BOLT LOAD CHANGES DURING INITIAL FACE ADVANCE AND CROSS-CUT BREAKTHROUGH

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ABSTRACT

The San Juan Mine and the National Institute for Occupational Safety and Health conducted a study to measure how development mining affected bolt loads. Twelve fully grouted, instrumented roof bolts were installed at two three-way intersections as part of the standard bolting pattern. Newly developed miniature data acquisition systems (MIDAS) were used to measure bolt load changes during initial face advance and cross-cut breakthrough. The effects of cut placement and depth on roof bolt loads were studied.

This test showed how bolt loads increased at five positions along the bolt length during initial mining. Both entry advance and cross-cut breakthrough produced a similar *percentage* of increase in bolt loads. Geologic differences between the test sites were probably responsible for the differences in *amounts* of bolt loading. The test site with more top coal and a higher rock quality designation (RQD) had lower bolt loads.

BACKGROUND

The operator of a continuous miner cannot go inby permanent support. MSHA regulations limited cut depth to 6 m (20 ft) until the development of remote-controlled miners, which permitted cut depth to be extended up to 12 m (40 ft). At this depth, an operator of a shuttle car is just outby the last row of supports. Extended-cut mining began in the 1980's and has become very popular because this method increases productivity. However, not every ground condition is suitable for extended-cut mining. To address safety concerns, studies were done by the U.S. Bureau of Mines and the National Institute for Occupational Safety and Health (NIOSH). Some studies looked at the accidents statistics of extended-cut mining versus cuts of normal depth (Bauer et al., 1993; Grau et al., 1997). Mark (1999) correlated Coal Mine Roof Rating (CMRR), entry width, and overburden to roof standup time and determined that CMRR values less than 38 indicated that extended-cut mining was not feasible. Thus, while this method is excellent as an overall design guideline, it may not be practical where ground conditions are marginal nor address questions about how deep a cut can be taken under various mining conditions.

One way to evaluate site-specific conditions is to monitor roof behavior. Strain-gauged bolts have proven to be invaluable for monitoring bolt loads in many different mine situations. Previous studies at eight different coal mine sites (Signer, 2000) where 92 strain-gauged bolts were installed showed that 75% of the bolts reached the yield point of the steel (0.2% strain) and 50% of the bolts exceeded the yield point. Thus the use of strain-gauged bolts could indicate roof behavior during extended-cut mining. However, this type of instrument has never measured bolt load during mining because attaching a data acquisition system would interfere with mining. It is important to note that loading on a bolt only measures movement in adjacent rock and may not give a complete picture of roof behavior at some distance away.

Researchers at NIOSH have developed a miniature data acquisition system (MIDAS) designed to withstand the harsh environments of underground mines (Sunderman et al., 2003). MIDAS was designed to measure strain from resistive sensors, such as strain-gauged bolts, cable bolts, CSIRO stress-measuring gauges, pressure transducers, and string pots. MIDAS is attached directly to the instruments so no long lead wires are required. Up to 16 monitoring channels can be selected. A 125-kbyte, on-board flash memory can store 2,192 data scans if all 16 channels are read. An on-board clock sets the scan rate for readings in real time and time-stamps each scan. A thermistor records temperature during each data scan, and a RS232/RS485/IRdA port can communicate with any computer.

The low power requirement enables long-term testing. A 9-V battery will provide enough power to take daily readings on all channels and run the light-emitting diode (LED) lights for 6 months. If the battery voltage does run low, the data are still available for downloading. The small size (30.5 mm in diameter by 216 mm long [1.2 by 8.5 in]) makes the MIDAS adaptable for almost any location. Because it is so small and self-contained, it can monitor instruments while a continuous miner is cutting coal. The instrument has an experimental MSHA permissibility approval, which allows monitoring instruments to be operated when methane is present, so the bolts can be monitored during the initial phase of mining.

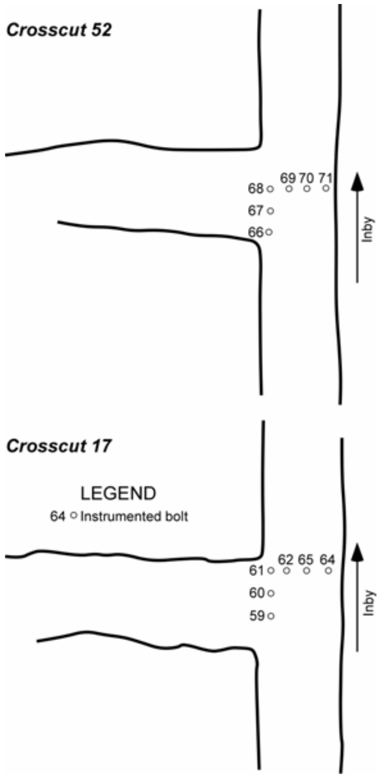

Figure 1.—Test sites

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shown in figure 3. The first cut began on the left side and is marked A. This cut advanced 4.6 m (15 ft), then the miner changed sides to B. This was repeated for cuts C and D, which were advanced approximately 3.6 m (12 ft). E is the time that entry mining was completed. The cross-cut breakthrough is marked F.

TYPES OF BOLT LOADING

Bolt loads can be axial, bending, and/or shear. Axial loading is generally the primary force on a steel bolt, although under some conditions, combinations of axial, bending, and/or shear forces can cause bolt failure. Shear loads are impossible to estimate with this type of instrument because of the nature of the loading mechanisms and the uncertainties of load locations. However, when joint movement is present, shear loading can be critical when designing bolt systems, and additional research is required for a better understanding of this loading mechanism.

A design engineer should consider several factors when calculating bending moments as measured by instrumented bolts. Maximum bending moments can be localized and may not be measured accurately. Bending is measured in only one plane, but can take place in other directions, especially if high horizontal stress fields are present. Bending moments can also be caused by joint movement, large-block rotation, and/or differential loading in mats and meshes.

INSTRUMENTS

The strain-gauged bolts were made by milling a slot 6.4 mm (1/4 in) wide and 3.2 mm (1/8 in) deep and attaching five strain gauges on both sides. The stain gauges were spaced at 406-mm (16-in) intervals from the head of the bolt. After the bolts were slotted, yield load was 149 kN (33,500 lb), ultimate load was 249 kN (55,900 lb), and cross-sectional area was 3.61 cm^2 (0.56 in^2). Prior to slotting, yield load had been 160 kN (36,000 lb), ultimate load 269 kN (60,500 lb), and cross-sectional area 3.87 cm^2 (0.60 in^2). The after-slotting figures represent a reduction in capacity of approximately 7%. Spacing of the instrumented bolts was reduced by 10% to account for the reduced capacity. The bolts were installed in a 35-mm (1-3/8-in) diameter hole using slow-setting resin. During installation, all bolts were oriented with the strain gauges parallel to the entry ribs.

Each strain-gauged roof bolt had a MIDAS unit attached. The MIDAS amplifier gain and frequency response were set to measure over a range of ±562.5 mV (250,000 microstrain) with a resolution of approximately 0.067 mV (0.03 microstrain). Variations in the roof bolts and strain gauges produced more noise than the resolution of the MIDAS, which made it a perfect choice for measuring strain-gauged bolts.

Bolt strain was calculated directly from the voltage readings based on the equation—

$$\epsilon = \frac{4\ \Delta V}{(GF)(EV)}$$

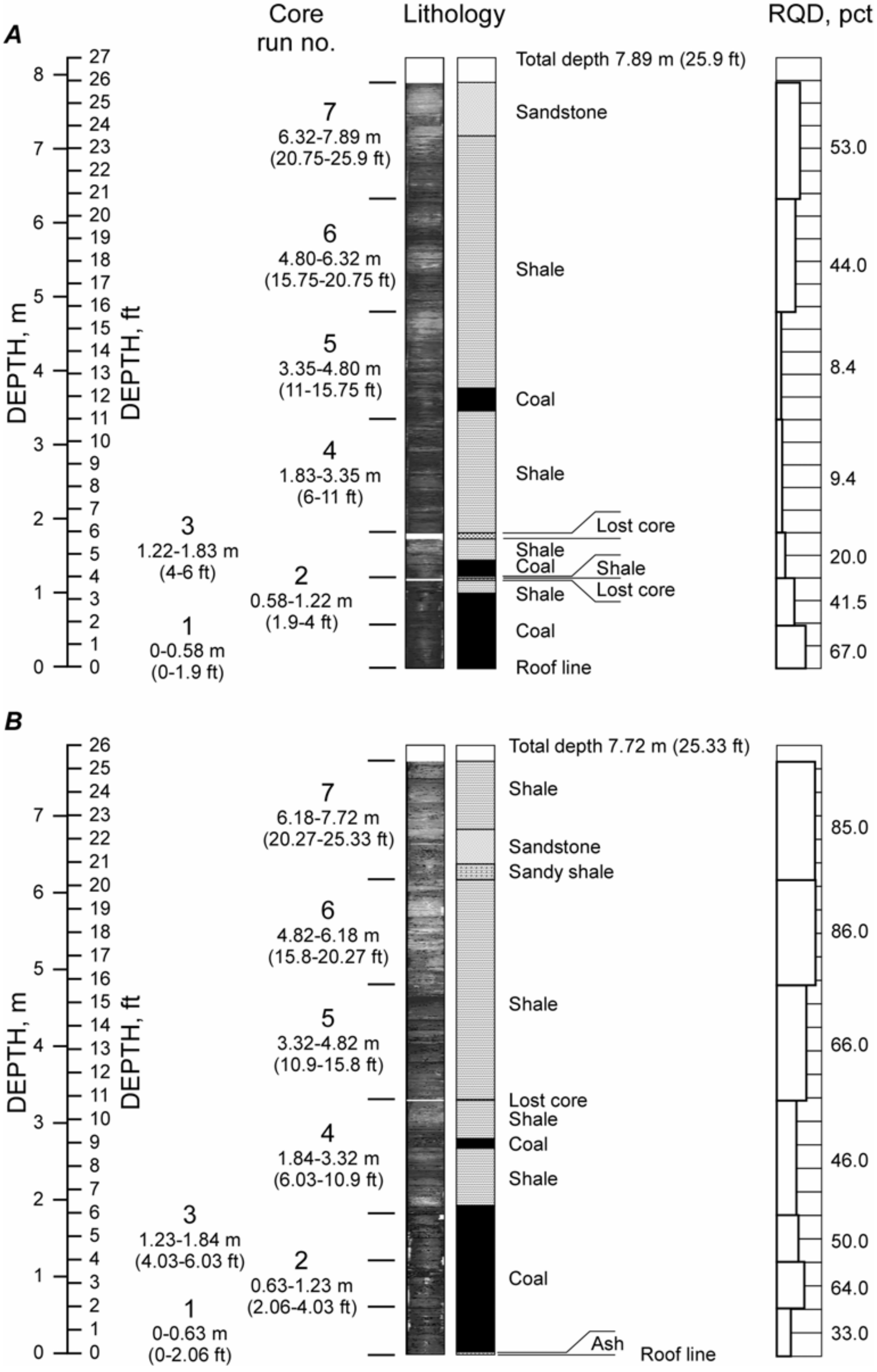

Figure 2.—Roof geology at *A,* cross-cut 17, and *B,* cross-cut 52

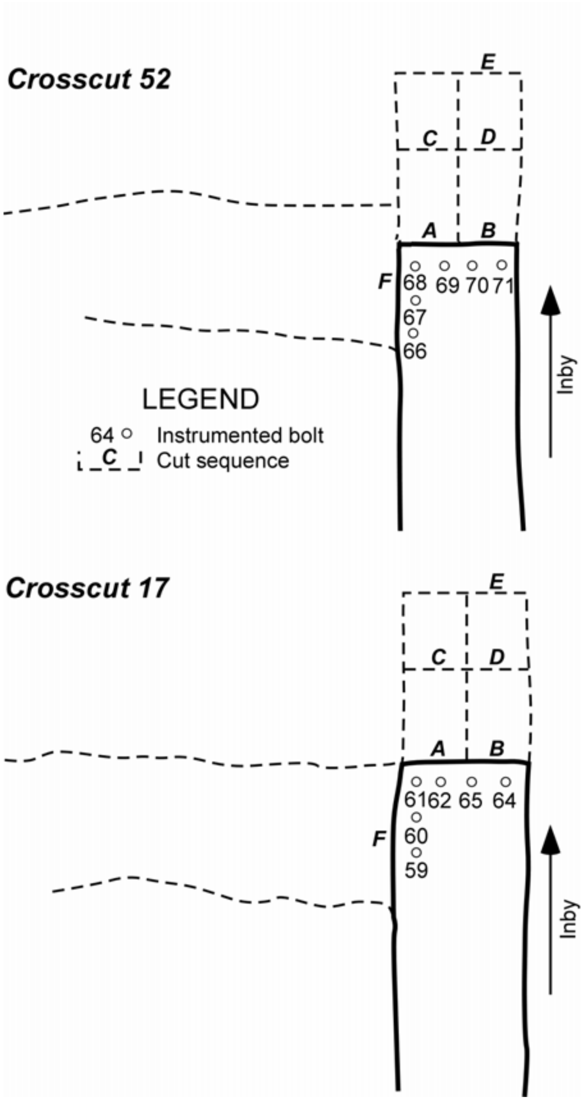

Figure 3.—Cut sequence

where ε = Strain, in/in,
.V = Change, V
GF = Gauge factor,
and EV = Excitation voltage.

Bolt load was calculated by the formula—

$$P = E A \epsilon$$

where E = Modulus of elasticity
and A = Bolt area.

If bolt strain exceeded the yield point of the steel, then the nonlinear stress-strain curve derived from laboratory tests was used to calculate bolt load from strain. Axial loading was calculated by averaging the load on each side of the bolt at each gauge position.

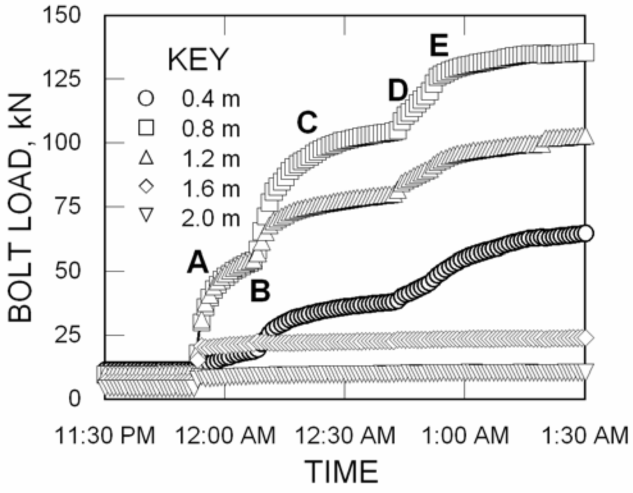

Figure 4.—Axial load on bolt 62 from time A to time E

RESULTS

The electrical connector for bolt 65 was damaged during installation, so no data from that instrument are presented. Three gauges (at the 0.8-, 1.6-, and 2-m [32-, 64-, and 80-in] positions) on bolt 68 had open circuits after installation. Axial load at each of these positions was calculated using only one gauge, and bending strain is not shown. Figure 4 shows the change in axial load for bolt 62 as the continuous miner made the four advance cuts. Points A thru D represent the time when mining began on each cut. Point E represents the time during which mining stopped on the last cut. Each curve represents the change in axial load at that bolt section. The highest load occurred at the 0.8- and 1.2-m (32- and 80-ft) sections. In general, this was true for most of the bolts.

Figure 5 compares axial load at the 0.8-m (32-in) position for all bolts at both test sites during entry advance, and figure 6 shows the same information during the cross-cut breakthrough. The highest loads occurred at the bolts in the center of the entry during entry advance. When the cross-cut was broken through, the bolts in the center of the span loaded to almost the same levels as the bolts in the center of the entry. Figures 7 and 8 show a representation of axial load in kilonewtons on all bolts at three time intervals. Bolts 61 and 68 are in both rows, so are shown twice. Time A is the load before any mining activity, E is after entry development, and F is after the cross-cut breakthrough. Yield load for the instrumented bolts is 149 kN, and only two bolt sections reached that load, both on bolt 62. Maximum axial load for each bolt was averaged with respect to test section, location (entry or cross-cut), and time (table 1).

Figures 9 and 10 show bending strain for the bolts in cross-cuts 17 and 52. The highest bending load changes occurred during the cross-cut breakthrough. Bending strains for the bolts in cross-cut 52 were significantly lower than for cross-cut 17. Bolt yield occurred at approximately 2,000 microstrain. One bolt section reached that strain level; all other bending values were significantly less than yield. The position that showed the most consistent bending was at 0.8 m (32 in).

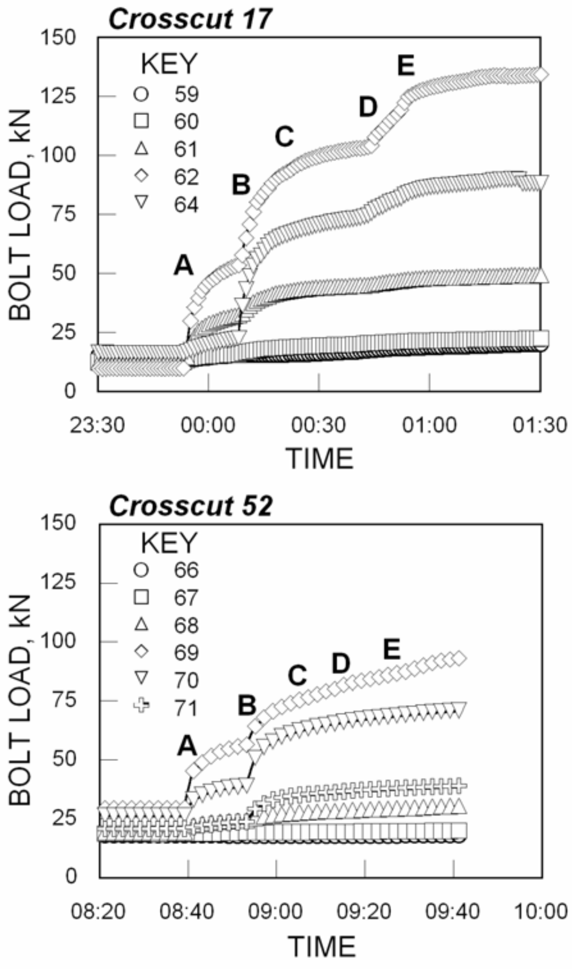

Figure 5.—Comparison of axial load during entry advance at gauge position 0.8 m

DISCUSSION

Bolts at the center of the entry loaded faster and to higher values when the entry cut was directly in front of the bolts, and the bolts farthest away loaded to lower values. This is what was expected. As the third and fourth cuts were taken, loads on the bolts increased at a slower rate and stabilized until the cross-cut was broken through. Then most of the load increase was on the cross-cut bolts, with load in the center increasing the fastest. The highest loads occurred just below the midsection bolt, which was consistent with previous studies where the roof was not subjected to high horizontal stresses. Bolt yield only occurred on one bolt, and that was after the cross-cut had been broken through.

The largest percentage of increase in bolt load resulting from entry development occurred in the lower midsection of the bolt, where load was already highest. When the cross-cut was broken through, the largest percentage of increase was at the ends of the bolts in the cross-cut. The highest amount of loading in these bolts was farther up in the roof and indicates more stress was being applied to the bolt anchorage. One reason the percentage of increase was higher at the end of the bolts was that load levels at this position were initially low.

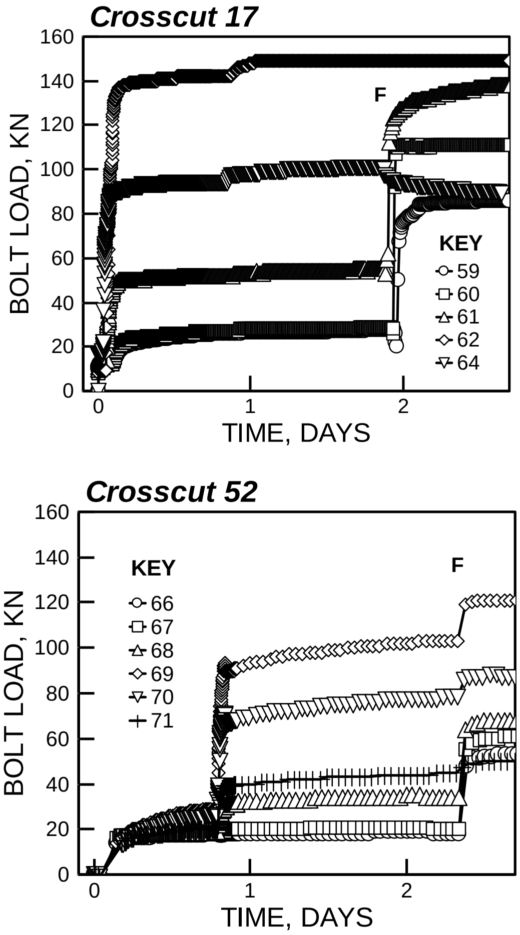

Figure 6.—Comparisons of axial load during cross-cut breakthrough at gauge position at 0.8 m

Table 1. Average of maximum axial loads, kN

Time	Cross-cut 17			Cross-cut 52		
	All	Entry	Cross-cut	All	Entry	Cross-cut
A	18	21	19	20	23	18
B	30	40	24	34	42	20
C	51	73	26	40	51	21
D	55	79	28	42	54	21
E	60	87	29	43	56	22
F	119	123	116	71	79	58

Geological differences between test sites were probably the biggest factor affecting bolt loads. The additional top coal at cross-cut 52 combined with more competent rock strata produced bolt loads significantly lower than at cross-cut 17. The results indicate that a bedding plane was present in the cross-cut 17 test site and produced some movement during initial mining. The movement may have resulted from the influence of the anomalous geology, as this bending behavior was not evident at all at cross-cut 52. Movement could have also contributed to roof degradation.

CONCLUSIONS

The highest bolt loads during entry advance were in the center of the entry at the cross-cut 17 test site. The largest increase in bolt load occurred when the cross-cut was broken through. The entry face advance increased the *average* of maximum bolt loads by 75% at cross-cut 17 and 59% at cross-cut 52. When the cross-cut was broken through, the average maximum bolt load increased by 75% and 62%, respectively.

The largest increase in loading on the entry bolts occurred when both sides of the initial advance cuts were taken. The second set of cuts produced less bolt loading. Geological differences between the test sites were probably the biggest factor in these differences. The additional top coal at cross-cut 52, combined with more competent rock strata, produced bolt loads significantly lower than in cross-cut 17. The results indicate that a bedding plane in the cross-cut 17 test site produced some movement during initial mining.

The MIDAS datalogger provided the ability to measure bolt loads during initial mining. Because the strain-gauged bolts only measure localized rock movement, the question of whether this type of instrument can be used to determine the depth of cut for extended cuts remains unanswered. This test is a good case study of how bolts load quickly during initial mining around a section and the effects of geological conditions on bolt loading.

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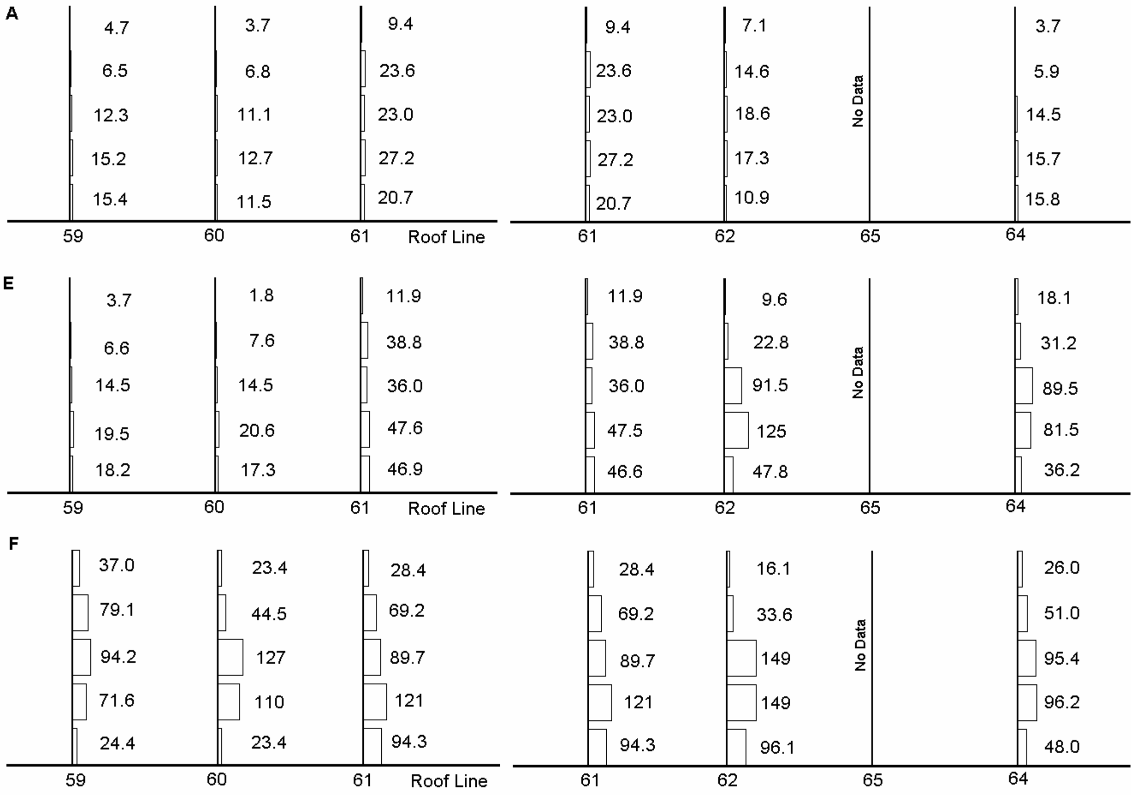

Figure 7.—Axial bolt loads at times A, E, and F for cross-cut 17, kilonewtons

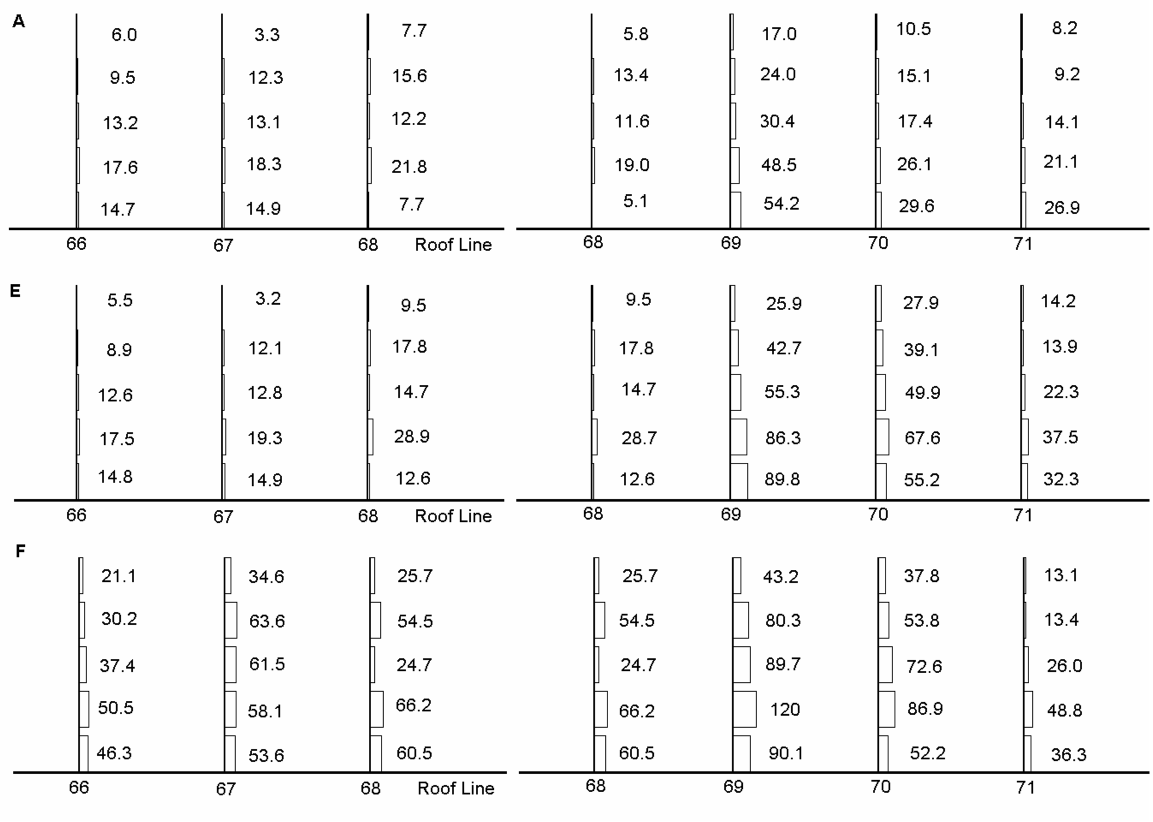

Figure 8.—Axial bolt loads at times A, E, and F for cross-cut 52, kilonewtons.

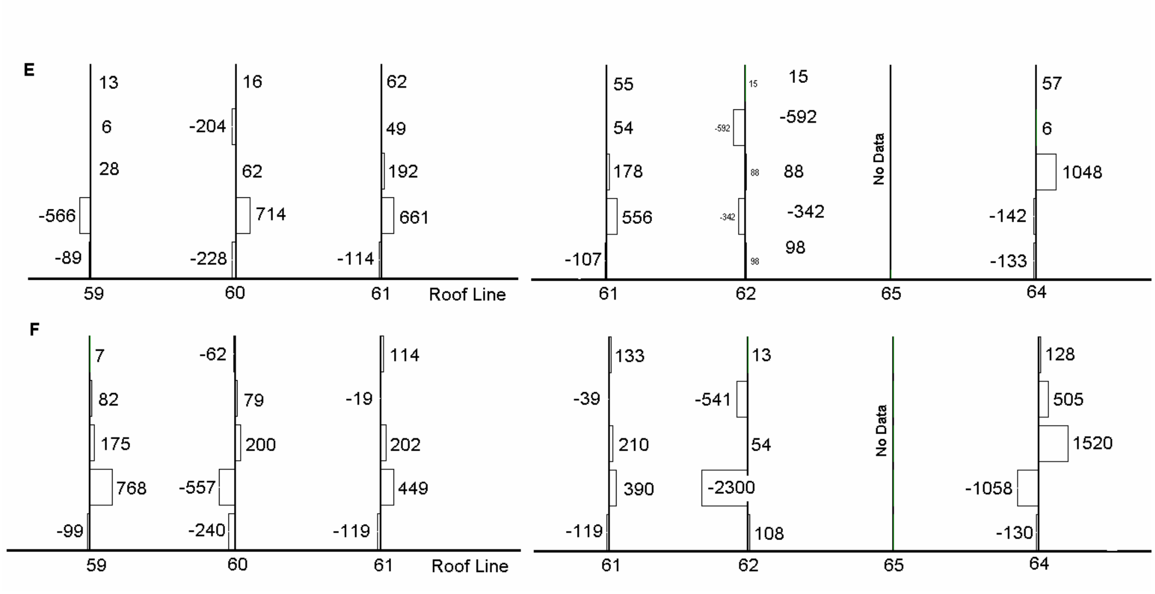

Figure 9.—Bending at times E and F at cross-cut 17, microstrain

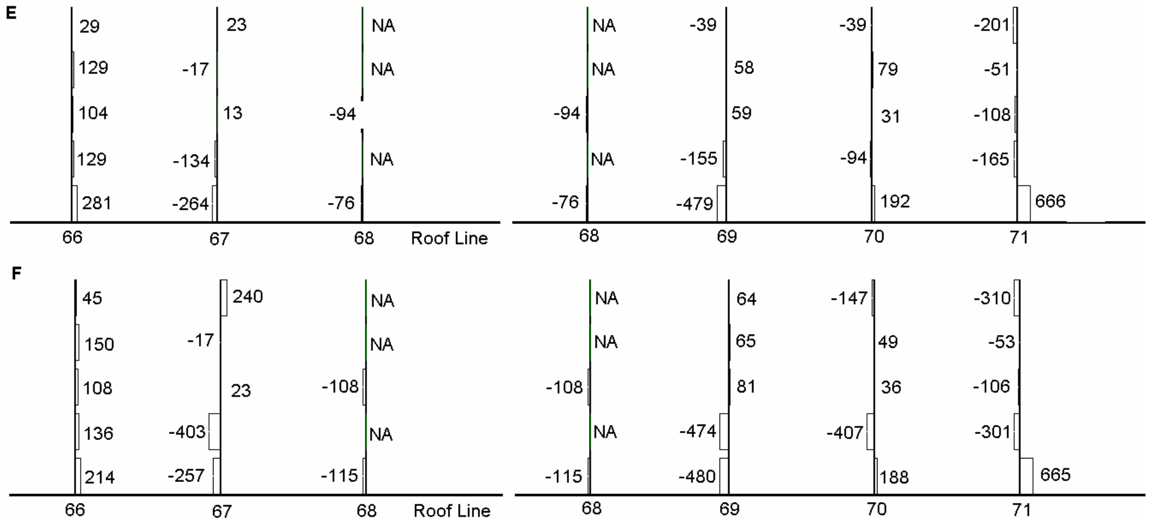

Figure 10.—Bending at times E and F at cross-cut 52, microstrain