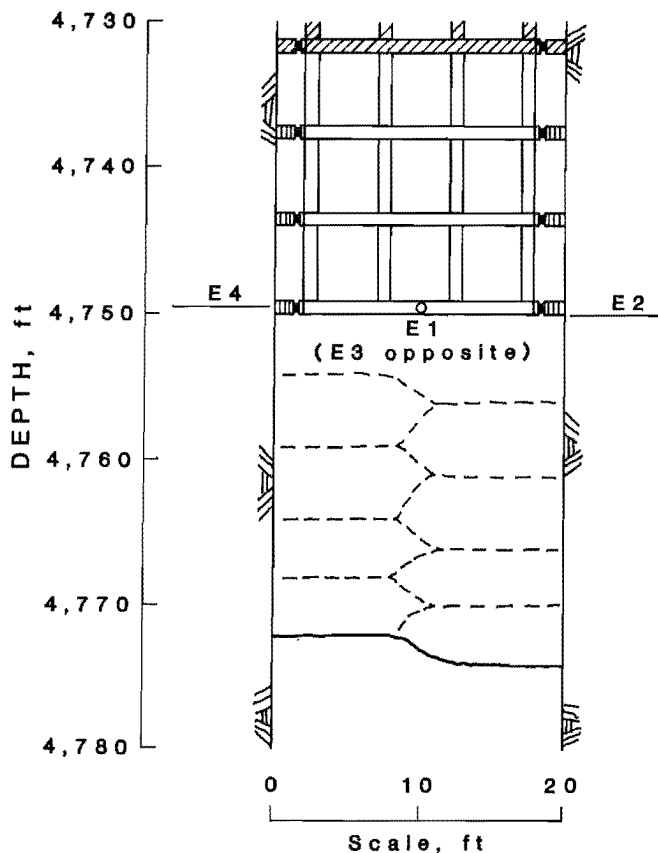


FIGURE 7.—Shaft test level showing timber sets and bench excavation associated with the instrumentation.

Time-dependent displacement was also observed when shaft sinking was halted for 3 days (for timber installation and a weekend) during the smooth last third of figure 8A-D. The time-dependent displacement continued even after the shaft had advanced 75 ft (30 days) past the instrumentation level, well past the point where the advancing face would affect displacement elasticity (5). The displacement rate gradually decayed to insignificance about 90 days after instrumentation (table 1).

The long-term displacements (table 1), as well as the total displacements (fig. 8A-D), showed a wide variance between MPBX's. A plot of displacement versus anchor depth for the MPBX's 5 days after installation (fig. 10) summarizes this variation. There is a remarkable similarity between the endwall displacements measured by E2 and E4. On the other hand, the longwall displacements (E1 and E3) showed little similarity throughout, suggesting that the water-bearing fault hit by the E1 borehole had a significant local influence. The mechanism of influence is unclear, but could include local stress relief from water drainage, or opening of the fault with shaft advance. The absence of an anchor on the opposite side of the fault precluded definite evaluation, but numerical modeling may provide further insight into possible mechanisms.

The E3 deep-anchor displacements surpassed the respective endwall deep anchors, while the E1 deep anchors showed virtually no displacement (relative to the 38-ft anchor, which does not cross the fault). Large endwall displacements were consistent with experience in the district with larger displacements where the bedding was parallel to the side of

TABLE 1. Total collar displacement for 30-day periods, in inches

| MPBX    | Time, days after installation |       |        |         |
|---------|-------------------------------|-------|--------|---------|
|         | 30-60                         | 60-90 | 90-120 | 120-180 |
| E1..... | 0.03                          | 0.01  | 0.01   | 0.01    |
| E2..... | .25                           | .14   | .06    | .04     |
| E3..... | .06                           | .02   | .01    | .004    |
| E4..... | .28                           | .15   | .03    | .08     |

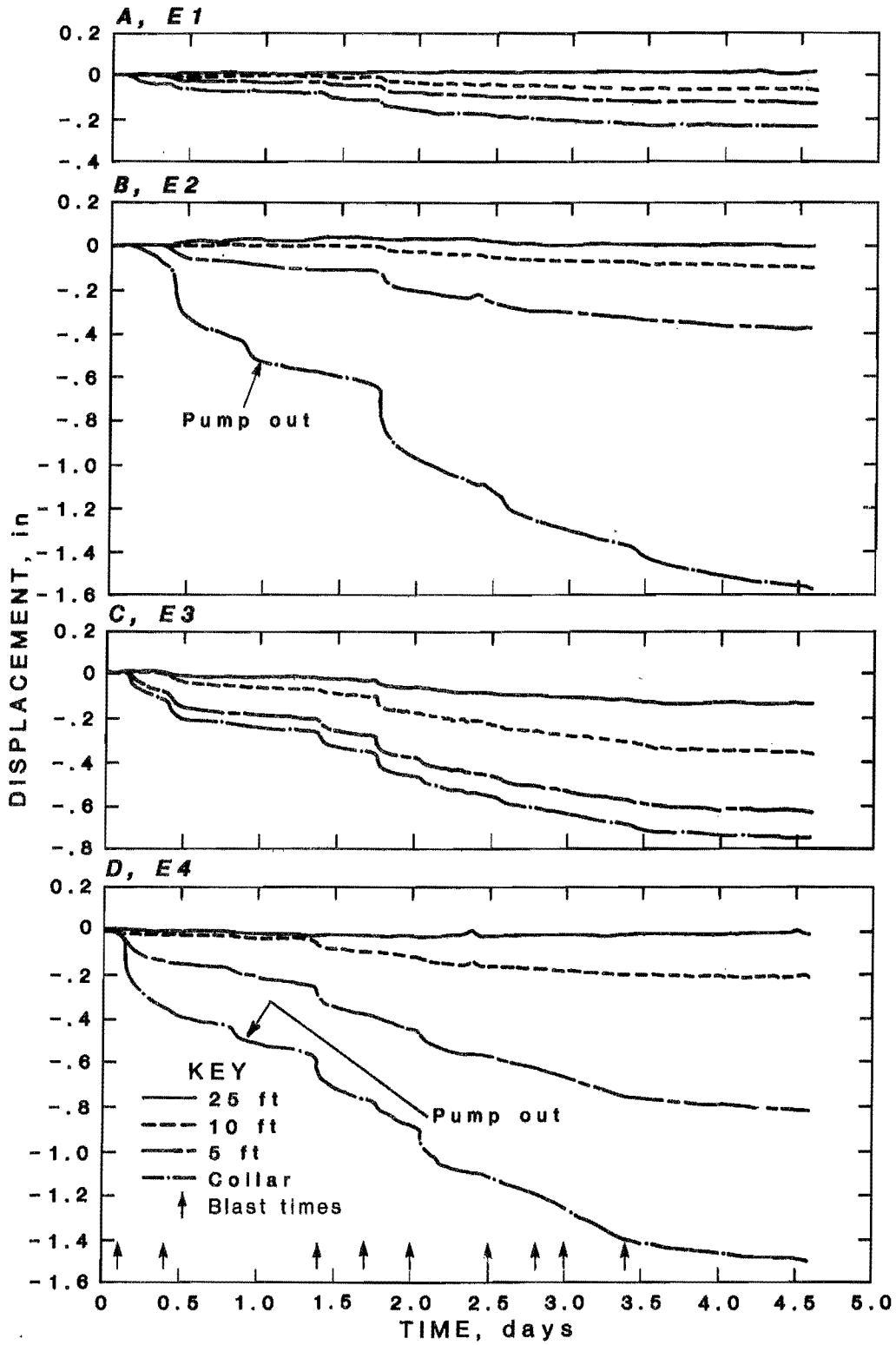


FIGURE 8.—Displacements of MPBX's for first 5 days after installation: A, E1; B, E2; C, E3; and D, E4.

an opening. This is contrary to elastic theory; however, elasticity does predict greater displacements for E3 deep anchors. The bedding probably controls displacement near the free face at the endwalls, where low normal stresses on the bedding plane allow slippage and separation, but is less important on the longwalls and deeper in the rock, where increased normal stresses suppress bedding plane slippage and separation.

Hence, while traditional elastic-plastic analyses may be sufficient for predicting deep-seated stress distributions and

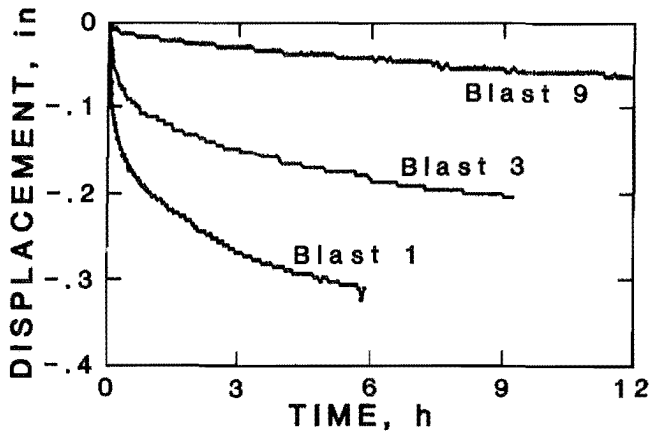


FIGURE 9.—Response of shaft wall at E4 to blasts 1, 3, and 9.

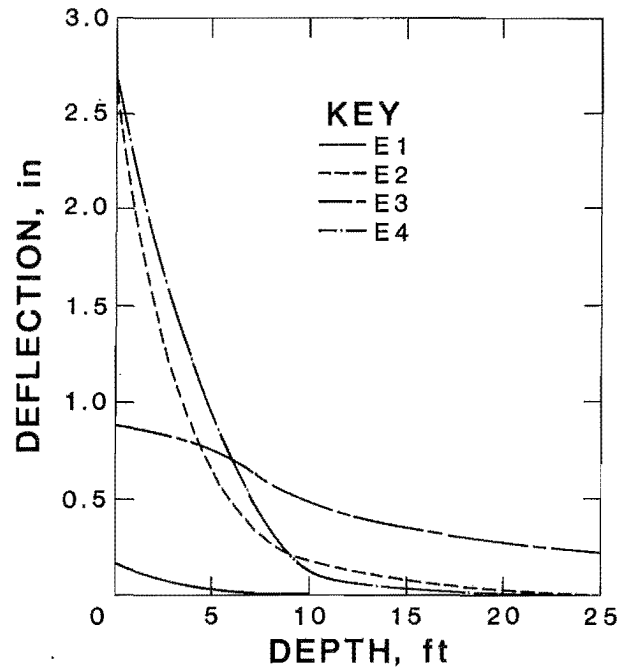


FIGURE 10.—Displacement versus depth at elapsed time of 5 days E1, E2, E3, and E4.

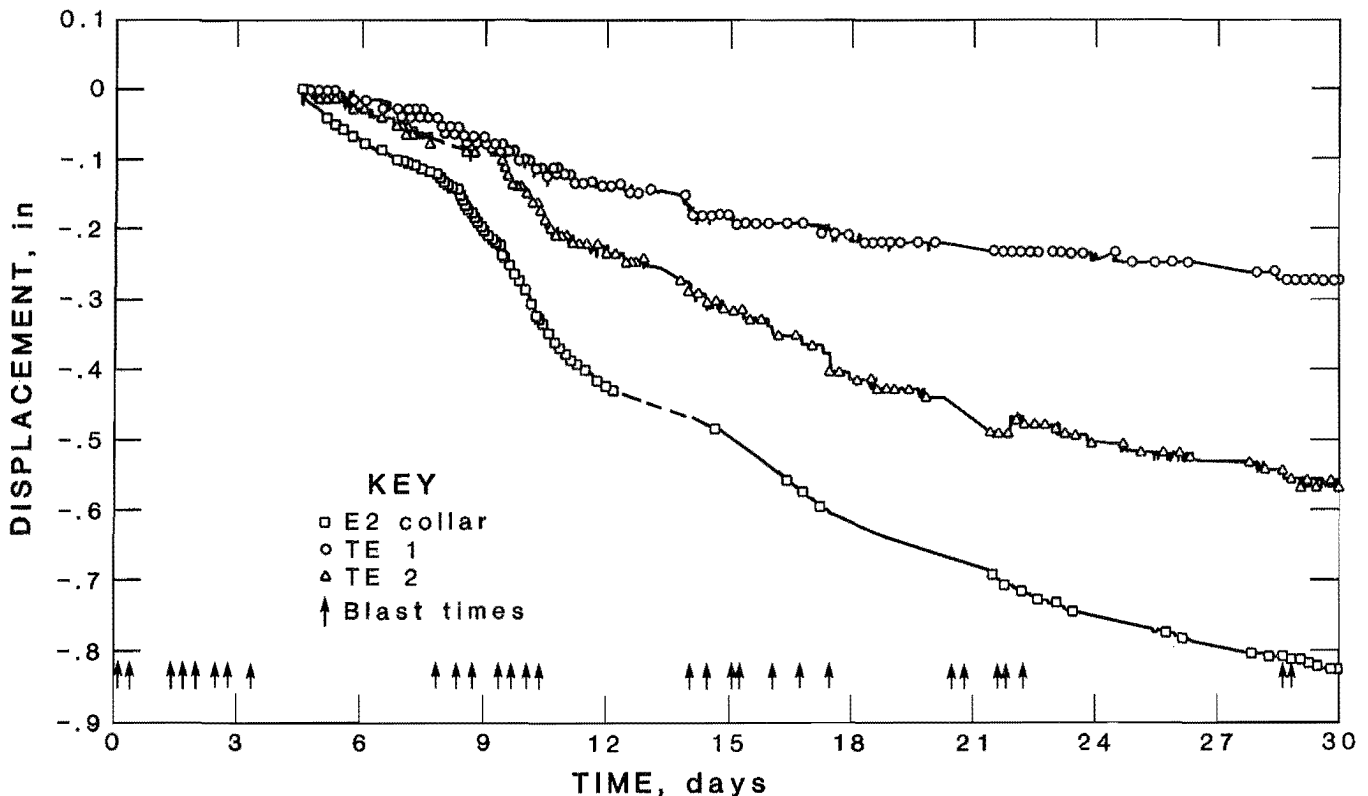


FIGURE 11.—Thirty-day shaft wall displacement plot for E2, TE1, and TE2.



displacements, consideration of bedding plane properties and orientation is essential for understanding shaft closure and behavior of the fractured zone.

Relative displacements between the rock and successive timber sets measured by TE1 and TE2 demonstrate the dependence of timber set deformation on face advance.

A plot of these data (fig. 11), with E2 data adjusted to zero displacement at the first reading of the TE's, shows a wide

variation in displacements. TE1 and TE2 were installed on a vertical line, only 6 ft apart, yet their measured displacements differ by a factor of 2, or nearly 0.3-in, in less than 30 days. E2, 20 ft above the face during timbering and 6 ft below TE2, recorded a similar increase in displacement, although direct comparison depends on the assumption that the timber sets did not move in the shaft.

#### CONCLUSIONS

A preliminary analysis of displacement data from the Caladay Shaft suggests--

1. There was a sudden but local displacement response to blasts, followed by decaying time-dependent displacement.

2. Displacement of the shaft walls continued at a decaying rate until stability was achieved, after 3 to 4 months.

3. Geologic structure had a major influence on rock displacements. The

bedding controlled shaft closure where normal stresses on the bedding planes were minimal. Deep-seated displacements corresponded qualitatively with elastic expectations. In addition, a water-bearing fault behind one longwall appeared to drastically affect (reduce) measured displacements.

4. The distance from the bottom at support installation had a significant effect on the displacement experienced by the timber sets.

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