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COMPLETE LOAD HISTORY OF ROOF BOLTS IN AN UNDERGROUND COAL MINE

Syd S. Peng
College of Mineral and Energy Resources
West Virginia University
Morgantown, West Virginia

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INTRODUCTION

The key design parameters of roof bolting using expansion - shell type support for underground coal mine roof support are bolt length, bolt spacing, installed load and anchorage capacity. Depending on the utilization of suspension effect or friction effect, the bolt length is dictated either by the distance between the roof surface and the first overlying strong strata encountered or the desired magnitude of reduction in bending stress at the roof surface. The current prevailing practices about the bolt spacing and installed load are that an initial torque of 125 - 170 ft-lbs is applied and the bolts are spaced at 4- or 5- ft. square grid pattern. This seems to be a rather broad generalization in view of the great geological variances which are expected in underground coal mines.

A modest evaluation program to measure the effectiveness of current roof bolting practices is to monitor the load history of roof bolts during a complete mining cycle including the phases of room development and pillar robbing. The load history, when compared with the anchorage capacity of roof bolts determined by in-situ pull tests, will provide information for evaluating the installed load, the bolt spacing as well as the specifications for structural and anchorage characteristics of the bolt assemblies.

This paper presents a case history of monitoring the complete load histories of roof bolts in an underground coal mine of Pittsburgh seam.

The bolt load measuring device is a column type load cell as shown in Fig. 1. It consists of a hollow cylindrical column, 4 inches in diameter by 4 inches long. Four electrical resistance strain gages were mounted in the inner surface and wired to form a wheatstone bridge. An 1-in. hole was made in diametral direction for installing roof bolts. The surface at one end of this hole was machined flat to accept the 1 1/2-in. square bolt head for tight fit. The two leadwires from the four strain gages arranged in full wheatstone bridge inside the load cell were connected to the plugs located at the ends of a crossbar which was glued to one end of the load cell. Reading of the load cells were taken by connecting a portable strain indicator to these plugs. The end surfaces of the load cell was sealed with expozy for waterproofing.

Each load cell was calibrated in the laboratory prior to field installation. Load cells were placed in a universal testing machine and loaded compressively in the diametral direction parallel to the direction of bolt axis when installed. All load cells tested showed linear output up to 25,000 lbs. applied load. It was also found that loosening and tightening of leadwires during each load cell reading could cause an error of 65 lbs. at the maximum and approximately 25 lbs. on the average. This was considered insignificant when compared to the load histories and differences in load experienced by each load cell.

TEST AREA AND PROCEDURES

Conventional room-and-pillar mining method was used in the test area to extract coal of the Pittsburgh seam. The coal seam in the test area was 6-8 ft. thick. Its immediate roof was a weak and extremely friable draw slate of 5 ft. thick on the average. The draw slate was overlain by a layer of firm dark shale, roughly 1 ft. thick. Pillars were rectangular in shape and laid out on 60-ft. center between entries and 80-ft. center between crosscuts. Entries and crosscuts were 14 ft. wide.

The test area was an entry covering the full distance between two adjacent crosscuts and including an intersection. Fig. 2 showed the complete mining sequence and the location of test area. Roof bolts used were expansion-shell type, 3/4 inch in diameter and 6 ft. long. They were installed at approximately 3.5 ft. square grid pattern. Accordingly, 3 bolts were in a row and a total of 54 bolts were installed in the test area as shown in Fig. 3 A. During installation, the load cell was inserted between the bolt head and a bearing plate of 6-in. square. With the exception of bolt #28 to #33 all bolts were tightened by a torque wrench to 125 ft.-lb., or approximately 4800 lbs. of load. Bolt #28 to #33 were installed at various initial loads ranging from 685 to 5754 lbs. in order to evaluate the effect of initial load. Thirty nine of these instrumented roof bolts (bolt #1 to #39) were located between the pillars (Fig. 3 A) while the other fifteen (bolt #40 to #54) were at or near the intersection.

Anchorage capacity of same roof bolts installed at different initial torques was previously determined by in-situ pull test in the same panel (1). The anchorage capacity for the roof bolt installed at 125 ft.-lb. torque was approximately 22,000 lbs.

All of the roof bolts in the test area were installed in accordance with the mine practice for room development except that all bolts were hand-tightened with torque wrench. The change in roof bolt loads was monitored throughout a period of 39 days during which a complete mining cycle was experienced by the test area. The first day of the test period was defined as the day the first instrumented roof bolt was installed. Installation of the 54 instrumented roof bolts took the first five days including a two-day weekend. First reading (excluding zero reading at installation) of bolt loads was taken on the 8th day when the working face was approximately one intersection away from the test area. Development of the whole mining panel was completed on the 15th day and pillar mining was started on the 18th day. As the gobline came closer to the instrumented test area bolt load readings were taken more frequently (as often as 3 readings per day). Fig. 2 showed the highlight of the mining sequence while Fig. 3 B indicated the exact position of goblines within the test area during the last four days of the testing period.

TEST RESULTS

Fig. 4 and 5 show the complete load history of the 54 bolts. The general trend of load change is similar for all of them and can be divided into four distinct periods. Furthermore the difference in magnitude of load change suggests two groups of bolt behavior: Those between the pillars (bolt #1 to #39) and those at or near intersection (bolt #40 to #54).

<u>1st period</u> (1st to 8th day)

Seventy six (76) percents of the bolts showed bolt loads dropped during the first 8 days. The minimum reduction was 70 lbs. and the maximum was 2880 lbs. with an average of 850 lbs. The remaining 24%

showed increased loads during the same period. The minimum increase was 70 lbs. and the maximum was 2060 lbs. with an average of 950 lbs. Among those bolts which experienced load increase during this period, more than one half were installed initially at less than 4800 lbs. The load increase ranged from 500 to 2060 lbs. with an average of 1370 lbs.

2nd period (9th to 12th day)

The bolt loads began to increase at the 9th day and reached the maximum at the 12th day.

3rd period (13th to 35th day).

The bolt loads either stabilized at the maximum values attained during the 2nd period (especially for those bolts at or near the intersection) or gradually increased, or decreased at a slow rate. Two periods of rapid load change were observed: one between the 25th and 29th days and the other between the 34th and 36th days. The first one involved a rapid load reduction (ranging from 50 to 375 lbs. with an average of 167 lbs.) while the second one was a rapid load increase (ranging from 30 to 300 lbs. with an average of 170 lbs.)

4th period (36th to 39th day)

The roof bolts were in the 4th period when the gobline moved to a distance approximately from 10 to 12 ft. from the bolts. It was characterized by the bolt loads either increased or decreased rapidly depending on the fracture characteristics of the bolted roof. The maximum load increase was experienced by bolt #12 which reached 21,166 lbs. The average load for the bolts located between the pillars was 7400 lbs. when the bolted roof approached failure. Unfortunately at the time when gobline approached the instrumented intersection, the second rapid load increase occurred and obscured the results for roof bolts installed at or near intersection.

DISCUSSION AND CONCLUSIONS

Load histories of roof bolts as shown in Figs. 5 and 6 indicated that a definite trend existed and that it could be divided into four distinctive periods.

Majority of the bolts experienced load loss during the first period. This probably was due to the readjustment of expansion shell against the wall of drill hole at the anchor point. It was likely that during installation the downward movement of expansion shell due to the pulling of 4800 lbs. installed load cuased fracture in the wall rock which would certainly induce time-dependent deformation and thus load loss (2). Bolts that underwent load increase during the first period were those installed at the corners of the intersection (bolt #40, 42, and 54) or those with initial installed load ranging from 685 to 3425 obs. (bolts #28 to #32).

Once the loads reached the stabilized values at the 12th day, they were either insensitive to the mining activities or changed (either increased or decreased) slightly until rapid load change occurred in the fourth period. Surprisingly, those bolts at or near the intersection maintained their stabilized load well until the roof failed.

On the average, the maximum stabilized load during the third period for those installed at or near the intersection was 6570 lbs., approximately 1780 lbs. above the installed load. The maximum stabilized load for those at or near the intersection was expected, because the roof span at intersection was larger than that between pillars and consequently the larger sagging of immediate roof caused the higher stabilized load. Another general trend was that the maximum stabilized load was larger

(6340 lbs.) for bolts installed at mid-span between pillars and smaller (4790 lbs.) for riblines. This was also expected since the roof deflected more at mid-span than at both sides of the riblines. For those bolts at or near the intersection the average maximum stabilized load was about the same (6500 lbs.) at mid-span and along riblines. However, the loads of four bolts (#40, 42, 52 and 54) anchored around the four corners of the intersection increased immediately and continuously after installation and reached their maximum stabilized load at 6900 lbs. which was higher than the average of the bolts at or near the intersection.

Two rapid load jumps, a load reduction (from 35th to 29th day) and load increase (from 34th to 37th days), occurred in the third period. In each case the load returned to more or less the same value as it was before the jump. Sudden load increase could be due to rapid downward bending of bolted roof whereas sudden load reduction the rapid upward bending. This type of vibrational behavior of roof might be caused by certain sequential operation of pillar robbing.

Although the general trend of complete load history was similar for all bolts monitored, the magnitude of load change from the average installed load of 4800 lbs. differed from each other. Larger differences occurred for the bolts between pillars whereas differences among the bolts at or near intersection were much smaller. An attempt to correlate the magnitude of load change with the exact grid area covered by each bolt failed to produce any meaningful results.

Except the continued load increase observed during the first period, he load history of the bolts installed at various loads resembled those nstalled at 4800 lbs. It was surprising that bolt #28 and #30 which was nitially installed at 960 and 680 lbs. survived the whole mining cycle just like the others. However, the load increase from the installed load to maximum stabilized load for the bolts installed at various loads was much larger than that for those installed at 4800 lbs. (2080 lbs. vs. 500 lbs. on the average). The continued increase of load during the first period indicated the bolts were taking load immediately. Lack of load loss for the bolts installed at lower initial loads in the first period might be an indication of the installed load being adequate, and that no fracture-induced time-dependent deformation occurred. Their average maximum stabilized load was 4760 lbs., which was 540 lbs. below that of the bolts installed at 4800 lbs. Unfortunately, the second load jump occurred between 34th and 37th days coincided with the time when the gobline moved in and thus the exact load in fourth period was not clear for this group of bolts.

Another interesting result was that of bolt #33 which was installed at 5800 lbs., about 1000 lbs. above the average installed load. The installed load was maintained well throughout the entire roof bolt life until roof failure occurred. It seemed, therefore, that all the bolts could be installed at a load far below 4800 lbs. and would still be expected to perform satisfactorily.

The in-situ anchorage capacity tests performed earlier indicated that roof bolts installed at 4800 lbs. (125 ft.-lb.) would resist approximately 11 tons of bolt load before failure of anchorage occurred. The average maximum attainable load observed in this study when the gobline closed in was 8500 lbs. which was far below the 11-ton capacity. With the 6-ft. long roof bolts suspending a weak draw slate of 5 feet thick from the overlying firm shale, the average maximum suspension load (assuming the 5-ft. draw slate could not support itself) for the roof bolts which had been spaced at approximately 4 feet square grid was estimated at 12,000 bs. per bolt - a value about 1 1/2 times the actual average peak load of 500 lbs. per bolt. This means that in fact, the deadweight of the 5-ft. raw slate layer was not totally transferred to the bolts during the com- lete mining cycle, and that the roof bolts had an excessive load capacity. ccordingly, roof bolting pattern currently practiced in this mine is con- idered overdesigned.

ACKNOWLEDGEMENT

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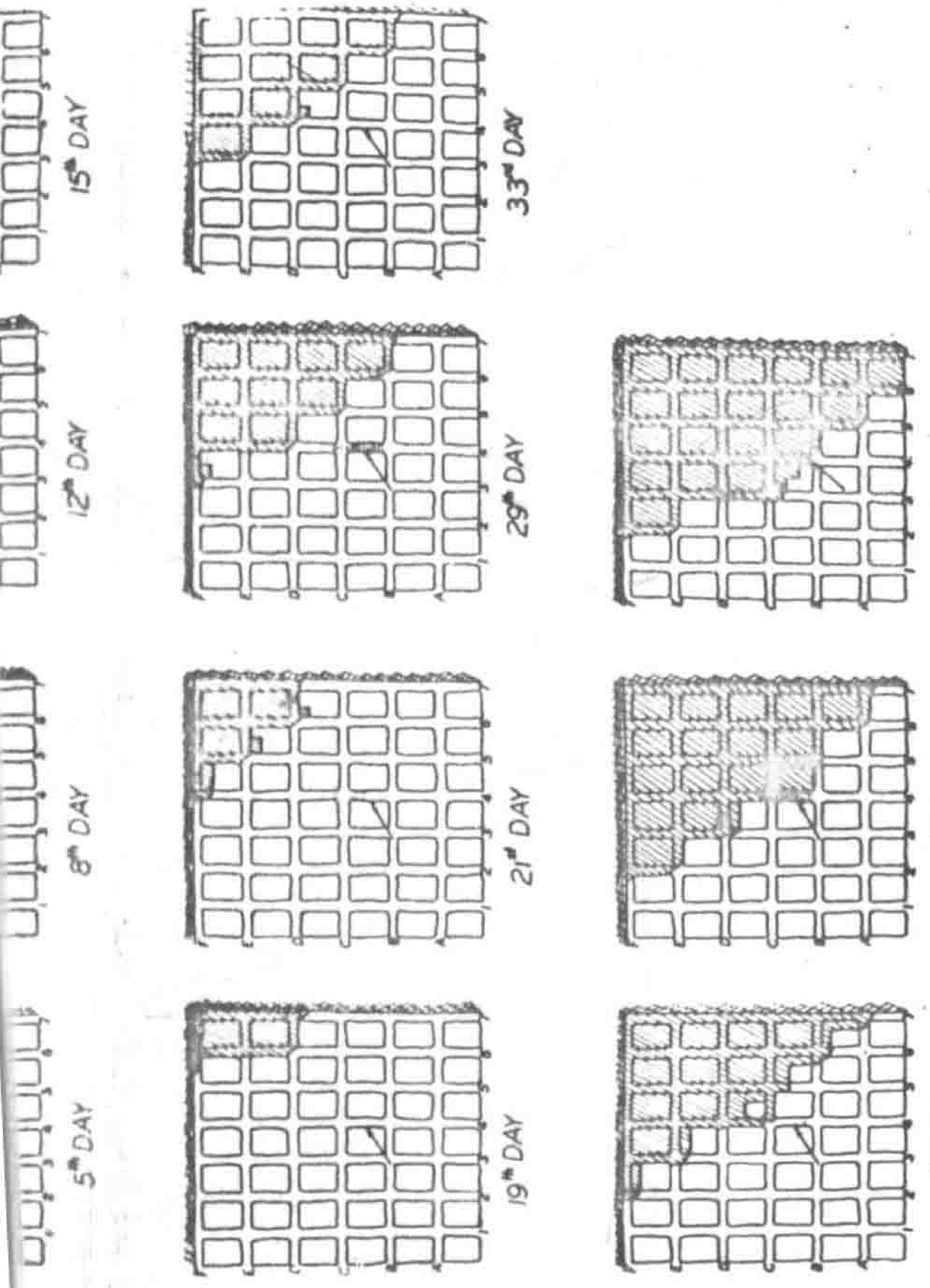
Fig. 1 Load cell



. 2 The mining sequence of the test section

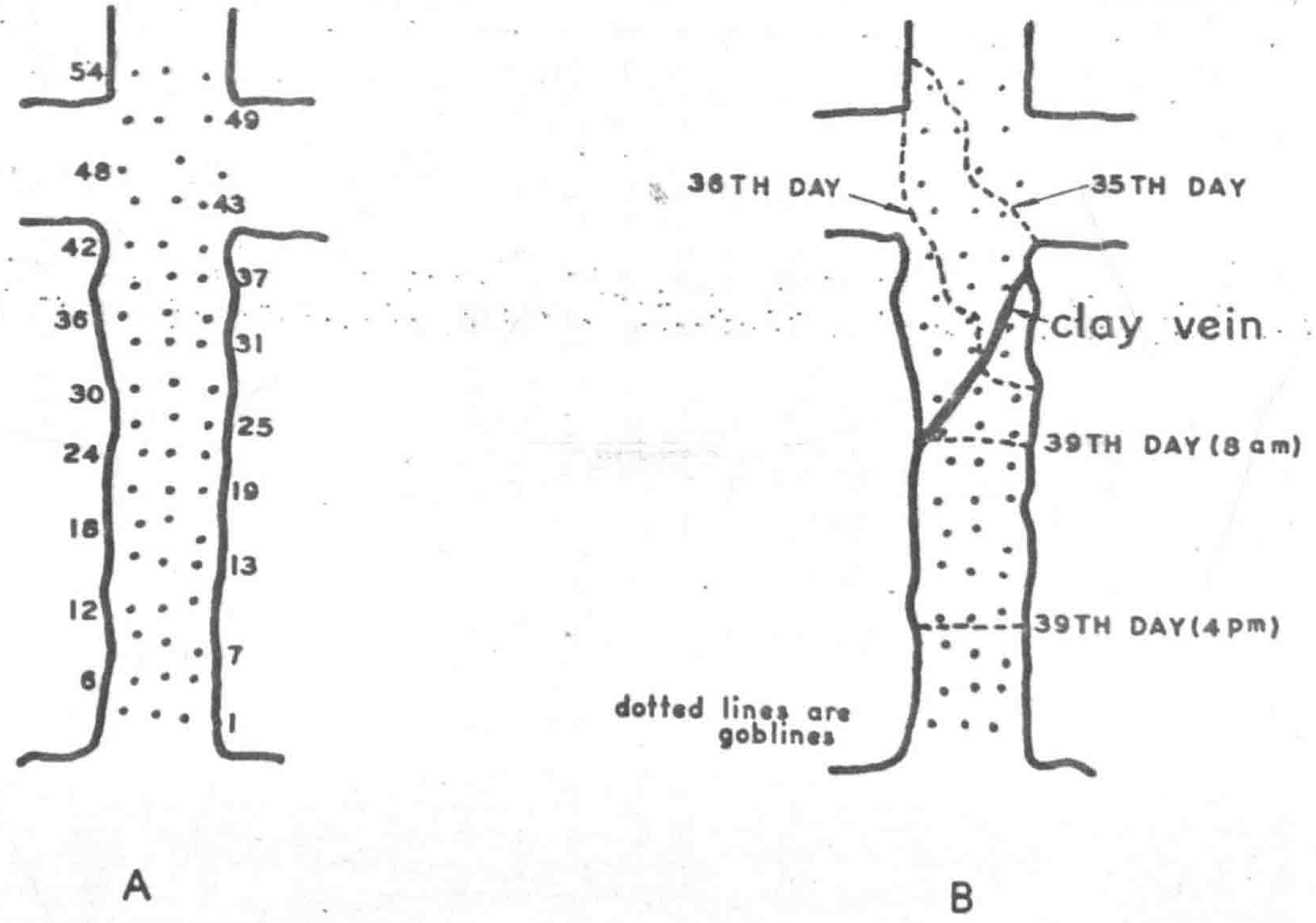
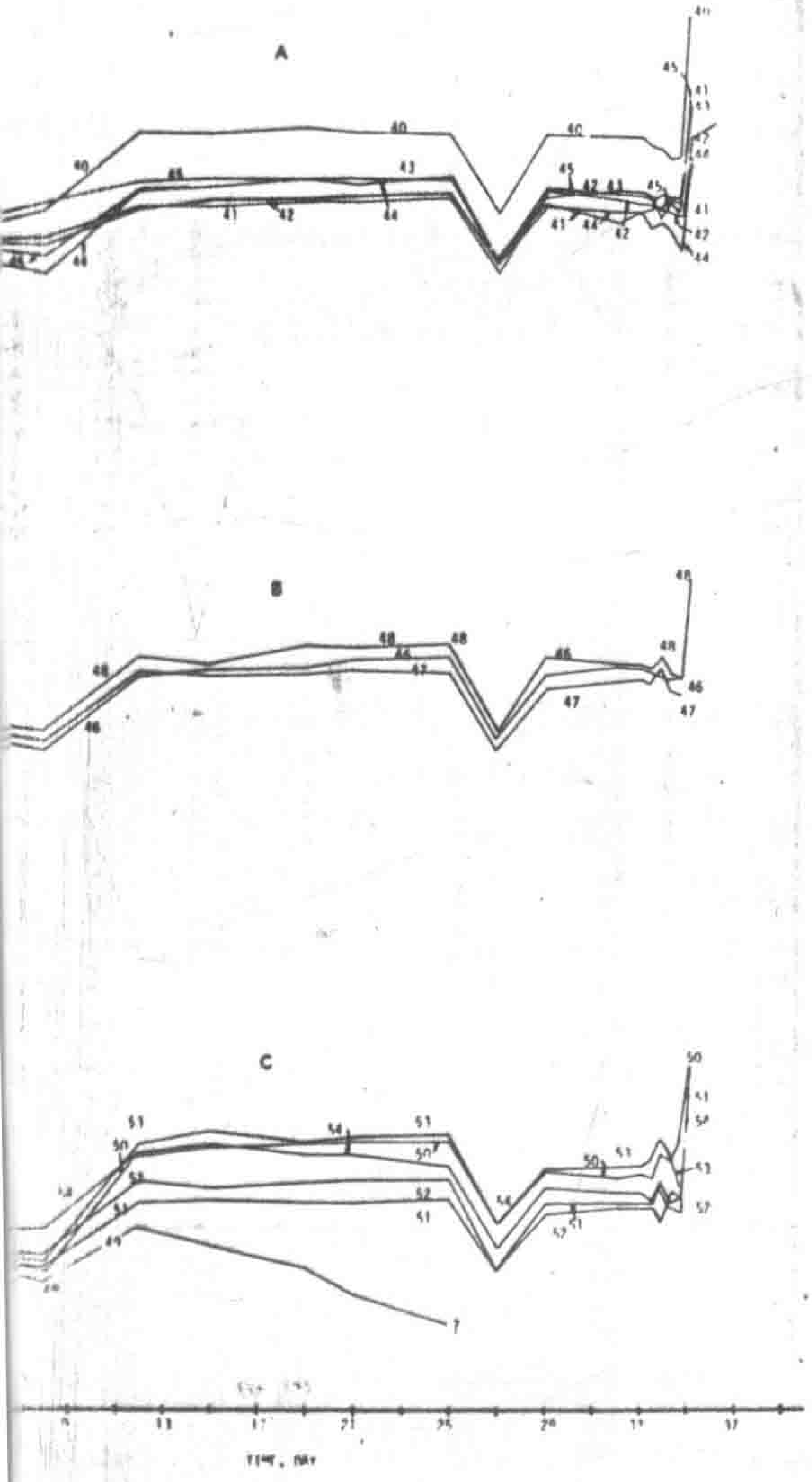


Fig. 3 Detailed arrangement of instrumented roof bolts in the test section



te load history for roof bolts installed between pillars

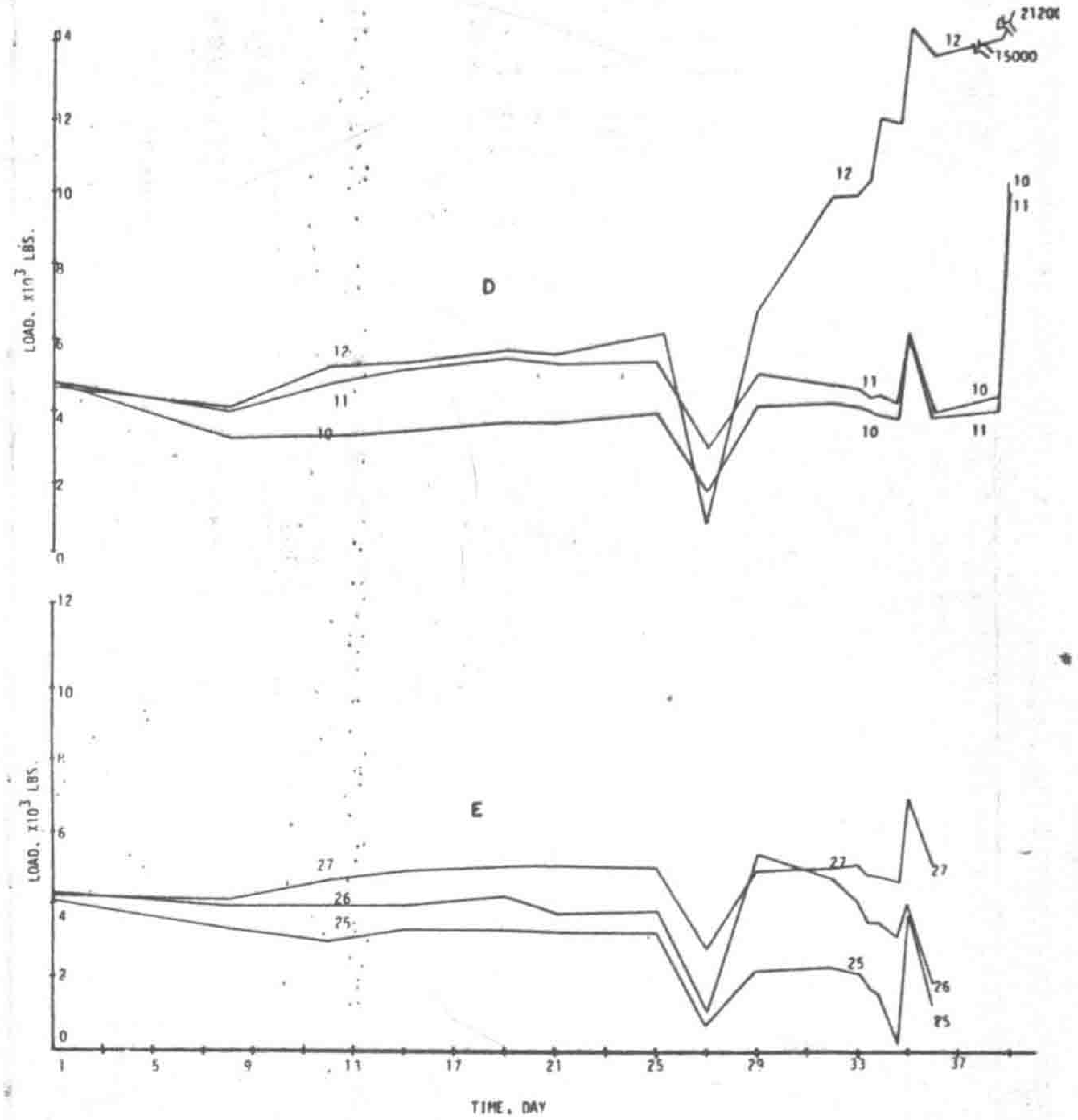
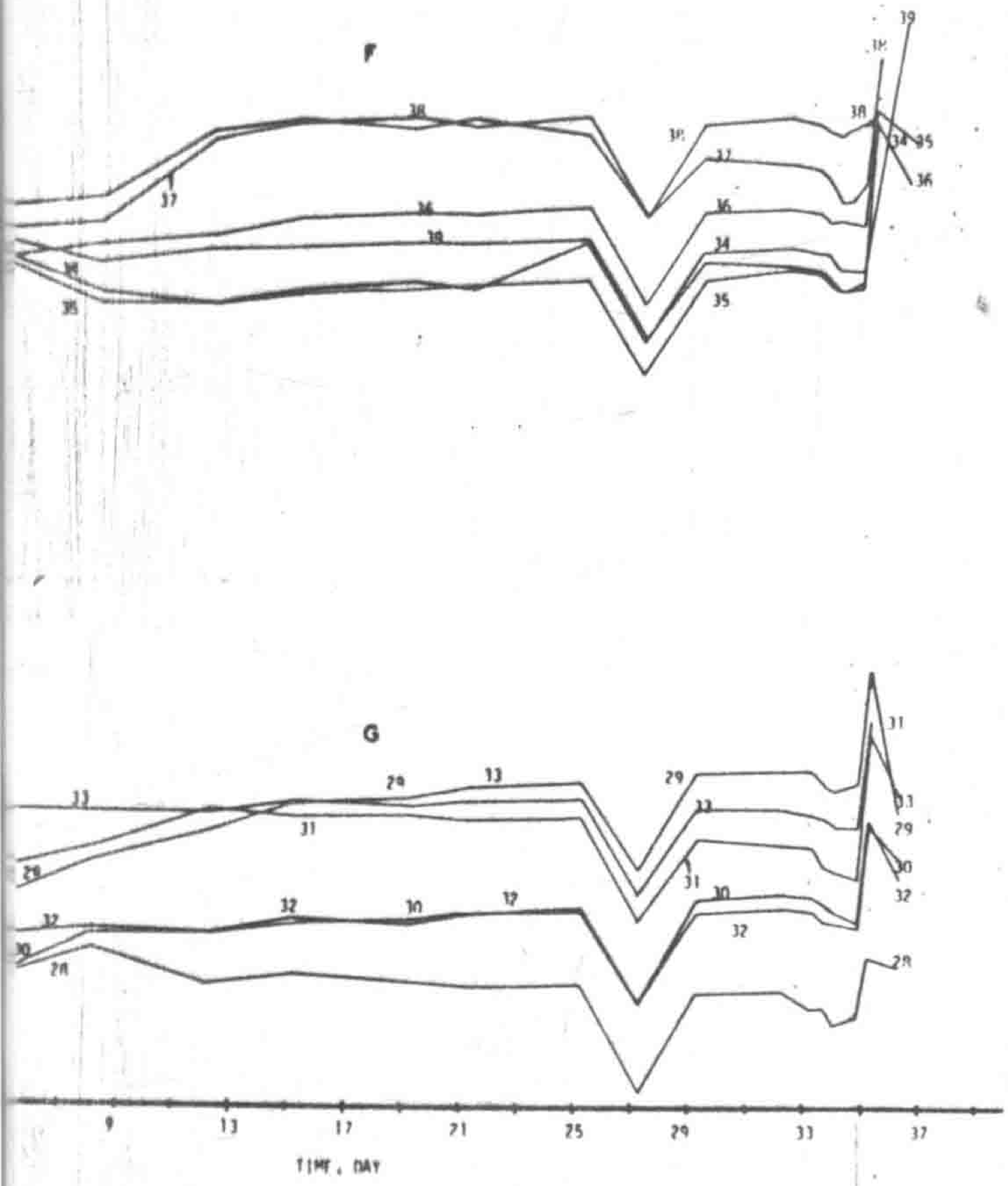


Fig. 4 Complete load history for roof bolts installed between pillars (Continued)



Complete load history for roof bolts installed between pillars (Continued)

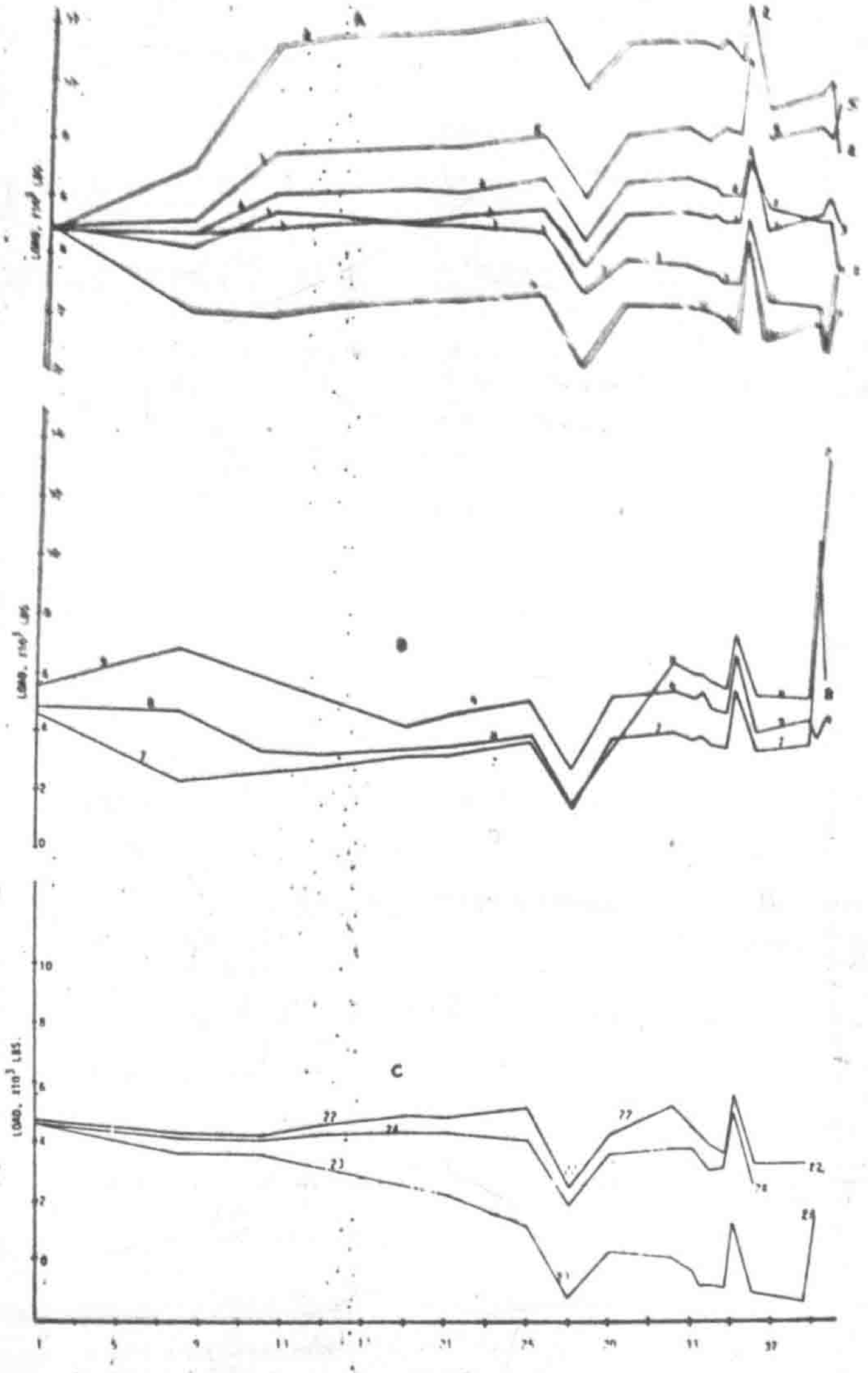


Fig. 5 Complete load history for roof bolts installed at or near intersection