Measurement of Salt Pillar Movement

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Problems related to rock mechanics in dry salt mines and brine fields have been a project of long-standing with the Development Department of International Salt Company. With respect to the stability of the openings of our four dry salt mining operations, the simple observation of convergence began in June of 1949. These observations were conducted through the use of a convergence gauge that consisted of two pieces of concentric tubing. One of these pieces of tubing was bolted to the roof while the other was bolted to the floor. This gave a measure of total movement including any separation or parting of the laminae in the floor and roof.

Work with the stratascope told us that the amount of separation in our bedding planes overlying our mine roofs was a major contribution to the total apparent movement. At this point, our efforts turned toward the measurement of the dilation of the pillars. A pillar under load thickens laterally. This expansion is measured by dilation pins, as shown in Fig. 1-A.

It consists of a string of five feet long steel rods inserted into a hole drilled into the pillar. The length of this string of rods can be varied to meet the purpose for which the observations are desired. In this sketch a ten foot long rod is shown. The rods are anchored at the bottom of the hole with a common roof bolt anchor. The outer end of the pin is tipped with a stainless steel bolt. When the pillar expands laterally, the wall will move outward and the pin will, therefore, appear to be drawn into the inside of the pillar. By keeping a record of the distance between the stainless steel bolt head and a point in the bore of the hole referenced to the surface, one measures the dilation of the pillar.

One difficulty with this type of gauge is that small blasting and stress cracks are present just beneath the surface. These may camouflage the true pillar deformation. Thus, it is better to measure the relative movement between the far end of the pin and a point back of the surface and not on the pillar surface. The distance of the point behind the surface of the pillar will vary with a variation of conditions. In our case, we evade these superficial cracks by a device called the outer reference. Fig. 1-B shows this outer reference installed. It is essentially a tube slipped over the pin, and glued to the wall of the hole at a depth of two feet. The recorded movement between the stainless steel bolt and the end of the outer reference is therefore equal to the expansion or dilation of the rock between the anchor and the indicated point, two feet underneath the pillar surface.

Figure 1-C shows a magnified view of the outer reference device. It consists of a piece of steel tubing with a cup screwed on at the end. This cup is filled with an epoxy adhesive. The adhesive is squeezed out of the cup by a plunger which is actuated by a push tube and a jam nut.

Figure 2 shows the outer reference again, as it is glued in place. The dilation pin is read by screwing a micrometer depth gauge on the outer reference, and turning the micrometer until the micrometer rod is felt to touch the head of the stainless steel bolt.

If dilation pins have to be installed in hazardous locations, or in areas which will become inaccessible, one can adapt them for remote reading. Figure 3 shows the outer end of a dilation

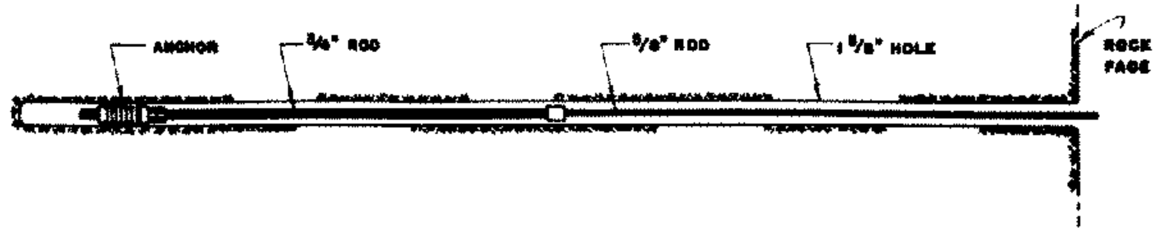


Figure 1-A. Inserted Anchor Bolt -- Elevation.

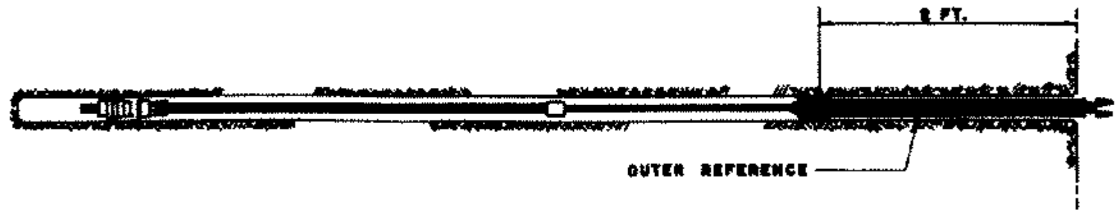


Figure 1-B. Anchor Bolt and Outer Reference.

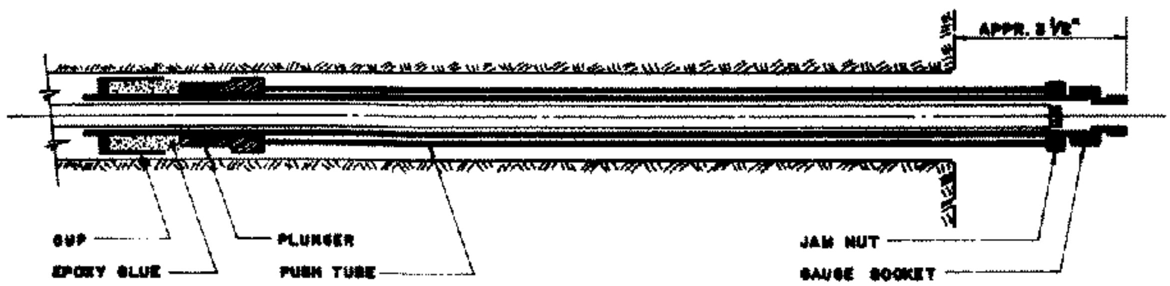


Figure 1-C. Detail of Outer Reference.

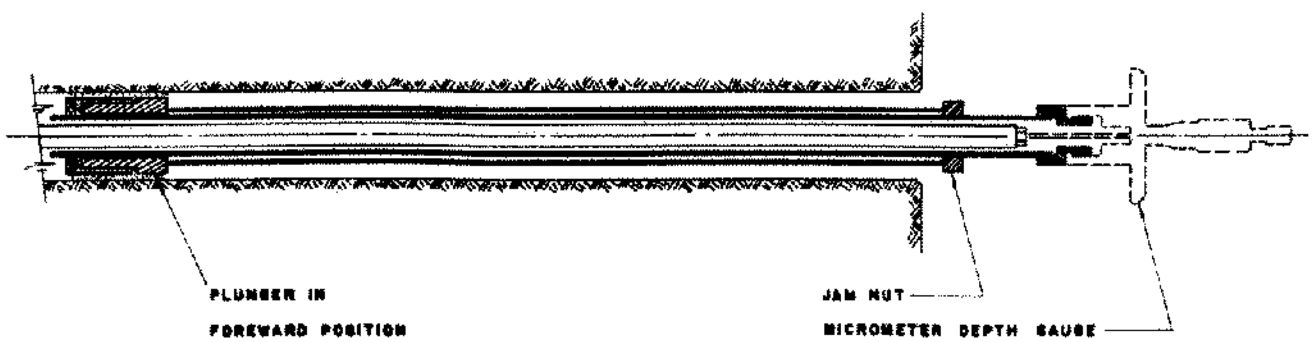


Figure 2. Detail of Outer Reference with Attached Depth Gauge.

pin. A stainless steel sleeve, screwed on the gauge socket, serves as an adaptor for a displacement transducer. The transducer which we used is a differential transformer. The dilation pin movement shifts the transformer core that in turn, changes the output voltage of this transformer. The voltage output of the transformer is therefore a measure of pillar dilation. The differential transformers we use are driven with six volts of direct current. They were equipped with a built-in modulator located in front of the primary coil, and a demodulator and filter after the secondary coils. Thus the output is direct current. The electric circuitry consisted of a DC power supply,

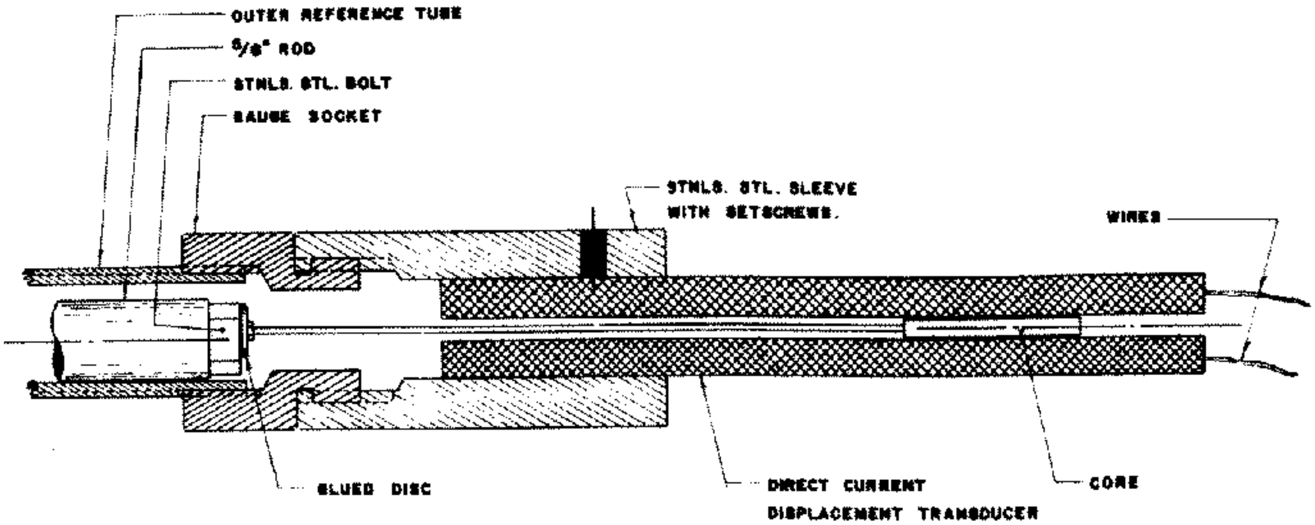


Figure 3. Displacement Transducer Mounted on Dilation Pin for Remote Reading.

driven from a 115 V AC power outlet. The output voltage of the transducers is measured by a digital millivoltmeter. A displacement of one thousands of an inch at the dilation pins, reads as a voltage change of approximately two millivolts at the voltmeter. The continued reliability of the installation was checked by periodically testing the resistance of the transducers, both the primary and the secondary circuits, and by keeping a dummy transducer at the dilation pins.

Shortening of pillars under load is being measured by convergence gauges illustrated in Fig. 4. A convergence gauge consists of two telescoping aluminum tubes. Their ends are glued to the bottom of holes drilled in both roof and floor close to the pillar, thus eliminating the measurement of voids created by strata separations near the roof. Two collars are mounted on the two tubes, and the distance between the two will change as the pillar shortens under load. The readings are taken by inserting a micrometer depth gauge through the hole in the lower collar, and turning the micrometer until the micrometer rod is felt to touch the underside of the upper collar. The lateral pressure in roof and floor will tend to deform the rock strata pierced by these holes which extend four feet into the roof and into the floor. Thus the measurements are not strictly an accurate measurement of the shortening of the free height of the pillar.

In the following we present some typical applications of the gauges discussed. Figure 5 shows the plan of part of one of our mines. The rooms were 100 feet wide, 100 feet high, the pillars measured 100 feet square. At the indicated locations the room height was only 30 feet. Because of the excellence of the salt quality, it was decided to bench another 30 feet of salt in 70 foot widths. In creating pillars 130 feet high, it was important to have confirmation of their continued stability. Seven dilation pin stations were set in this area. Each of these stations contained two dilation pins. One 15 foot long and one 45 feet in length. The 15-foot pin measured the salt expansion or dilation in a zone from two feet to 15 feet behind the pillar surface. This zone we call the pillar shell. The zone between a depth of 15 feet to a depth of 45 inside the pillar, we have called the pillar core. The dilation measurements divided by the width of the respective zones and by time gave the dilation rate in terms of micro inches per inch per day.

Figure 6-A shows a graphical presentation of the dilation rates at Stations No. 1 and 2. Note that the dilation rate of pillar core and pillar shell are almost equal, only in the magnitude of micro inch per inch per day. Note further that the pillars show changes of strain rate although the floor mining activities have long since moved hundreds of feet away. The movement of the pins at Station No. 1 on the periphery of the floor mining area was reduced more quickly to an undisturbed pattern of deformation than the pins at Station No. 2. The movement indicated by pins at Station No. 2, stabilized only after the mining operations of the whole area were completed. Note that the maximum deformation rate coincided with the time of maximum mining activity, namely from June to August 1963.

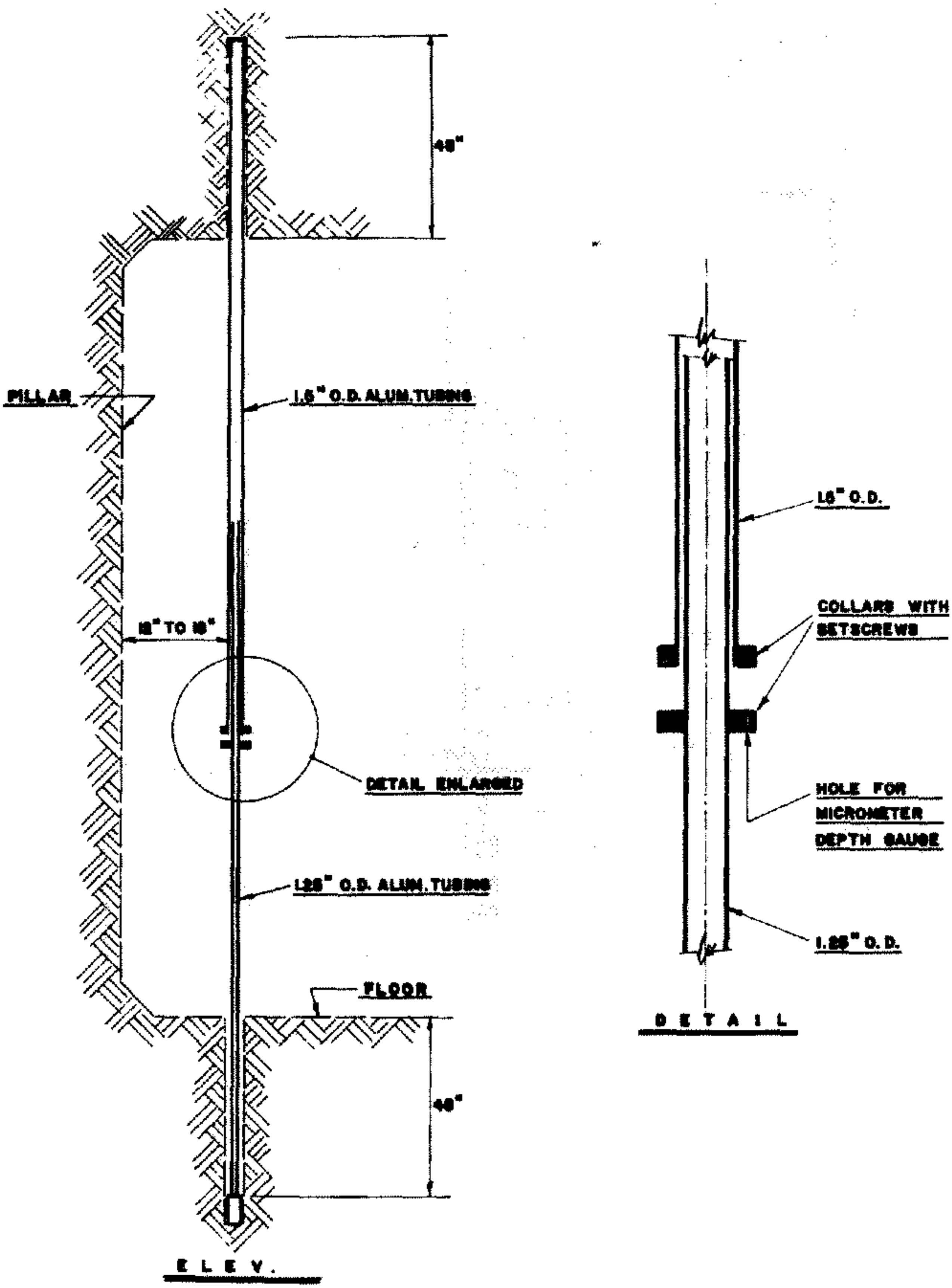
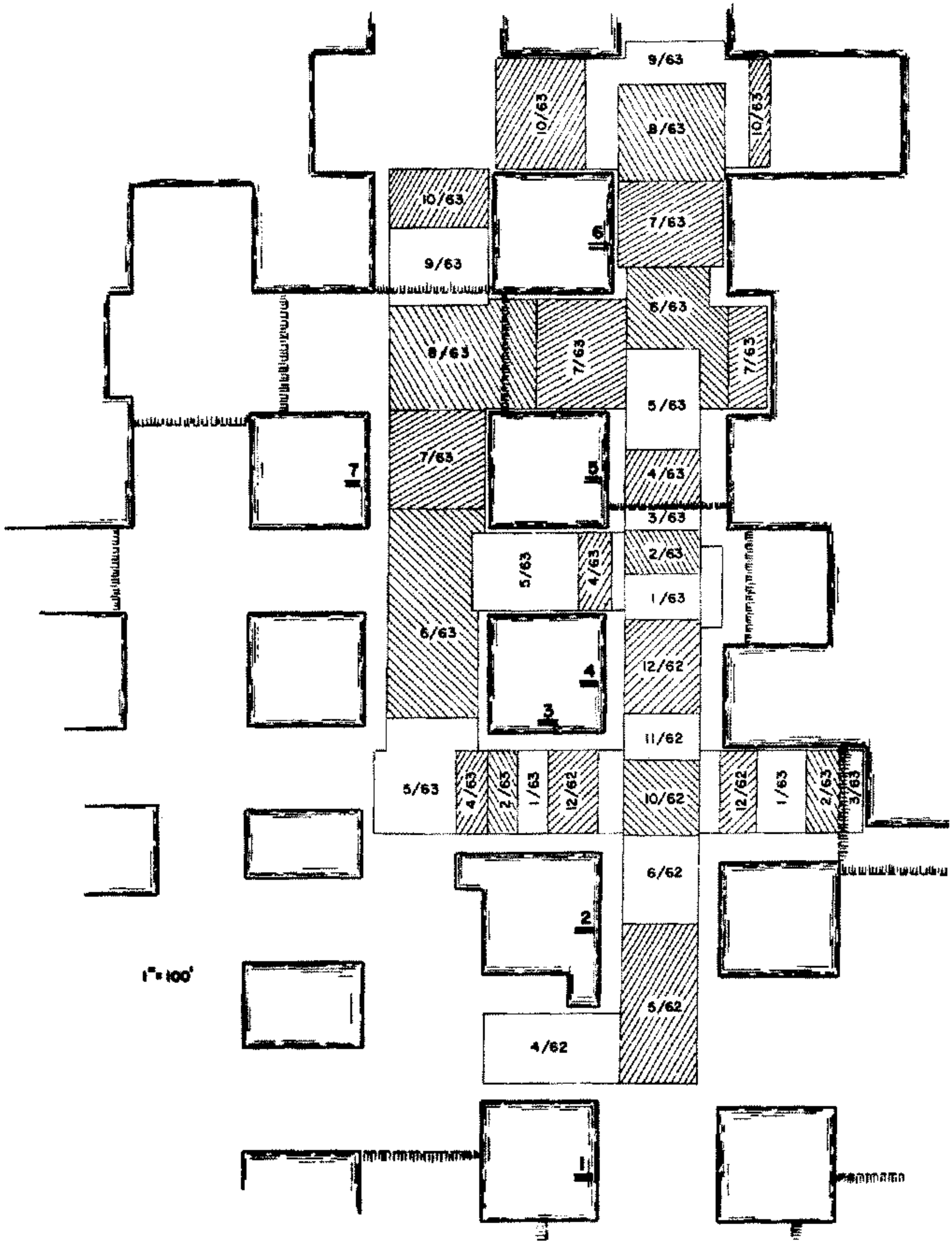

48"
PILLAR
1.5" O.D. ALUM. TUBING
12" TO 18"
DETAIL ENLARGED
1.25" O.D. ALUM. TUBING
FLOOR
48"
ELEV.
1.5" O.D.
COLLARS WITH
SETSCREWS
HOLE FOR
MICROMETER
DEPTH GAUGE
1.25" O.D.
DETAIL

Figure 4


9/63
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2/63
1/63
12/62
10/62
12/62
1/63
2/63
3/63
6/62
2
1"=100'
5/62
4/62
1

Figure 5

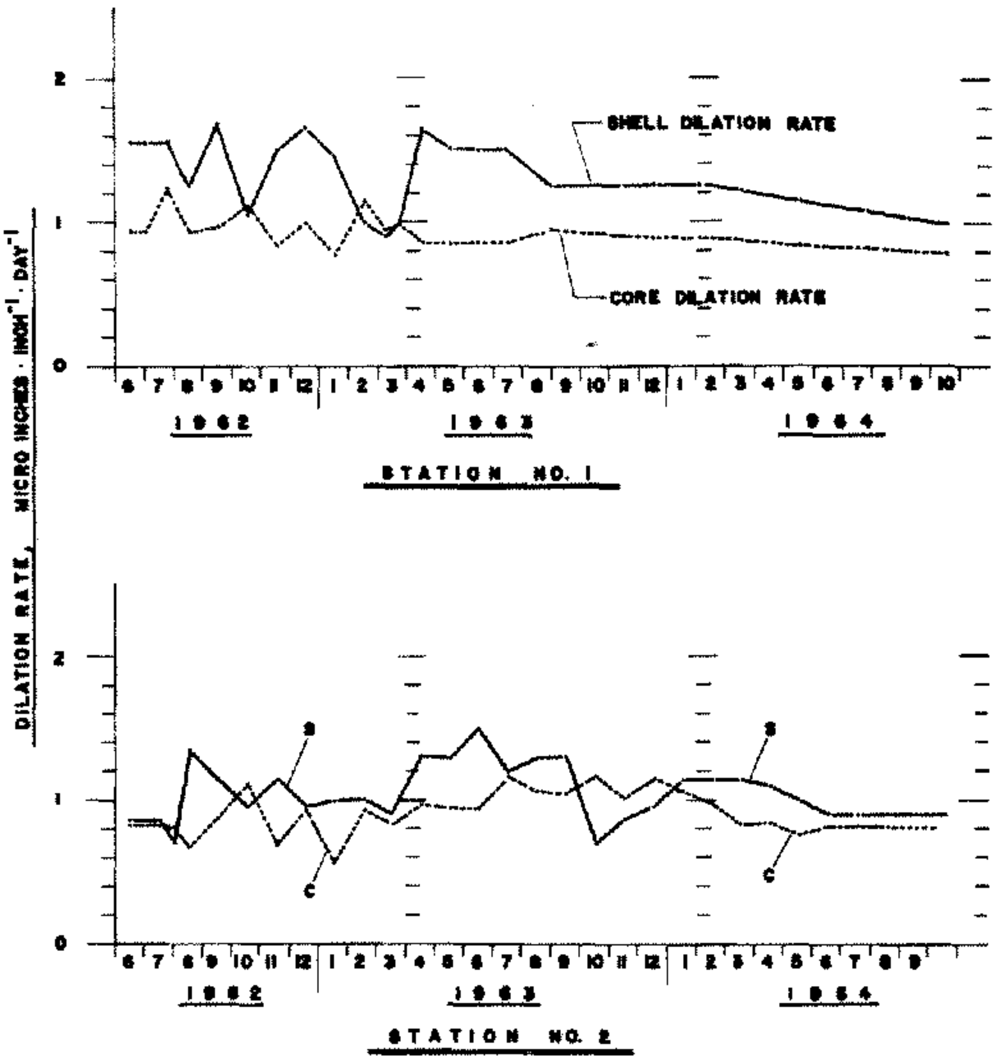


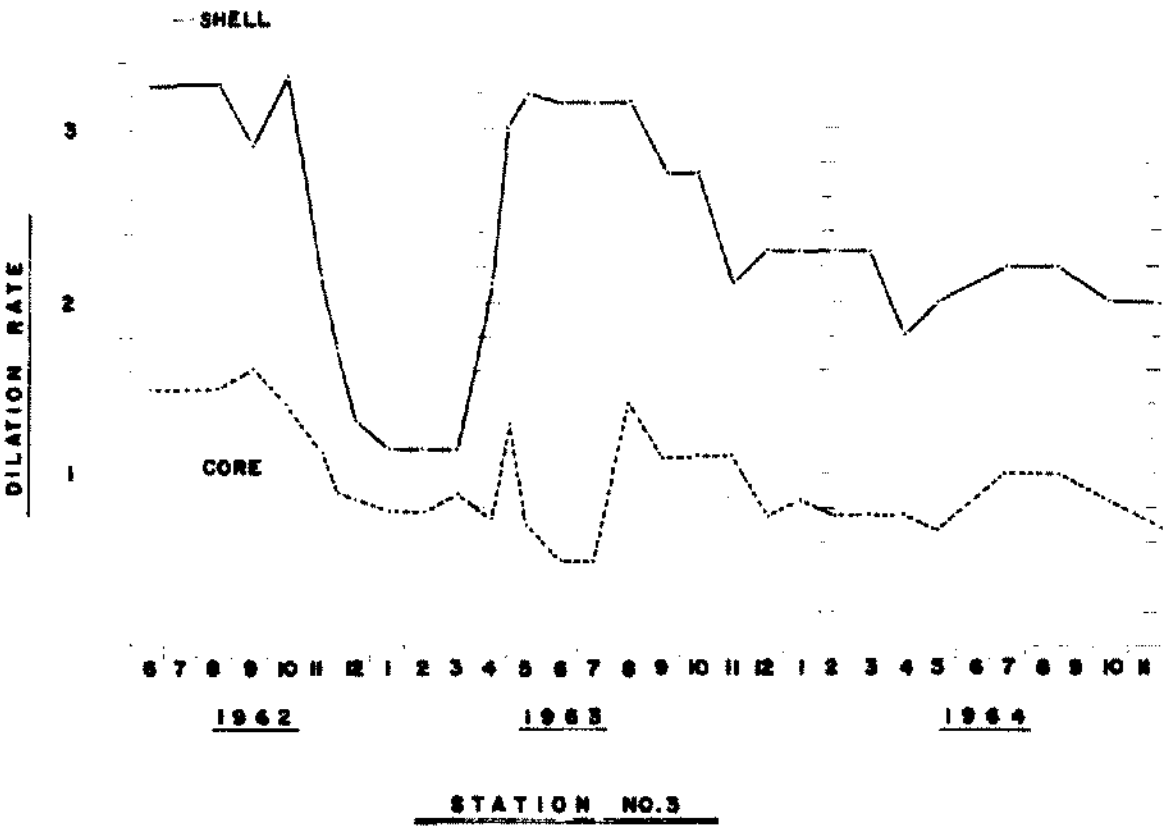
Figure 6-A

Figure 6-B shows the deformation rates at Stations No. 3 and No. 4. It will be observed that the dilation rate dropped sharply after the floor mining activities passed by the pillar. The rate of deformation comes back sharply to its previous level as the floor mining has surrounded the pillar completely.

Figure 6-C illustrates the deformation rate at Station No. 5. Again we see that the rate of dilation of the pillar reaches a minimum just as the floor mining passes by the station, followed by an upswing as mining is completed all around the pillar. Dilation measurements at Station No. 6 are not shown here. The deformation rates at Stations No. 5 and No. 6 are very similar except that the ups and downs at Station No. 6 are not as radical. Both stations show a double peak of shell dilation rate curve, but only one peak of the pillar core dilation rate.

The reason why the dilation rates at Station No. 5 are so violent, as are recorded, is probably due to the fact that this station is located directly under the transition point where the room height changes from 130 feet to 60 feet, resulting in an abnormal concentration of stresses.

In Fig. 7 the plan of a small segment of one of our mines is depicted. A surveying error caused one pillar to become exceedingly narrow. A decision was made to place dilation pins in this pillar so as to be forewarned of a complete crushing action. One five-foot pin was placed in the thin edge of the pillar perpendicular to its long axis, and two dilation pins, five feet and ten feet long, in a direction perpendicular to its short axis. They were set approximately two months


SHELL
CORE
DILATION RATE
3
2
1
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11
1962
1963
1964
STATION NO.3

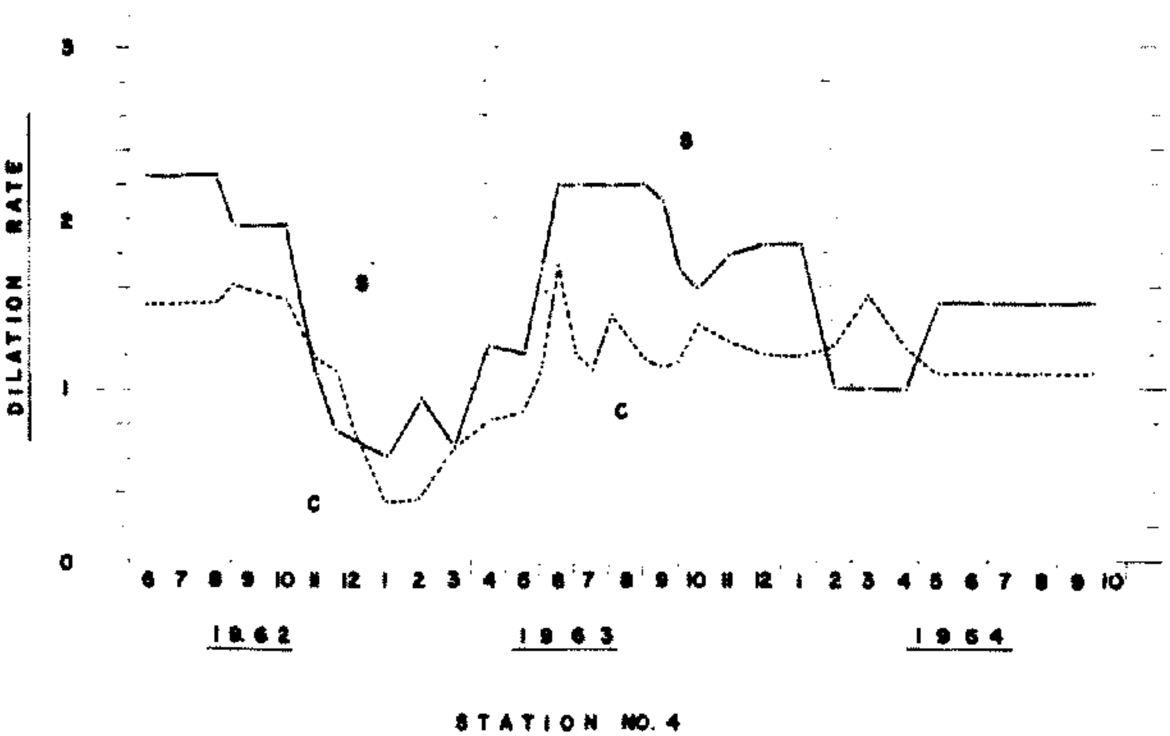

DILATION RATE
3
2
1
0
S
C
S
C
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1962
1963
1964
STATION NO. 4

Figure 6-B

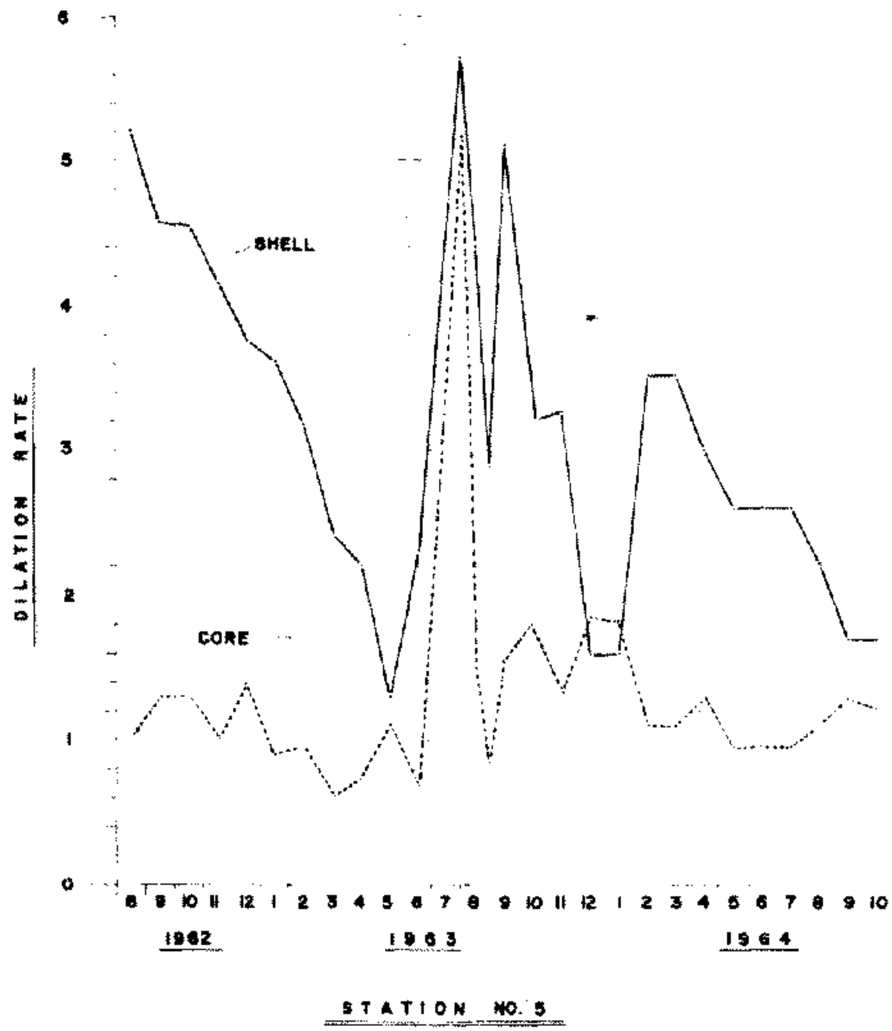


Figure 6-C

after the pillar was created. After another two months, it was found necessary to use the entire area as a space for waste rock from the excavation of our new underground preparation station. This would make the dilation pins inaccessible so they were fitted with displacement transducers in the manner previously described. One dummy transducer was placed in the same area to check the continued reliability of the readings. The measurements were made from a distance of 500 feet.

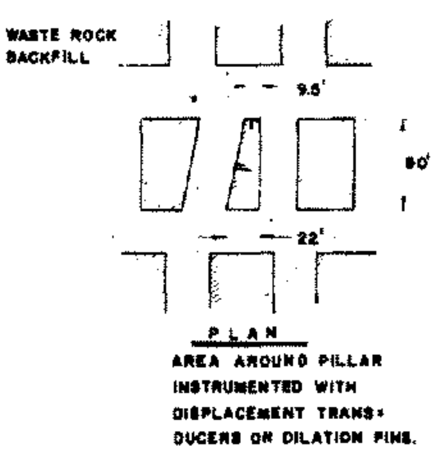


Figure 7

The dilation of this pillar is depicted in Fig. 8. Comparisons of the shell dilation rates show that the movement along the short axis of the pillar is about twice as fast as the rate in the direction of the long axis. This shows, speaking in exaggerated terms, that the pillar has a tendency to split along its longitudinal axis. We are not certain as to whether or not the similarity of the core dilation rate and that of the pillar edge, is a coincidence. Since the dilation rates settled to acceptable values in both the core and the shell, we concluded that the pillar would not split or crush, but rather continue to deform plastically.

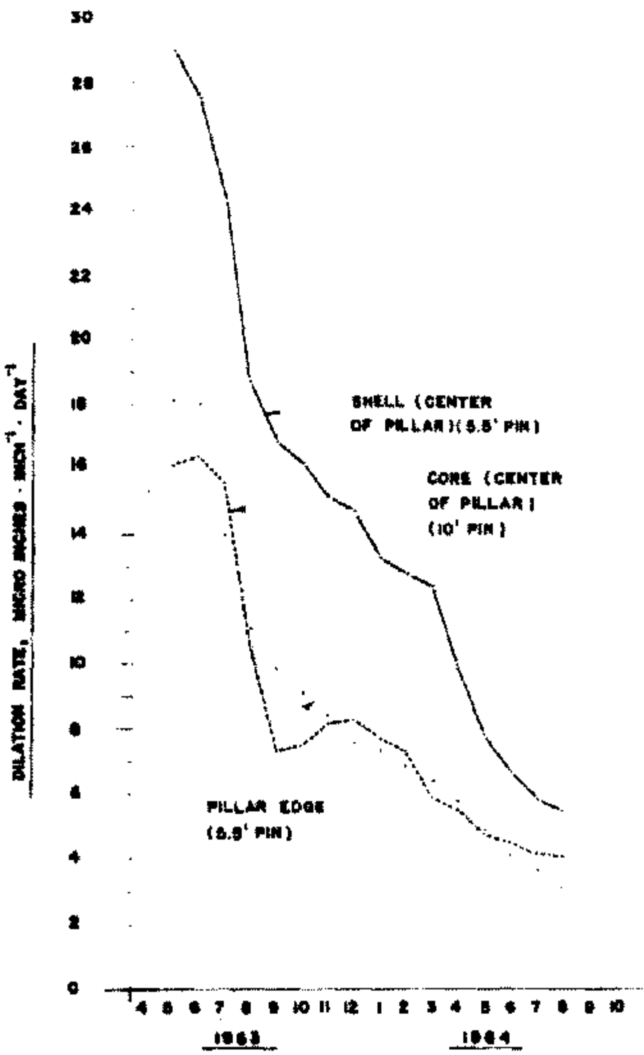


Figure 8

The plan of another of our mines is illustrated in Fig. 9. The convergence gauges at Stations E through J were set approximately two and one half months after the pillars were created. Since then, most of the mining was accomplished to the right of Station E, and only minor volumes were extracted above Stations E and F. The sketch shows a section through the room with the row of stations.

Figure 10 shows the section through the room with the observation stations. Above that section we plotted the convergence in terms of microinches per inch per day. For the first 28 days of observation, we measured an average convergence of almost 80 microinches per inch per day at Station E; during the following 78 days, the convergence settled down to an average of 38 microinches per inch per day, and again less in subsequent periods. Unfortunately, it was not possible to take measurements in equal periods of time. Noteworthy is the relationship between the location of the stations and the indicated shortening of the pillars. There is an almost perfect linear relationship. If one extends the graph to the left of Station J, one notes that the lines intersect the datum line at or around a point 280 feet inside virgin ground. From this we draw the tentative conclusion that from that distance on the ground remains unstressed by mining activities. As we go from Station G in direction of Station E, we note that the linear relation is disturbed, and the convergence at Station E disproportionally larger. This may be explained by the fact that mining continued to the right of Station E. We also note that, as mining activities moved away from

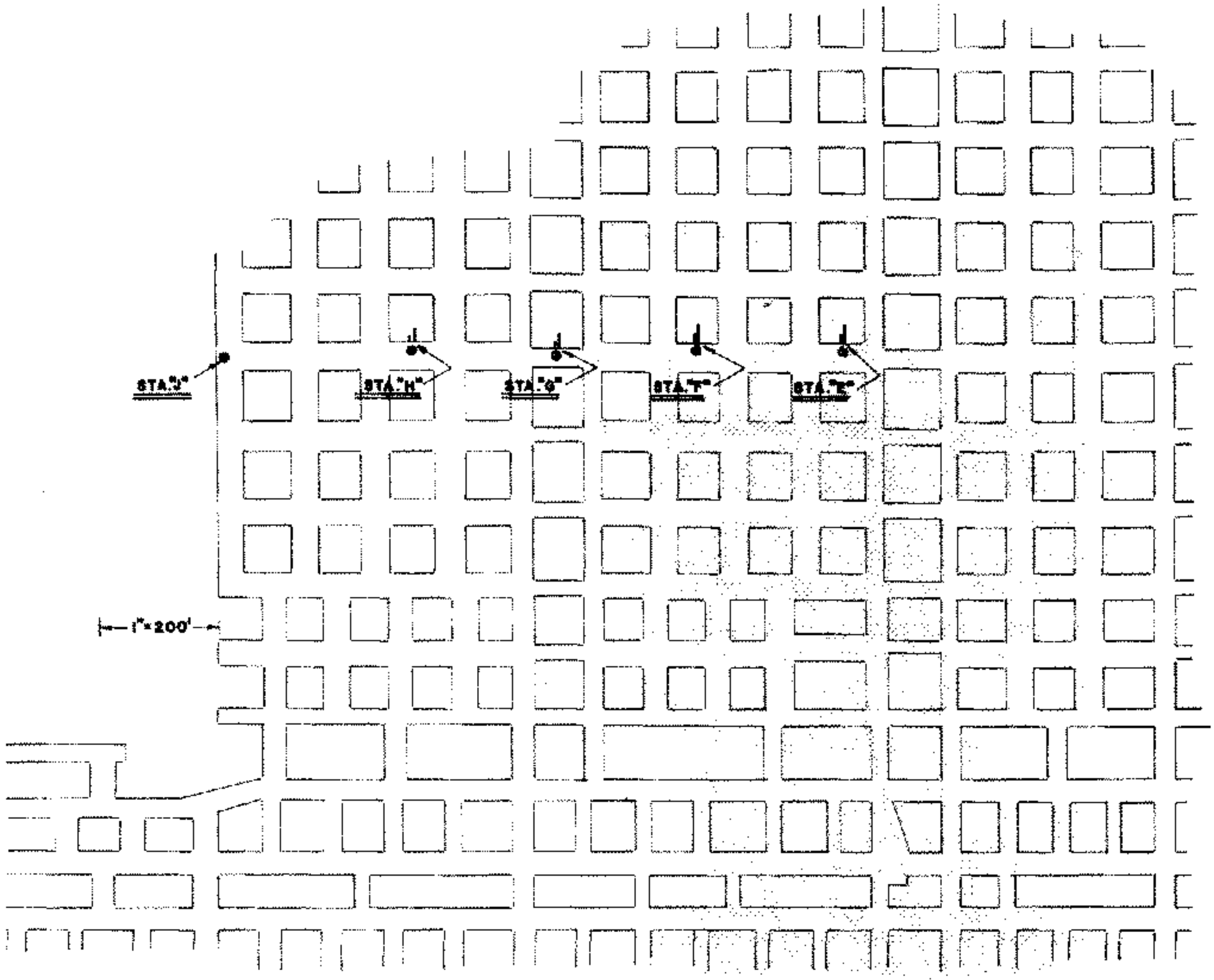


Figure 9

ation E, the cause for this stronger convergence is removed, and the convergence rate seems, time, to come back to its anticipated relationship with the other stations.

Photoelastic model tests done in the past indicate that two mine openings side by side create eater stress concentrations in the surrounding ground than just one opening; three openings, side side, create still greater stresses. But the increase in pillar stress becomes insignificant as e number of openings, side by side, goes beyond five or six. However, from the data shown re, and from data from other mines, we were compelled to conclude that the number of rooms de by side has a much larger influence than indicated by photoelastic model tests. In other ords, a certain extraction rate, and a certain pillar size may be all right for a small mining nel, but may not be safe for a large mining area, unless large barrier pillars are left between ining panels.

From the presented material and similar data we have accumulated, we conclude that both nvergence rate and dilation rate measurements are useful, and can give a meaningful description the structural behavior of a mine. Where data indicated that remedial action was or might be cessary in the future, changes were instituted in our mining plans. In some cases, these anges constituted reduction in the percentage of extraction; construction of barrier pillars; in-eases in the size of pillars or alteration of the mining pattern.

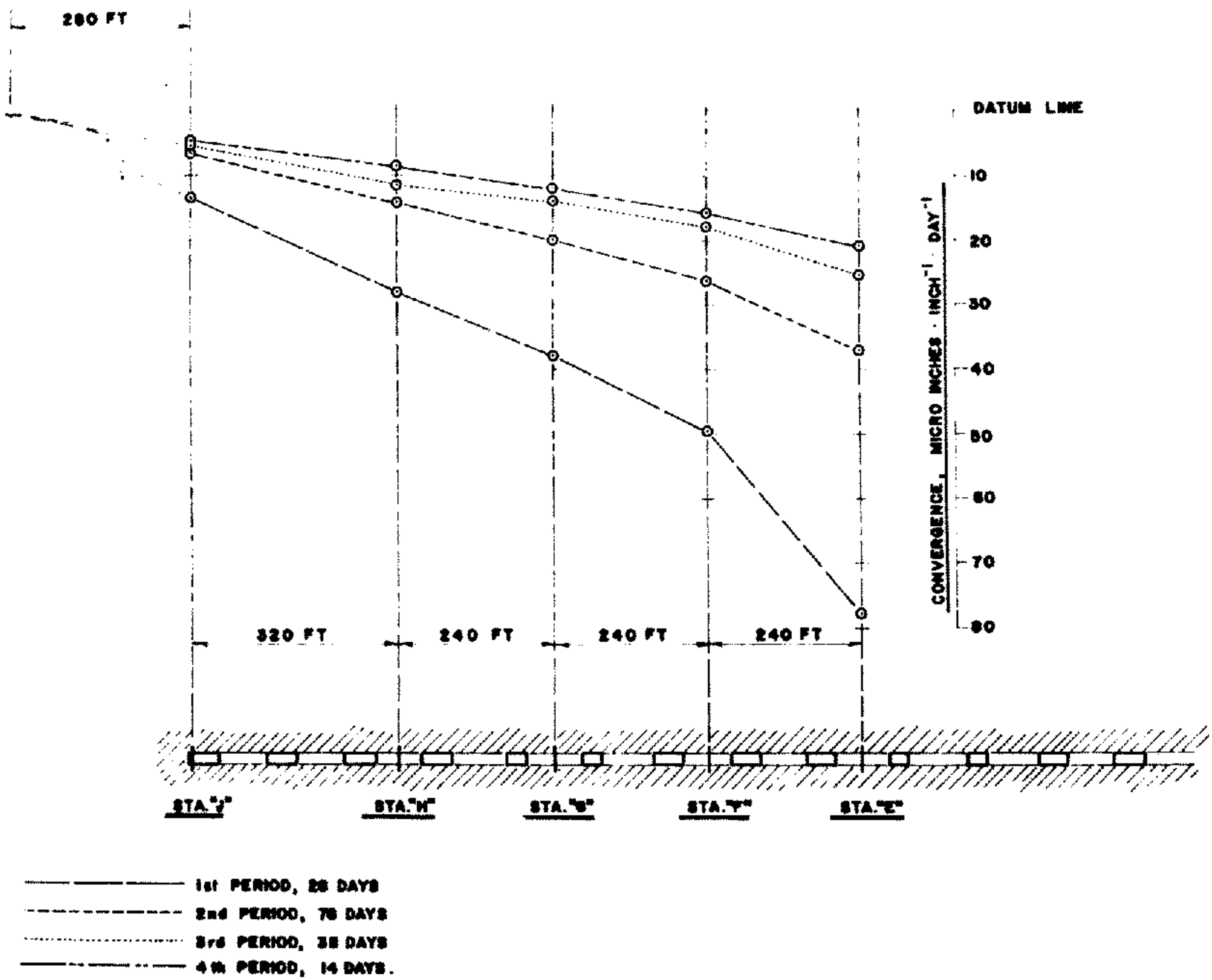

280 FT
DATUM LINE
CONVERGENCE, MICRO INCHES · INCH^{-1} · DAY^{-1}
10
20
30
40
50
60
70
80
320 FT
240 FT
240 FT
240 FT
STA."H"
STA."F"
STA."E"
1st PERIOD, DAYS
2nd PERIOD, DAYS
3rd PERIOD, DAYS
4th PERIOD, 14 DAYS.

Figure 10