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Special research report.

SPECIAL REPORT OF RESEARCH

conducted in

Department of Mining
College of Mineral Industries
The Pennsylvania State University

ROOF BOLT LOAD
AND
DIFFERENTIAL SAG MEASUREMENTS

by

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and

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An Investigation
Conducted Under the Auspices
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STATEMENT OF TRANSMITTAL

Special Report SR-53 transmitted herewith has been prepared by the Coal Research Section of the Mineral Industries Experiment Station. Each of the Special Reports presents the results of a phase of one of the research projects supported by The Pennsylvania Coal Research Board or a technical discussion of related research. It is intended to present all of the important results of the Coal Board research in Special Reports, although some of the results may already have been presented in progress reports. The following is a list of Special Research Reports issued previously.

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SR-17	The Combustion of Dust Clouds: A Survey of the Literature	November 30, 1959
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SR-19	Changes in Coal Sulfur During Carbonization	August 1, 1960
SR-20	The Radiation Chemistry of Coal in Various Atmospheres	September 12, 1960
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SR-22	The Nature and Occurrence of Ash Forming Minerals in Anthracite	December 30, 1960
SR-23	A Phenomenological Approach to the Batch Grinding of Coals	January 20, 1961
SR-24	The Unsteady State Diffusion of Gases from Anthracite at High Temperatures	January 21, 1961
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SR-28	Preparation and Properties of Activated Carbons Prepared from Nitric Acid Treatment of Bituminous Coal	August 15, 1961
SR-29	The Reactions of Selected Bituminous Coals with Concentrated Sulfuric Acid	August 31, 1961
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SR-34	Reactions of Coal with Atomic Species	September 24, 1962
SR-35	The Preparation Characteristics of the Bituminous Coal Reserves in Pennsylvania with Special Emphasis on Sulfur Reduction	October 31, 1962
SR-36	A Study of the Burning Velocity of Laminar Coal Dust Flames	November 5, 1962
SR-37	Molecular Sieve Material From Anthracite	November 16, 1962
SR-38	Studies of Anthracite Coals at High Pressures and Temperatures	April 29, 1963
SR-39	Coal Flotation of Low-Grade Pennsylvania Anthracite Silts	May 13, 1963
SR-40	Changes in the Physical Properties of Anthracite Upon Heat Treatment	July 10, 1963
SR-41	Some Aspects of the Chemistry of Sulfur in Relation to Its Presence in Coal	August 20, 1963
SR-42	The Unsteady State Diffusion of Gases from Coals	February 15, 1964
SR-43	The Effect of Concentration and Particle Size on the Burning Velocity of Laminar Coal Dust Flames	March 1, 1964
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SR-45	An Investigation of the Cyclone for Fine Coal Cleaning	May 30, 1964
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SR-48	Beneficiation of Fly Ash	April 12, 1965
SR-49	Application of Linear Programming Methods to Mine Planning and Scheduling	July 10, 1965
SR-50	Petrographic Composition and Sulfur Content of Selected Pennsylvania Bituminous Coal Seams	August 2, 1965
SR-51	Preliminary Investigations of Fog Disposal Methods Applicable to Greater Pittsburgh Airport	August 20, 1965
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ABSTRACT

Differential measuring equipment was constructed and used in an underground installation at the No. 20 Mine of the Barnes and Tucker Coal Co. to measure possible bed separation. Simultaneously, 12 bolts were instrumented to measure bolt loads at installation or any time thereafter.

Almost instantly, bolt load bleed-off occurred, and bed separation occurred at three horizons, two above the anchorage plane and one within the zone of bolt clamping influence. Both bolt bleed-off and bed separation were accelerated by blasting. Measurements indicated that the bolts were not performing in the desired manner and soon roof conditions become very bad and the place was too hazardous to work.

To combine accuracy and sensitivity with economy and simplicity, a ring cell based on the proving ring principle was designed, calibrated and thoroughly tested in the laboratory. As a result of the findings, 12 have been made and calibrated for imminent use in an underground installation.

The underground testing technique was found to indicate the efficiency of bolting and therefore is very important. With this system, it is possible to experiment with improved anchorage systems until a more effective roof support system evolves. Thus costly trial-and-error techniques can be replaced by a more scientific selection of a support system and its effectiveness can be immediately evaluated without exposing personnel to needless danger.

SUMMATION OF RESULTS

The results of an underground test installation and laboratory study are reported. Research to determine the effectiveness of roof bolting in the No. 20 Mine of the Barnes and Tucker Coal Company revealed some interesting results. The test arrangement permitted the measurement of bolt loads and bed separation simultaneously. The beds began to separate almost immediately after roof exposure, and blasting had an adverse affect. One separation plane occurred in the bolt zone of influence but two major separations were located above the plane of anchorage. With bolt load loss, the top broke and the place became very hazardous to work.

As a result of the field work, it became apparent that a bolt load cell was needed that would combine accuracy and sensitivity with economy and simplicity. Since such a device was not available, it was decided to develop one. A cell was constructed on the same principle as a proving ring. It is essentially a steel ring with two holes drilled diametrically opposite to allow the insertion of the bolt. This ring is placed between the head of the bolt and the plate during installation. Upon torquing the bolt, the ring deflection is measured by a precision dial gage and the bolt load is revealed precisely. Twelve ring gages have been constructed and calibrated and are now ready for field use.

Roof bolts today are the major method of support in coal mines. Nevertheless, it is rare when instrumentation exists to evaluate the

SUMMATION OF RESULTS (Continued)

bolt load upon installation or anytime thereafter. The torque wrench at best gives only a crude approximation and can be in great error. To the authors' knowledge, no one in Pennsylvania is attempting to measure the effectiveness of bolting by studying bed separation simultaneously. Yet, unless the effectiveness of bolting can be evaluated, it is impossible to improve anchorage efficiency. The type of research program described in this report is very significant and could lead to the scientific selection of a bolting system instead of the trial-and-error techniques employed to date.

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A. UNDERGROUND CORRELATION OF DIFFERENTIAL SAG MEASUREMENTS AND BLEED-OFF

INTRODUCTION

Sag measurements have been carried out in the mining industry in order to obtain a better understanding of roof behavior during mining operations (1). In addition, a few measurements have been made to determine bleed-off in roof bolts with essentially a similar objective (2, 3). It is generally accepted that the outstanding success of roof bolts for support in coal mines can be attributed to their ability to bond or hold the multiple strata overlying an opening into a beam in order to reduce slippage along bedding planes and avoid subsequent separation of the individual stratum.

From the foregoing it seems quite logical that a simultaneous determination and eventual correlation of differential roof sag and roof bolt bleed-off would furnish more meaningful data that could be utilized to devise better systems for stabilizing roofs in coal mines. This portion of the report describes an initial field installation to secure the stated objectives.

EQUIPMENT UTILIZED

(A) Bed separation measurements

1. Bed separation frame with three dial gages (sensitivity - 0.0001 inch). See Fig. 1.

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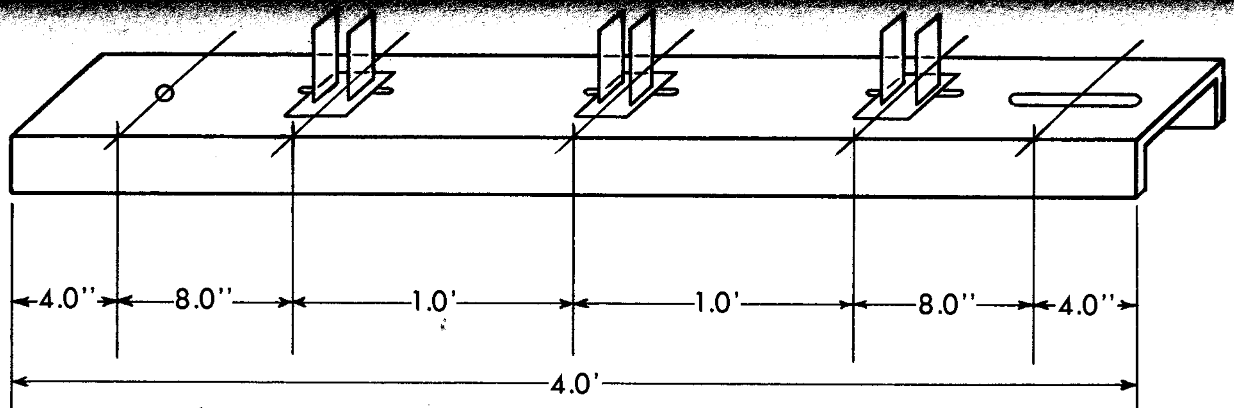
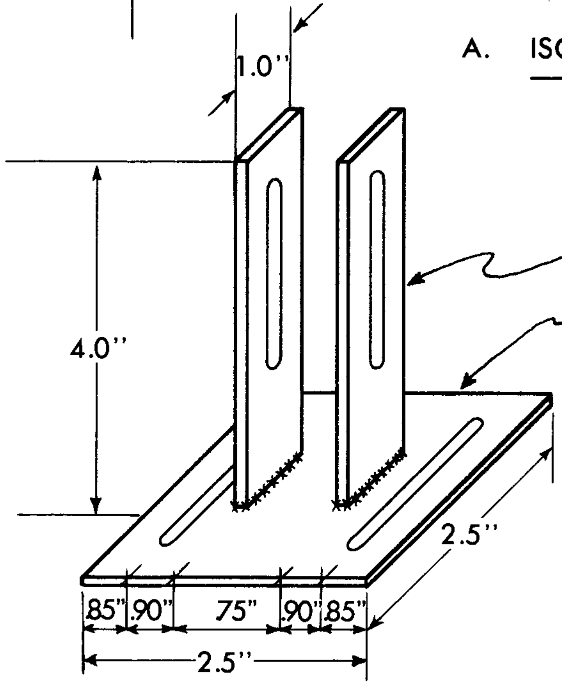
(1) References at end of report



A. ISOMETRIC VIEW OF FRAME



ALUMINUM CHANNEL - 3¼" × ¼" × 4'

THICKNESS = 0.25"
SLOTS = 0.125" WIDTH

B. DETAIL OF A DIAL GAGE HOLDER

Fig. 1. SKETCH OF
BED SEPARATION FRAME
(not to scale)

2. Set of bolts for anchoring at different horizons in the roof.
3. Hole location template.

(B) Bolt load indicator

1. Calibrated compression pads with ring gages.
2. Hydraulic jack with pressure gage (10-ton capacity).

(C) Roof bolting equipment

PROCEDURE

An underground test site was selected which incorporated the following features:

(A) It was a newly exposed roof (within one hour of exposure).

(B) Relatively dry, to prevent the destruction of instruments and avoid the complicating influence of water on strata behavior.

(C) Relatively flat (not jagged) and apparently competent roof so that only a conventional roof bolting pattern was employed for support.

(D) Located in an area in which tramming mining equipment would not disturb the installation.

Of the six entries inspected on the main development (see Fig. 2), No. 2 and No. 3 appeared to satisfy the foregoing requirements. However, entries No. 1 and No. 4 were far ahead (about 3 blocks or 180 feet) of the others, and production work at the time of the study was concentrated in the No. 5 and No. 6 entries in order to bring these entries in line with the others. The roof of the No. 5 entry had caved for as much as two to four feet above the normal roof line. This made the roof too jagged for an installation, and roof bolts had to be supplemented by heavy rails.

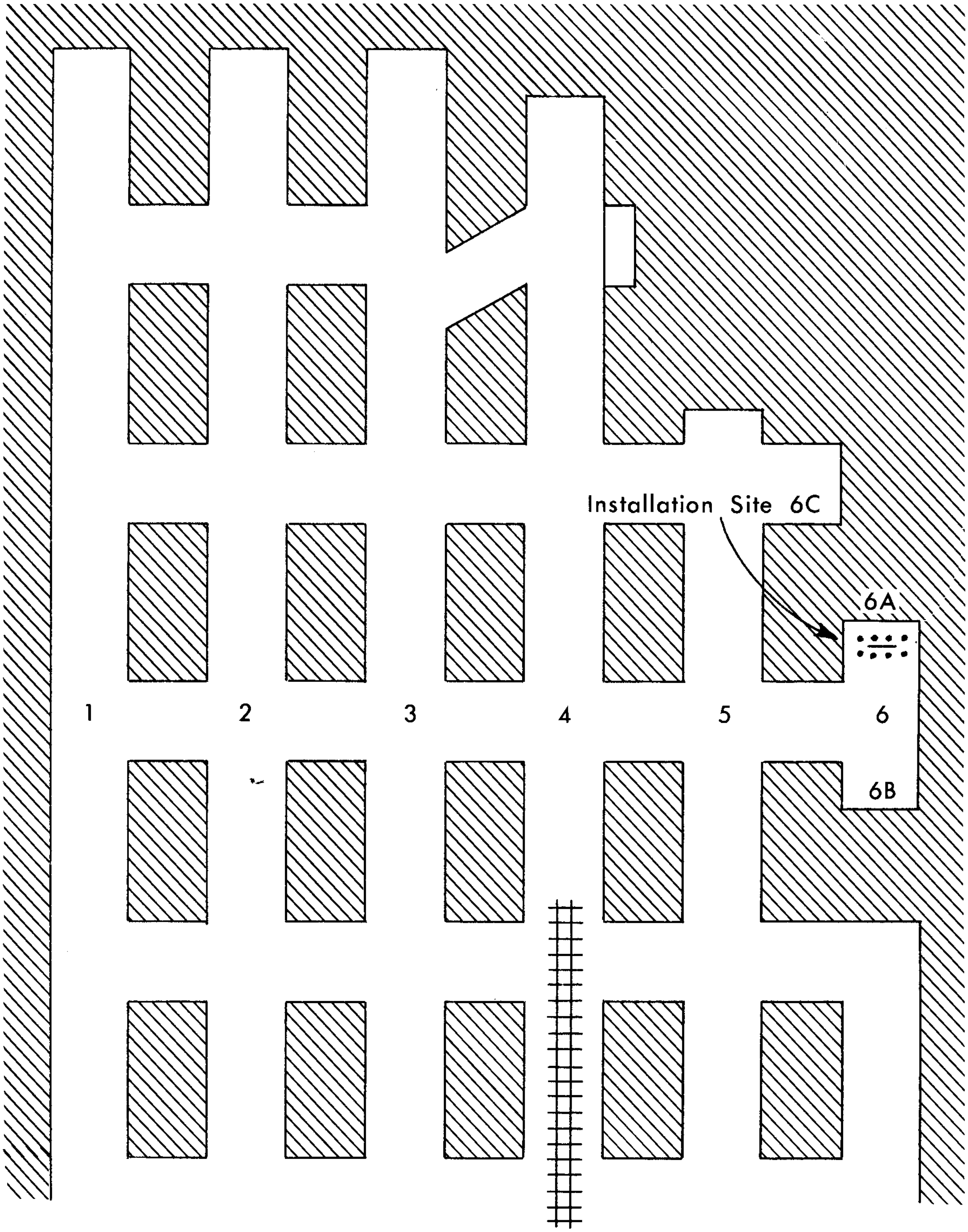
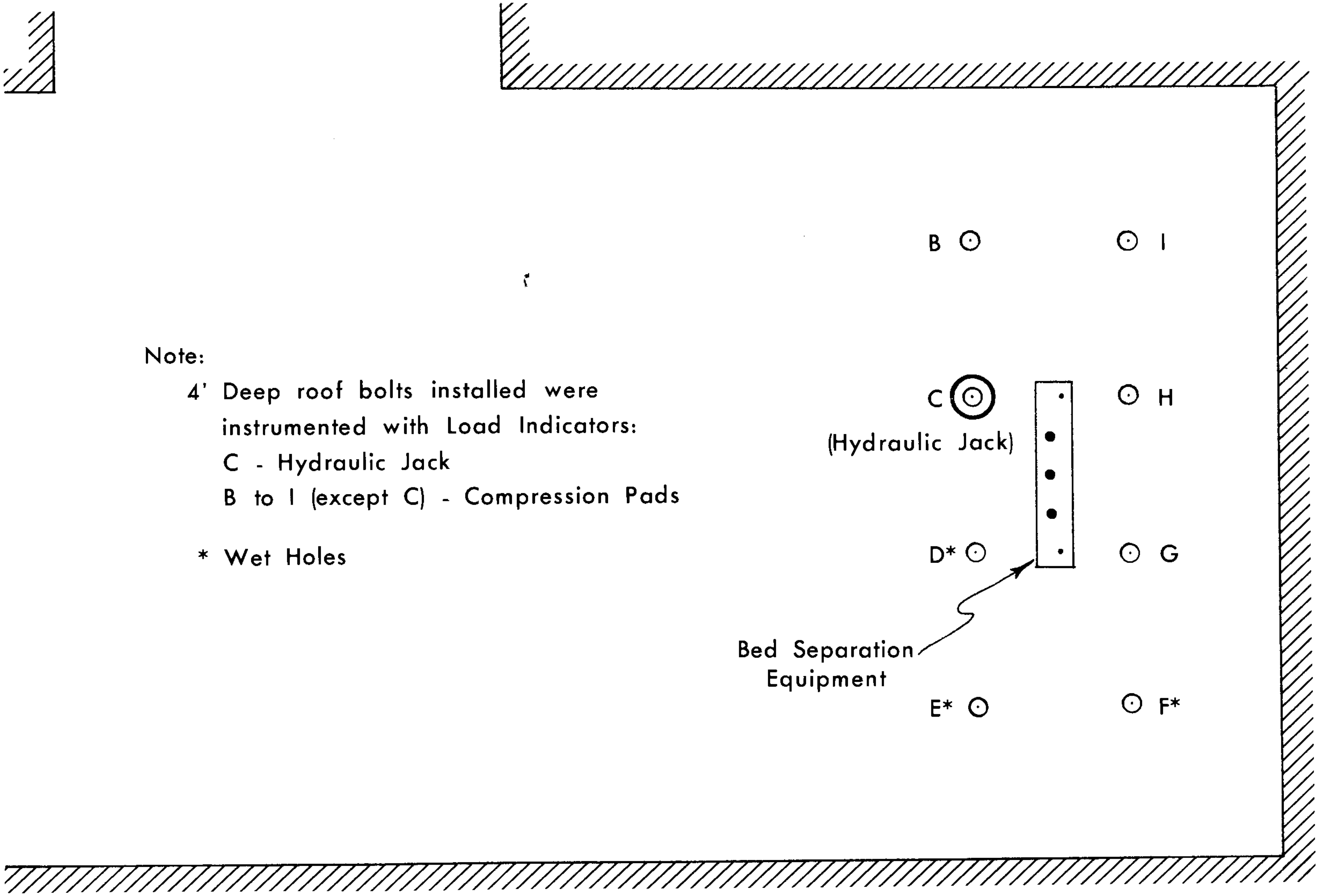


Fig. 2 UNDERGROUND TEST SITE

Entry No. 6 satisfied most of the requirements and was therefore chosen. The face was about 26 feet in by the crosscut. While the roof was relatively dry at the face, it was dripping quite profusely several feet in an outby direction. The roof of the crosscut-entry intersection was held by roof bolts and reinforced with heavy rails on 4-ft.centers. Rails were either supported by props or held by bolts. Considerable spalling occurred and exposed a jagged roof.

The roof and floor at the test site, however, were flat and appeared competent enough so that only a conventional bolting pattern was required for support. Water was coming out of three holes (D, E, and F, Fig. 3), but otherwise, the test site appeared ideal. Since the mine officials had agreed to cut back through to the installation, no tramming disturbances from miners and mining equipment occurred.

The regular mining cycle was adhered to during the course of the investigation. After the face was cleaned up, the roof was bolted to within 4 feet of the face using approximately 140-170 ft-lbs of torque applied by the bolting machine. No modifications in the bolting procedure or pattern were made since a secondary purpose of the test was to evaluate the efficiency of bolting practice. Compression pads and a hydraulic jack were installed in the last two rows of bolts to detect original and subsequent changes in bolt load (Fig. 3). This instrumentation does not interfere with normal bolt installation practices. Readings were taken immediately after bolts were installed as well as at periodic intervals thereafter to detect bolt load with time.



Note:

4' Deep roof bolts installed were instrumented with Load Indicators:

C - Hydraulic Jack

B to I (except C) - Compression Pads

* Wet Holes

Fig. 3. DETAILS OF TEST SITE

Between the two rows of instrumented bolts (Fig. 3), five holes were drilled for the bed separation equipment; a template was used for precise hole location. Two end holes 18" deep were employed to hold the frame firmly and horizontally. The other three holes, drilled at depths of 3 ft., 6 ft., and 9 ft., were for hanging corresponding lengths of bolts. These hanging bolts protruded approximately 1 in. below the collar of the holes. The bed separation equipment was installed and hourly readings were taken until the conclusion of the test.

Mining activity generally affects both differential sag measurements and bolt load bleed-off. Therefore, close and constant observation of the test was carried out during the first few days of the installation, during top cutting and blasting of nearby openings, and when connections were eventually made between 6C and 6A (see Fig. 2).

No unusual roof or floor movements were noted during the 5-day period immediately following instrument installation, including the moment when connection was first made, although the intersection of the outby crosscut with the entry had previously been reinforced with props. However, approximately 18 hours after connection was made between 6C and 6A, floor heave of about 12 in. to 18 in. occurred at the test site, and the face foreman deemed it necessary to reinforce the area with numerous props. More than 16 props were installed in a limited area of 20 x 10 ft. Also, quite a few rock falls occurred around this area during this time.

Because of the added supports and the fact that water came out of the 6-ft. hole and trickled down from the 9-ft.- and 3-ft. holes, damaging the dial gages, it was decided to discontinue the test.

TEST RESULTS

Bolt Load Bleed-Off Measurements

A graph of the bolt load bleed-off, measured by compression pads and a hydraulic jack, plotted against time in days, is shown in Fig. 4. It will be noted that there is a wide variation in the initially installed loads, the lowest and the highest being 4, 500 and 12, 500 lbs., respectively. This is characteristic of underground roof bolting since bolt load is dependent on the torque value established by the roof bolting machine, a rather crude control of installation values. Several factors in each installation that may affect the bolt load are not considered at all utilizing this procedure.

The amount of bleed-off varied from one roof bolt to another, with no distinct correlation of the rate of bleed-off with the initial bolt load. This is a very significant observation and appears to confirm previous observations obtained in laboratory tests (4).

All the curves indicate a rapid drop in bolt load during the first hour of the test followed by a decreasing rate until it approximately stabilized within 24 hours. The fact that the load leveled off does not imply that stabilization of the strata had been attained since small changes in bolt load are not detectable by the compression pads. The hydraulic jack with pressure gage (curve C, Fig. 4) gave

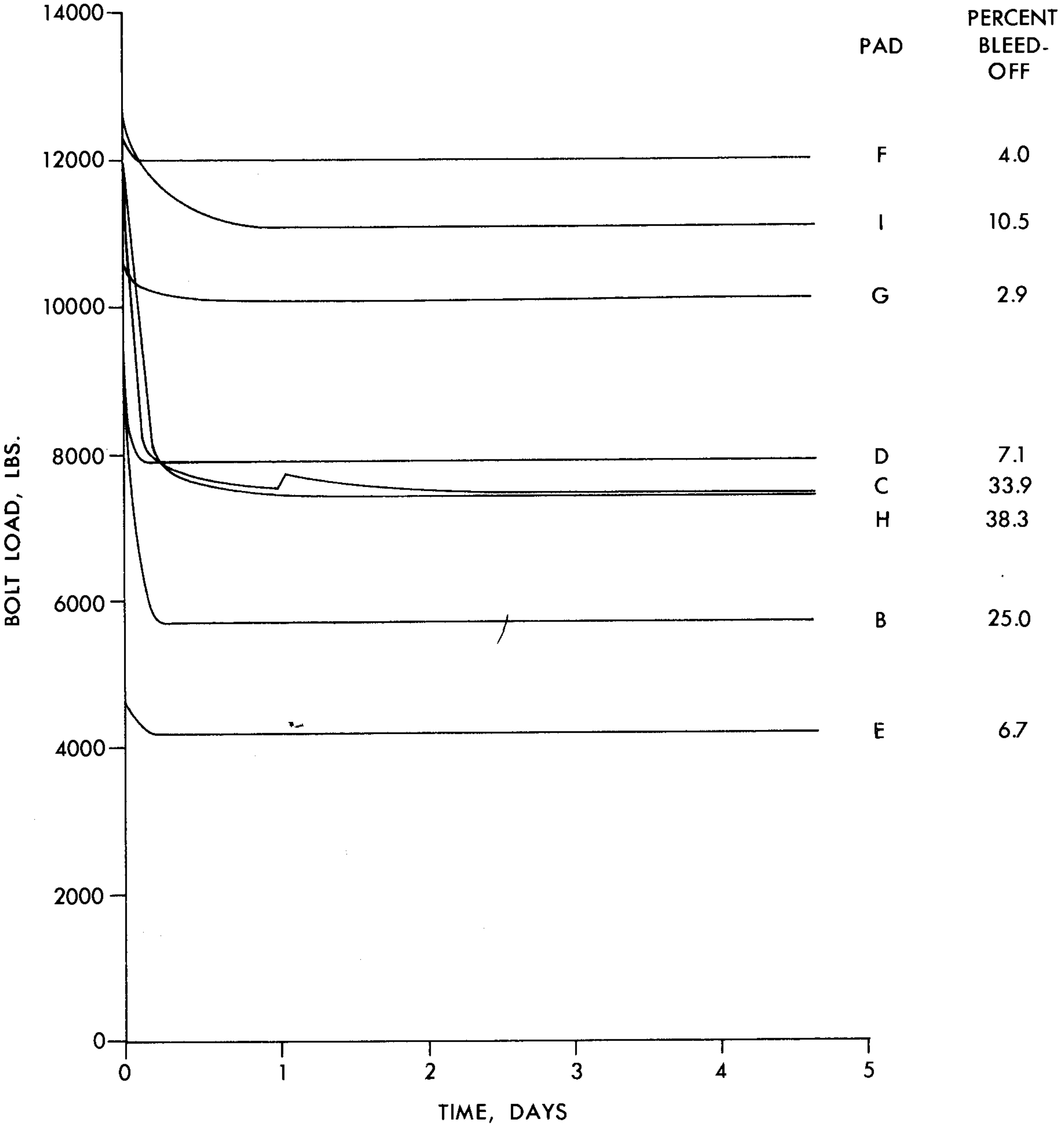


Fig. 4. BOLT LOAD VARIATIONS WITH TIME

essentially a similar bolt load-time curve as the compression pads, although it showed a slight increase of about 200 lbs. after top cutting and blasting of 6B (see Fig. 2).

The rates of bleed-off, a measure of roof bolt efficiency, ranged from a low of 2.9% to a high of 38.3% with an average of 16% for the 8 instrumented bolts. This meant that for the average load of 9875 lbs. per bolt, 1580 lbs. in each bolt were lost through bleed-off, mostly during the first day of the installation. It should be realized, however, that the average values are of less significance since only the individual bolt behavior determines the effectiveness of the entire supporting system.

Differential Sag Measurements

A plot of differential bed deflection with time is shown in Fig. 5. Bolts were anchored at three different horizons, 3 ft., 6 ft., and 9 ft. with the immediate roof serving as the reference horizon.

In the first day of testing, there was no observed bed separation within the bolted layers up to 3 ft., although the 6-ft. and 9-ft. layers started to deflect and separate immediately. With top cutting and blasting of 6B, bed separation in all the layers took place, with the maximum occurring in the 9-ft. layer. At the end of the first day, individual separation between the 0 ft.-3 ft., 3 ft.-6 ft. and 6 ft.-9 ft. layers were 36×10^{-4}-, 29×10^{-4}-, and 71×10^{-4} inches, respectively.

During the cutting operation from 6C to 6A (see Fig. 2), bed deflection of the 6-ft.- and 9-ft. layers continued steadily until an

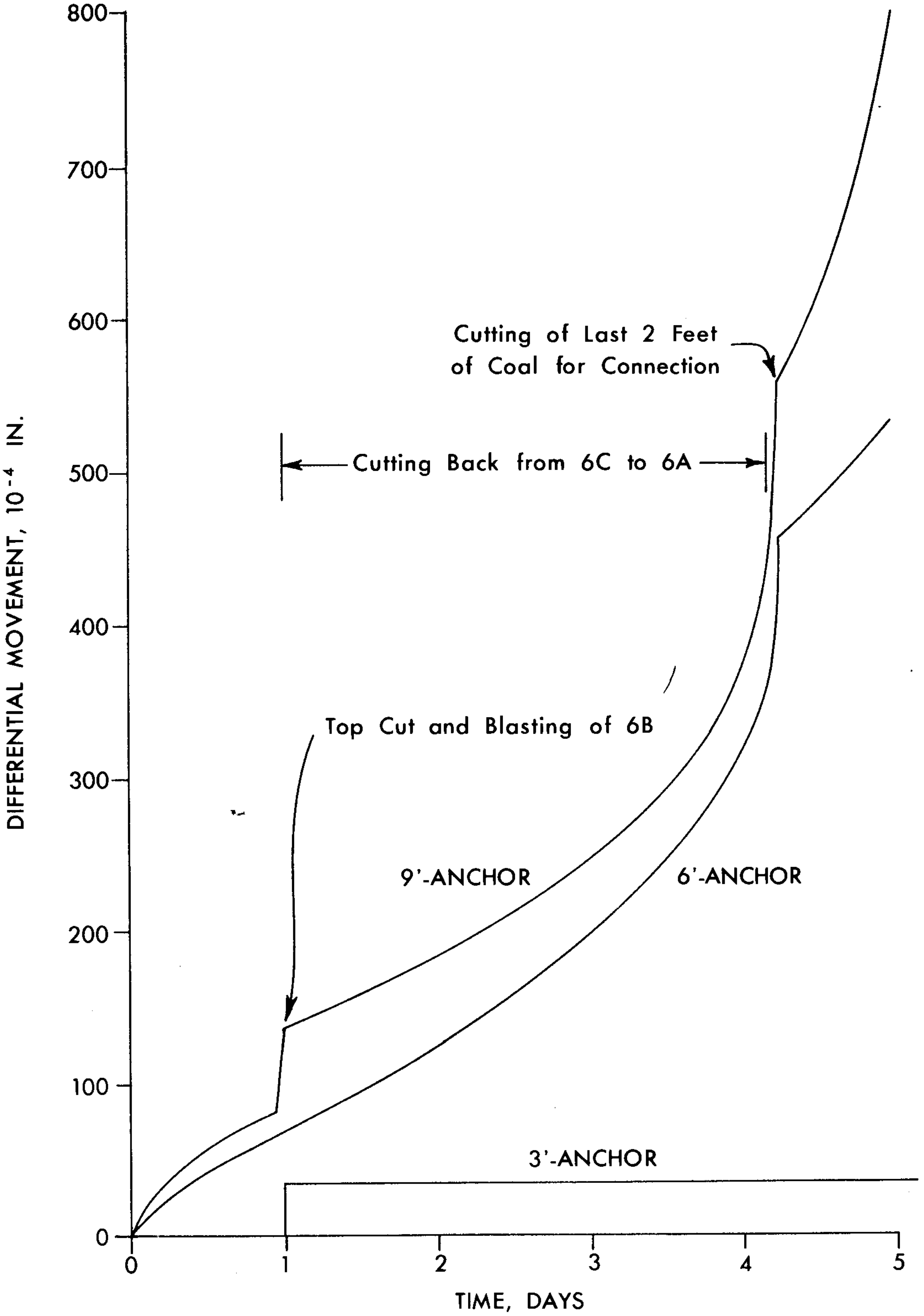


Fig. 5. DIFFERENTIAL MOVEMENT OF ANCHORS IN ROOF

abrupt increase with the cutting of the last 2 ft. of coal for complete connection. From then on, deflection and separation continued at a rapid pace up to the conclusion of the test.

An idealized sketch showing the set up for measuring differential bed movement is shown in Fig. 6, and the total amount of bed separation in each layer is also indicated.

DISCUSSION AND CONCLUSION

Bed separation at several horizons was detected during field testing. Only a minor separation (0.36×10^{-2} inch), occurred within the bolted layer, and this was observed only during the cutting and blasting phases of 6B (see Fig. 4). Vibration as well as the sudden addition of load could have caused this separation. The bolts appeared to maintain sufficient tension to minimize bed separation; however, blasting may have had some part in the bed separation that occurred on the first day of the test. Relatively large amounts (4.96×10^{-2} and 2.63×10^{-2} inches) of separation occurred between beds above the anchorage site and thus outside of the influence of the clamping action of the bolts. Separation took place continuously at a slow but steady rate. Cutting and blasting accelerated the rate of bed separation.

Compression pads and a hydraulic jack were used successfully as bolt load indicators. However, the pads were very insensitive to changes in bolt load and considerable care was necessary when readings were taken; however, the pad is still considered inadequate for the desired purpose. The hydraulic jack was sufficiently sensitive

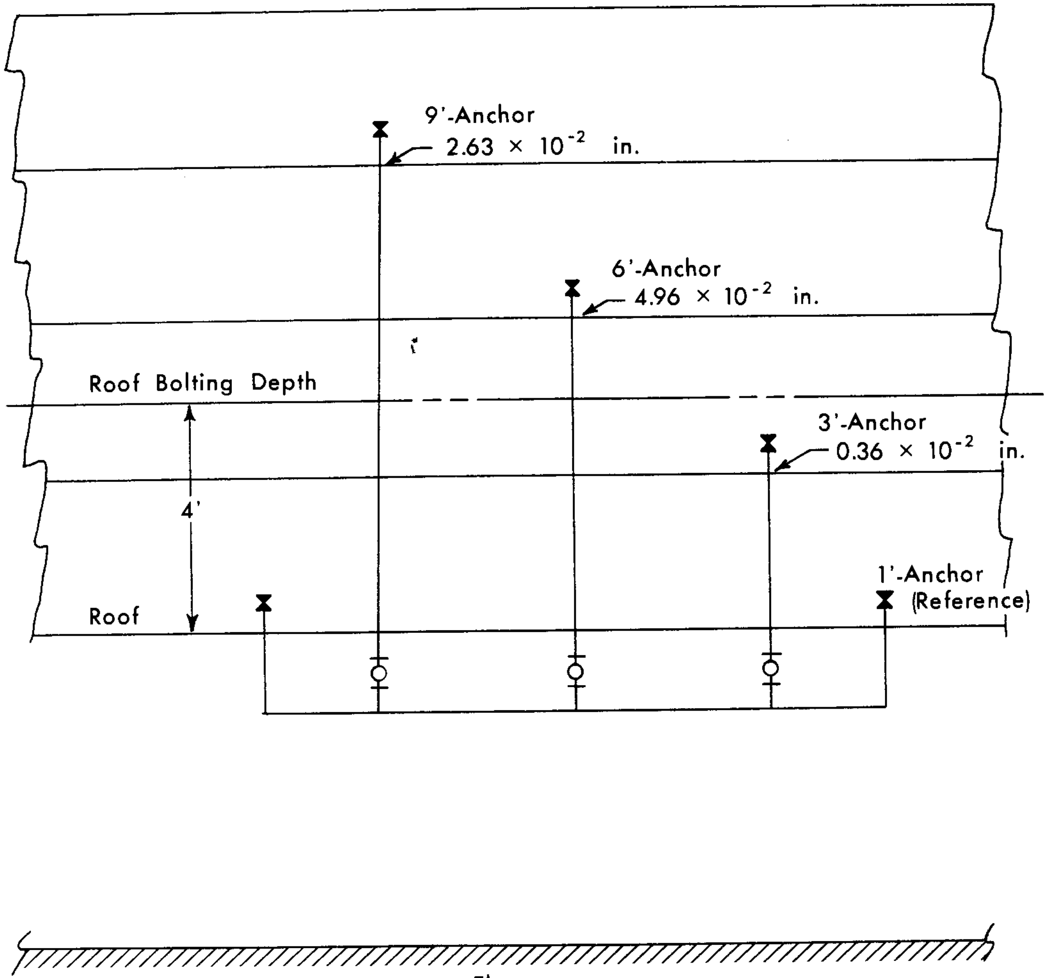


Fig. 6. ARRANGEMENT FOR MEASURING DIFFERENTIAL BED MOVEMENT (BED SEPARATION AT DIFFERENT HORIZONS INDICATED)

but excessive moisture underground as well as its protruding bulk negates its usefulness for test purposes.

Finally, no correlation of bolt load bleed-off with bed separation was attempted at this time mainly because of the insensitiveness of the readings taken with the bolt indicators.

RECOMMENDATIONS

The preliminary test has shown the feasibility of determining the magnitude by which the different beds are displaced. A minor modification of the bed separation equipment is desirable, however, in order to avoid the necessity of installing dial gages and keeping them in place with the frame. An additional flexibility is also necessary since the holes cannot be drilled exactly where they are desired.

Selection of a more competent roof and floor at or near the middle of the set of entries and in an area where water is not a problem is also very desirable. Finally, the effect of top cutting and blasting should be observed individually since each should have distinct effects.

B. DESIGN AND DEVELOPMENT OF A RING SHAPED BOLT LOAD INDICATOR

INTRODUCTION

It was observed in the underground installation that the installed roof bolt load changed with time. Stress redistribution in the mine strata may result in roof deflection, shearing along bedding planes, bed separation, tensile fracture and other physical phenomena, that may greatly increase the originally installed bolt load. If the yield strength of the bolt or anchor is not exceeded by the increase in bolt load, the roof or structure being supported may stabilize. Conversely, if the yield strength of either the bolt or the anchor is exceeded, failure of either the bolt or anchor results, and the roof will behave as an unsupported structure.

The original bolt load does not generally increase initially but has a tendency to relax as a result of anchorage deterioration. If the tension loss is not excessive and the reduction of the frictional resistance along bedding planes is not sufficient to allow bed separation, the decreased bolt load may still be adequate to hold the beam in a stable position. Otherwise, if the tension loss is excessive, allowing bed separation and bending of the layers to take place, an inadequate support results; obviously, if the bolt load is reduced to zero, the structure is left with no support at all. A rather complex analytical problem results if both phenomena occur alternately or simultaneously.

The necessity of accurately knowing the load of the bolt at any time during its useful life has prompted the mining industry to devise methods for determining the tension in the bolt during and at any time after installation. Unfortunately, the simple measuring techniques employed to date are incapable of distinguishing the various mechanisms contributing to bolt load changes.

A number of instruments and techniques have been developed to determine the tension or load in the bolt during and/or after installation. Some of these methods and/or equipment include the torque wrench, pull tests, rock bolt load cells, hydraulic load cells, compression pads, concave steel washers, photoelastic patches, photoelastic dynamometers, and for more accurate measurements for research purposes, the electrical resistance strain gages which are directly bonded onto the bolt and wired to a suitable strain indicator.

All of the above methods have limitations to some degree, some very serious and others quite tolerable. Generally and excepting for the bonded electrical resistance strain gages, the foregoing bolt load indicators give only a crude approximation of the actual bolt load. A complete coverage of bolt load indicators giving the advantages and disadvantages of each are given in reference 4. It was concluded that presently there is not a bolt-load measuring device incorporating all of the following desirable features: (a) low cost, (b) accuracy, (c) intrinsic safety, (d) remote indication and recording, (e) ease of application, (f) stability, and (g) compactness.

The design and development of a blot load indicator which incorporates most of the desirable features ennumerated above will now be given.

DESCRIPTION

Definition

The RSBLI (for Ring-Shaped Bolt Load Indicator) is an elastic steel ring for use in indicating the load on a bolt during installation or at any time thereafter. The load is a function of the deflection of the ring when loaded along a diameter. This deflection is measured by means of a dial gage mounted diametrically in the ring in a direction parallel to the axis of the bolt.

Design

Shape

Two views of a RSBLI are shown in Fig. 7. The indicator consists of a steel ring with two holes drilled on the opposite ends of the diameter and a deflection measuring device. When the bolt is tightened, the ring deflects, reducing the diameter along the axis of the bolt. The resulting deflection of the ring is measured with a precision dial gage which is placed into position for a reading and taken out when the reading is completed. The feet of the dial indicators were so modified to fit snugly on the inside surface of the ring. The contact areas must be carefully prepared to fit the dial gage, otherwise errors will be introduced that can be sizeable.

Dial Gage

The dial gage, a rugged shock-resistant precision model, is graduated into 100 divisions and numbered every ten divisions. Each division represents 0.0001 inch of linear deflection of the ring diameter. By interpolation, a reading of 1/4 of a division is possible which represents a sensitivity of 0.000025 inch of linear deflection. The number of rotations made by the large indicating dial are totalled on a smaller dial. The maximum travel is 0.1 inch, the distance being twice the designed maximum deflection of the ring diameter.

Two modifications were made of the commercial dial gage. The first involved the replacement of the back cover to avoid the protruding piece of metal that is used for hanging the gage. The second modification was to the feet of the gages. The feet were lengthened to

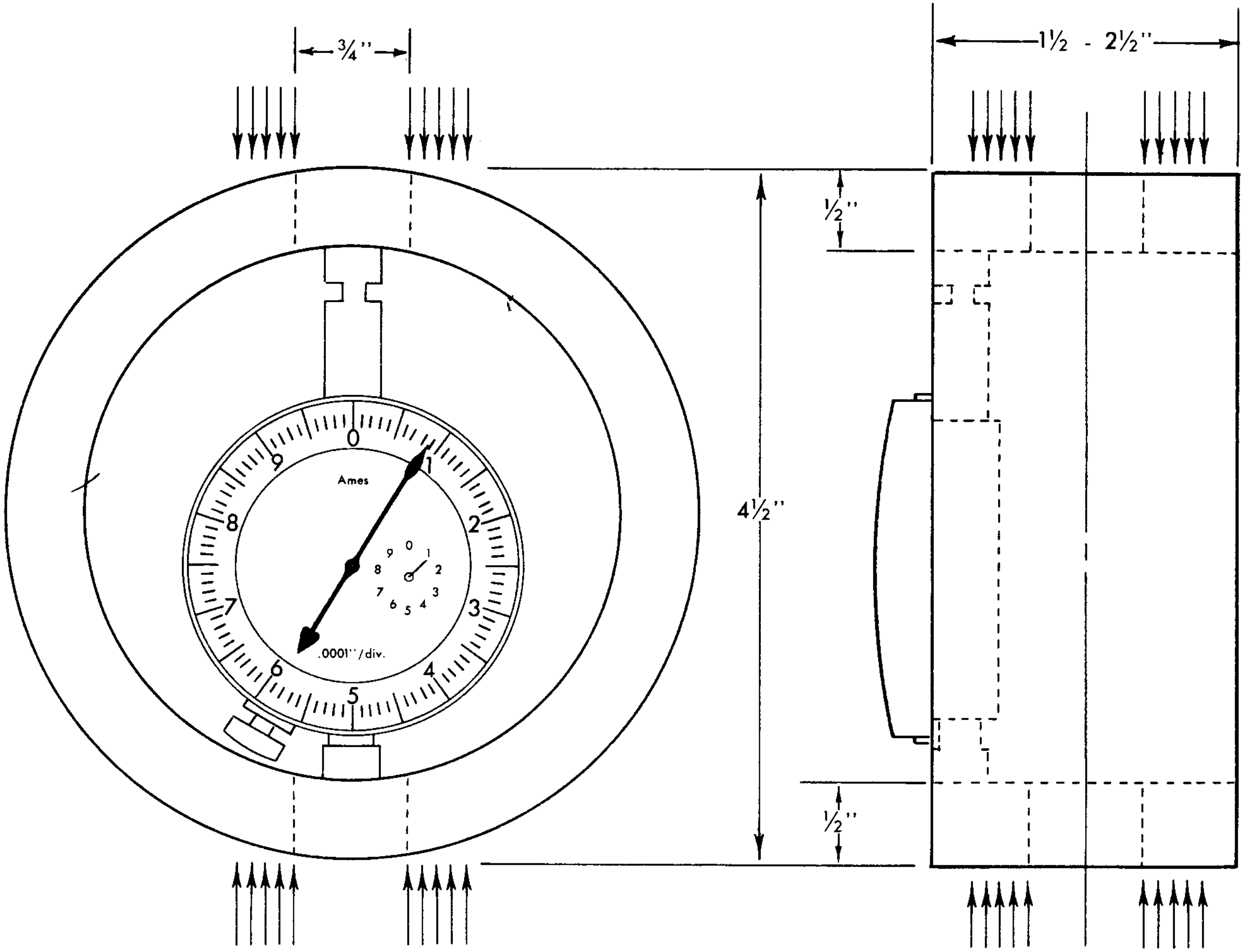


Fig. 7. RING-SHAPED BOLT LOAD INDICATOR FOR MEASURING TENSION IN ROOF BOLTS

fit the inner diameter of the ring and specially constructed shoes were fabricated for the ends to fit the inner surface of the ring and to increase gage stability. When the dial gage was placed in the unloaded ring, there was about 0.001 to 0.002 inch of prestrain in the dial indicator. This was necessary to insure a snug tight fit.

The feature of retractability of the dial gages has both some advantages and disadvantages. Among the advantages are:

(A) One dial gage can be used for several or all of the bolt load determinations.

(B) In water bearing strata, the gages are exposed only briefly during readings, and damage to the gage is minimized.

(C) Failure of the bolt when observations are not being conducted does not result in gage destruction.

(D) Cheaper overall cost of the method.

Among the disadvantages will be the difficulty in exactly locating the gage in precisely the same position each time a reading has to be made. Also, more time is involved in making the observations than if the gages remained in place.

In the final analysis, however, the greatly reduced cost as compared to a permanent indicator for each individual ring makes retractability the logical choice.

Ring Material and Finish

Primary requirements for the ring material, considering its function and possible use under the most adverse mining conditions are:

a. high yield strength, b. high tensile strength, c. high modulus of elasticity, d. cheap, and e. ease of fabrication.

These requirements were readily satisified by making the RSBLI from lengths of round tubing cut to the desired length. Cold drawn seamless tubing made from low carbon C1018 steel is readily available in a wide range of sizes and was therefore used.

The low carbon steel use, AISI No. C1018, has the following mechanical properties:

Tensile strength - 82,000 psi

Yield strength - 70,000 psi

% Elongation in 2" - 20

Rockwell hardness - B85

After the rings were cut and the diametrical holes drilled, the ends were ground in a lathe and the sides of the holes finished with a fine metal file.

Calculating Deflections

The choice of the ring material and dimensions of the RSBLI were governed primarily by the desire to achieve maximum sensitivity from dial gages for a given designed load. The desired deflection was a compromise between two extremes. If the deformation was too small, measured deflection would be too low and the sensitivity of the ring would be very poor. However, if the deflection is too high, the sensitivity will be very good but the maximum load carrying capacity of the ring will be too low. A reasonable deflection for the designed load would be from 0.05- to 0.075-inch under maximum load. The maximum load is, for all practical purposes, based on the yield strength of the bolt which is about 14,800 lbs. for a 5/8 inch high-strength bolt. The approximate dimensions of a ring that will have the desired deflection may be determined by means of equations given in engineering mechanics. Equations for computing the deflection of a plain ring (with no integral bosses or holes), loaded at opposite ends of a diameter by a concentrated force have been published by Timoshenko, Bach and Baumann, and Larard (5, 6, 7). The equation for a plain ring having a rectangular cross-section derived from Timoshenko follows:

$$\delta = \frac{Pr^2}{Eewh}\left\{ \frac{\pi}{4} - \frac{2}{\pi}\left(1 - \frac{e^2}{r^2}\right) + \frac{2e}{r}\left[\frac{2}{\pi}\left(1 - \frac{e}{r}\right) + 0.265\pi\right]\right\} \quad (1)$$

where δ = deflection of the ring in the direction of the loaded diameter, in.

P = applied load or tension in the bolt, lb.

r = radius of the centerline of the ring, in.

E = modulus of elasticity of the ring material, psi

w = width of the cross-section of the ring, in.

h = thickness of the cross-section of the ring, in.

$$e = r - \frac{h}{\ln\left(\frac{1 + h/2r}{1 - h/2r}\right)} \quad (2)$$

The measured deflections of a RSBLI will always be greater than the deflections computed by means of equations derived for plain rings for two reasons:

A. Weakening effect of the holes, and

B. Distributed loading along the periphery of the hole instead of theoretically assumed concentrated loadings at the ends of the diameter.

The above equation can be used for determining the approximate dimensions of the ring to provide sufficient sensitivity at the designed load. The exact relationship between the deflection of the ring and the applied load can be determined by calibration either with load cells or any similar device and would take into account the weakening effect of the hole and distributed loading.

Stress Calculations

To obtain satisfactory elastic behavior of a ring, the maximum stress must be lower than that required to produce a permanent set in the material. Equations for computing the maximum bending moment in a plain ring loaded at opposite ends of a diameter are given in the literature (5, 6, 7). The following equation derived from Timoshenko's results gives the maximum stress for a ring with rectangular cross-section:

$$\sigma_{max} = \frac{Pr}{\pi ewh} \left(1 - \frac{e}{r}\right) \left(\frac{h/2 - e}{r - h/2}\right) \qquad (3)$$

Where σ_{max} = maximum fiber stress across the inner cylindrical elements passing through the load line, psi.

All other notations are similar to those given previously.

This equation for plain rings does not accurately apply to rings with holes and distributed loading since both modifications influence the stress distribution in the plane containing the maximum bending moment. The stress calculated by the above equation will be below the actual maximum stress induced at the periphery of the holes since they act as "stress raisers". The above equation can be used to calculate approximately the stresses in the ring after an appropriate safety factor has been applied for the presence of the "stress raisers".

Theoretical Considerations

The deflections and maximum stresses for an arbitrarily selected ring size with different widths were calculated:

O.D. = 4.5 inches
I.D. = 3.5 inches
h = 0.5 inches
r = 2.0 inches
w_x = 1.40 inches,
= 1.75 inches,
= 2.00 inches,
E = 30 x 10^6 psi,
P = 10,000 lbs.

It was found that a ring width of 2 in. would resist a load of 10,000 lb. and provide maximum sensitivity.

LABORATORY TESTS

Introduction

It has been emphasized in the past by the authors that in the evaluation of the efficiency of roof bolts, two distinct but supplementary testing techniques are necessary to provide a complete picture of the performance of a bolting system (3, 4). Similar criteria are called for in the evaluation of the applicability of a given bolt load indicator that is used to evaluate the efficiency of the roof bolt. These testing techniques are:

(A) Dynamic testing or applying load at a rapid rate and observing the deflection of the ring along its instrumented diameter for each corresponding load level. This is carried out up to the capacity of the bolt, and

(B) Static testing or observation of the changes in bolt load with time as manifested by the change in the linear deflection of the ring gage once the desired load level has been reached. This is carried out until stability is attained.

The laboratory tests carried out in this report involved calibration of the ring gage by a dynamic testing procedure as well as a static or long-term testing procedure.

Dynamic Calibration

Procedure

Fig. 8 shows the testing arrangement for calibrating the ring gages. A high-strength 5/8-in. roof bolt of the appropriate length, A, is inserted through the ring cell, B, a roof bolt load cell, C, the bolt puller frame, D, and finally through a hollow-ram jack, E, and held in place with a nut, F. There were two other load indicators employed with the ring cell that was being tested: (a) a roof bolt load cell connected to a BLH type M strain indicator, and (b) the hollow-ram jack pressure gage combination used in the underground installation. The double check was made to more accurately assess the calibration characteristics of the ring gage.

The system was first cycled at least four times in order to remove the slack in the system and to stabilize and remove any hysteresis that may

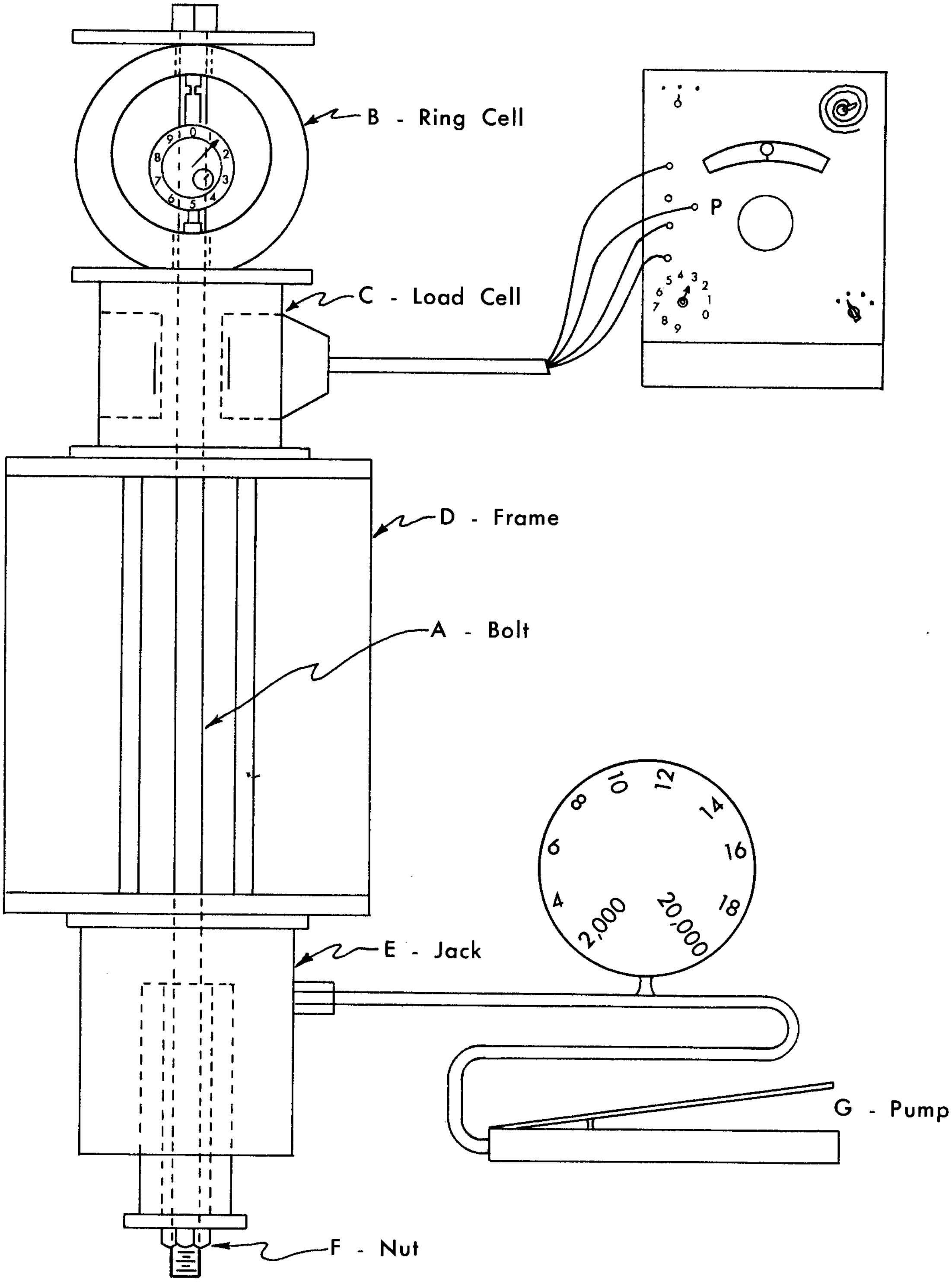


Fig. 8 ARRANGEMENT FOR RING GAGE CALIBRATION

be present. When pumping G, load was applied to the bolt compression cells B and C. The diametrical deflection of the ring was measured by the dial gage. By noting the difference between the initial zero reading and the loaded value, the deflection of the ring corresponding to a given load was obtained. Proceeding in this manner by loading in increments of 2400 lbs. and taking readings, the calibration chart of a particular ring was obtained.

Results

Fig. 9 shows the graph of the load versus the deflection for one group of rings of approximately the same size. The widths of the groups of rings varied from 1.9- to 2.1-inches. For any given ring, an essentially linear relationship is exhibited between the deflection and the applied load. The slight differences in deflection at each load level is due to the difference in size of the rings since the rings with larger widths will naturally have less deflection for the same load level.

Fig. 10 shows the graph of the applied load versus the observed deflection for the three ring sizes tested. For each ring size the deflection factor, which is the ratio of the load to the corresponding deflection, was computed. Obviously, the wider rings have larger deflection factors. A summary of the data obtained in calibration of the 1.75- and 2.00-inch width rings are given in Table A.

The above observed results are consistently repeatable and the percentage difference between the largest and smallest readings for a given load are well within the sensitivity of the dial gages and is much better than the expected accuracies of 50 to 100 lbs. per gage dial division.

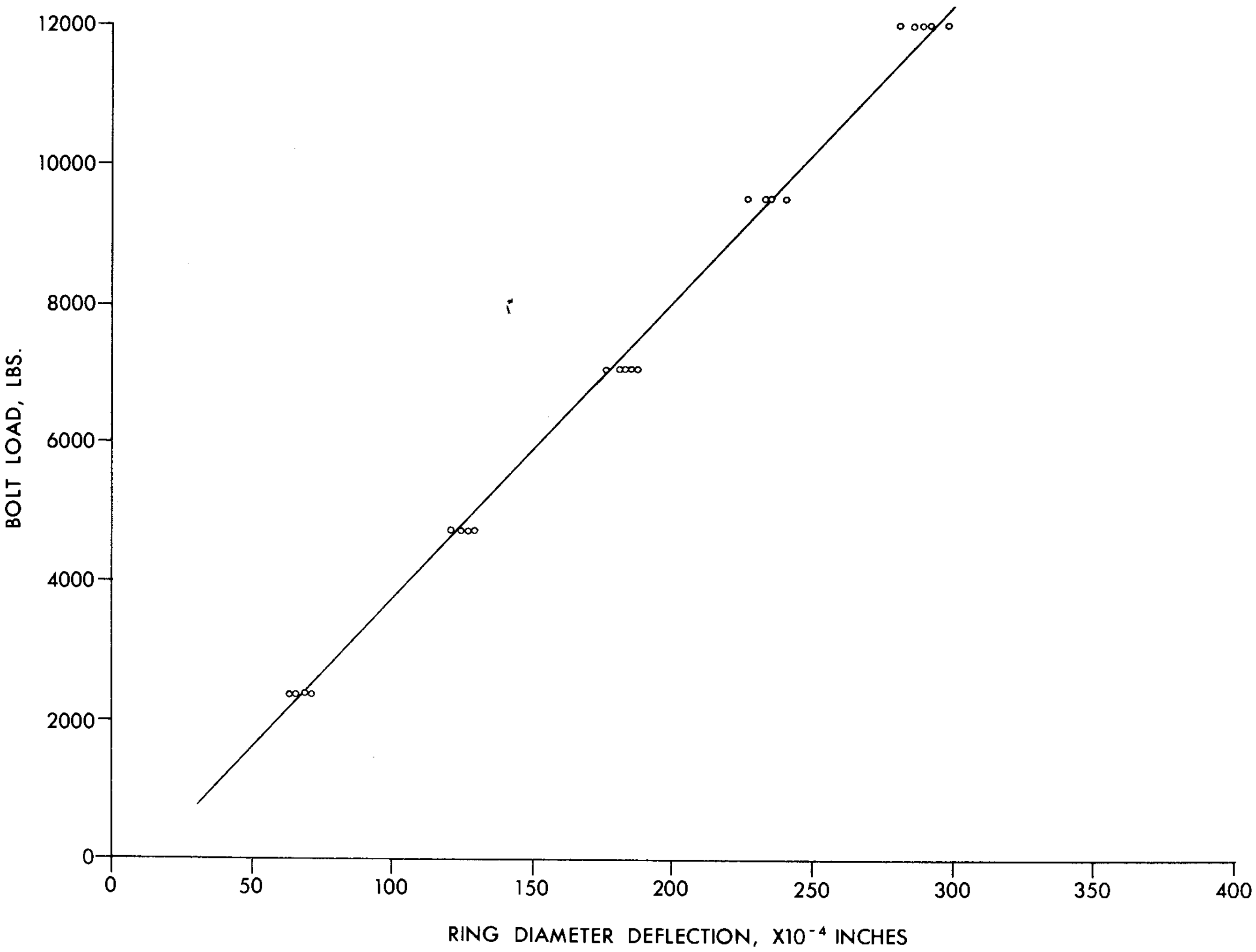


Fig. 9. CALIBRATION CURVES, RING GAGES OF APPROXIMATELY EQUAL SIZE

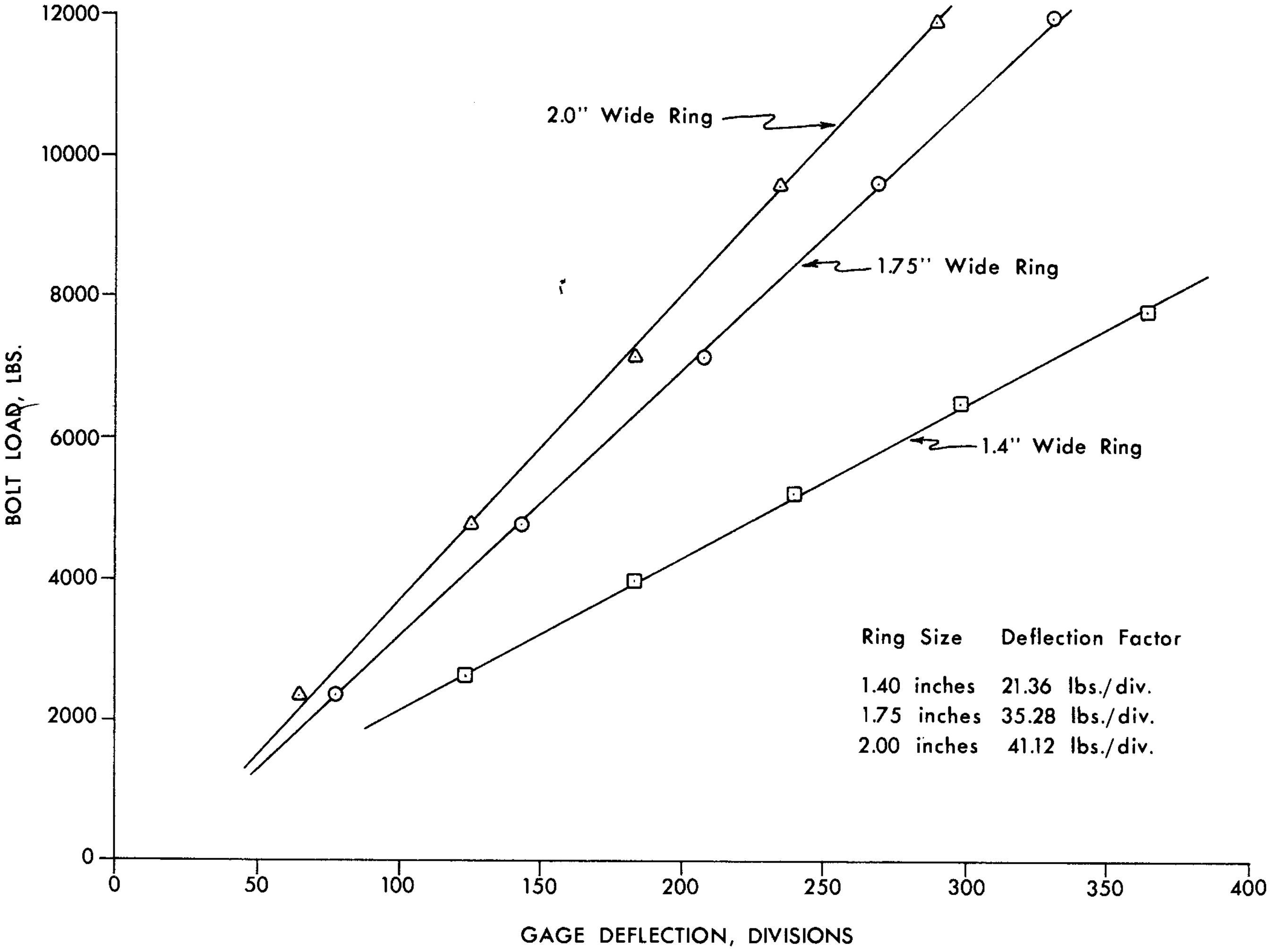


Fig. 10. CALIBRATION CURVES FOR THREE DIFFERENT RING SIZES

TABLE A

Summary of Ring Calibration:

LOAD lbs.	2'' -Wide Ring Deflection*						
	R	S	P	Q	T	U	Ave.
0	0	0	0	0	0	0	
2385	69	66	64	69	71	69	66
4770	126	125	121	129	128	126	126
7155	182	183	176	187	185	184	183
9540	233	235	227	241	236	235	235
11925	287	292	281	298	292	290	290
Sensitivity lb/div.	41.55	40.84	42.44	40.02	40.84	41.12	

LOAD lbs.	1 3/4'' -Wide Ring Deflection*						
	A	B	C	D	E	F	Ave.
0	0	0	0	0	0	0	
2385	78	75	79	78	75	77	77
4770	145	143	147	144	144	143	144
7155	210	208	213	209	214	206	210
9540	270	269	274	270	282	266	272
11925	336	335	341	336	350	330	338
Sensitivity lb/div.	35.49	35.60	34.97	35.49		36.14	35.28

* (X10^{-4} inches)

Half divisions could be readily estimated so that the above sensitivities could still be divided by two.

Static Calibration

Procedure

There were two distinct tests carried out under long-term conditions. First, the load was kept constant with time and secondly, the load was varied with time. The first test was carried out in order to test the stability of the bolt load indicator while the second test was to determine whether the load indicator could track the minutely changing bolt load with time.

The test arrangement for the constant load tests was similar to that shown in Fig. 8. An installed load of about 10,000 lbs. was applied through a 5/8-inch high strength bolt. This load was held at this level by closing the valves of the pump, and observing the pressure gages and roof bolt load cell for fluctuation. No bleed-off was expected since steel does not creep under normal room temperatures when loaded within the elastic limits. The only possible cause of bleed-off was for leaks in the hydraulic jack-pressure gage-pump connections which were minimized by closing the valves of the set after the desired load was reached.

In the second test, an underground installation was simulated with specially prepared anchorage specimens. The shell used was an experimentally designed conically shaped type. This permitted the simultaneous testing of two new innovations in the roof bolting industry - a revolutionary shell and a new bolt load indicator. The test arrangement is shown in Fig. 11. When the desired load was reached by rotation of the bolt, observation of the changing bolt load with time began.

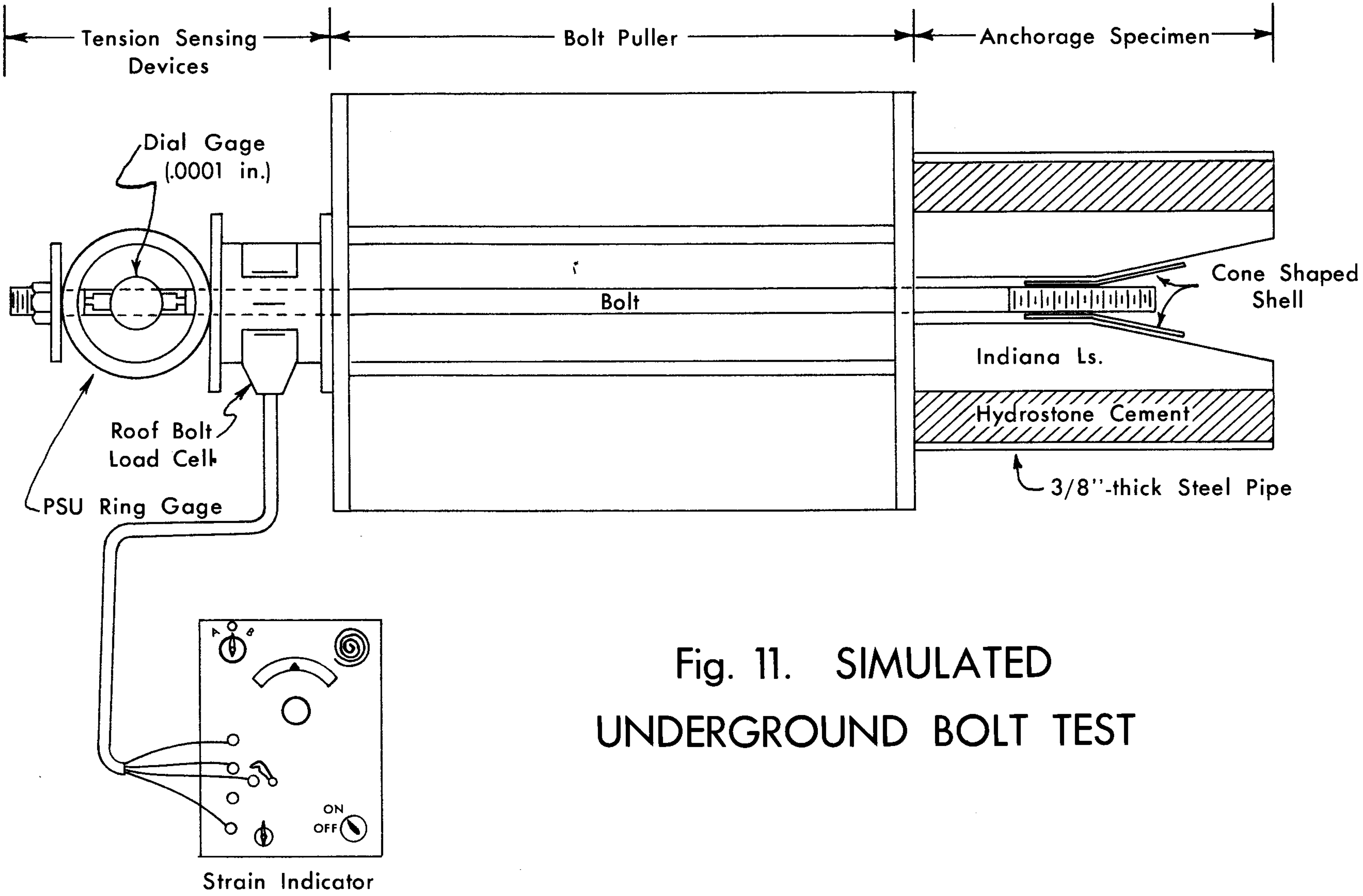


Fig. 11. SIMULATED UNDERGROUND BOLT TEST

Test Results

There was no change in bolt load with time as confirmed by the three load sensing devices employed. This test has therefore shown the dependability of the RSBLI as a blot dynamometer.

The result of the second test (see Fig. 12) showed that the changing bolt load with time was faithfully reproduced by the load indicators. It will be noted that the load sensing devices agree very closely and tend to be parallel to one another. There was a slight disagreement which appears to be approximately constant from the start to the conclusion of the test. This difference amounted to 45 lbs. at the start to 80 lbs. at the end of the test and is relatively insignificant.

CONCLUSIONS

The principle of operation of the ring cell has been based on the proving ring, a highly accurate and reproducible device in common use as a standard for calibrating testing machines. A plain ring with sufficient width was drilled along the opposite ends of a diameter and a dial gage was attached to measure the deflection. Calibration in the laboratory revealed that these cells reporduced data consistently with a high degree of accuracy and sensitivity.

Twelve gages have been constructed and calibrated, and are ready for field use. When correlated with differential sag measurements, a very effective instrumentation system will be available for detecting roof conditions.

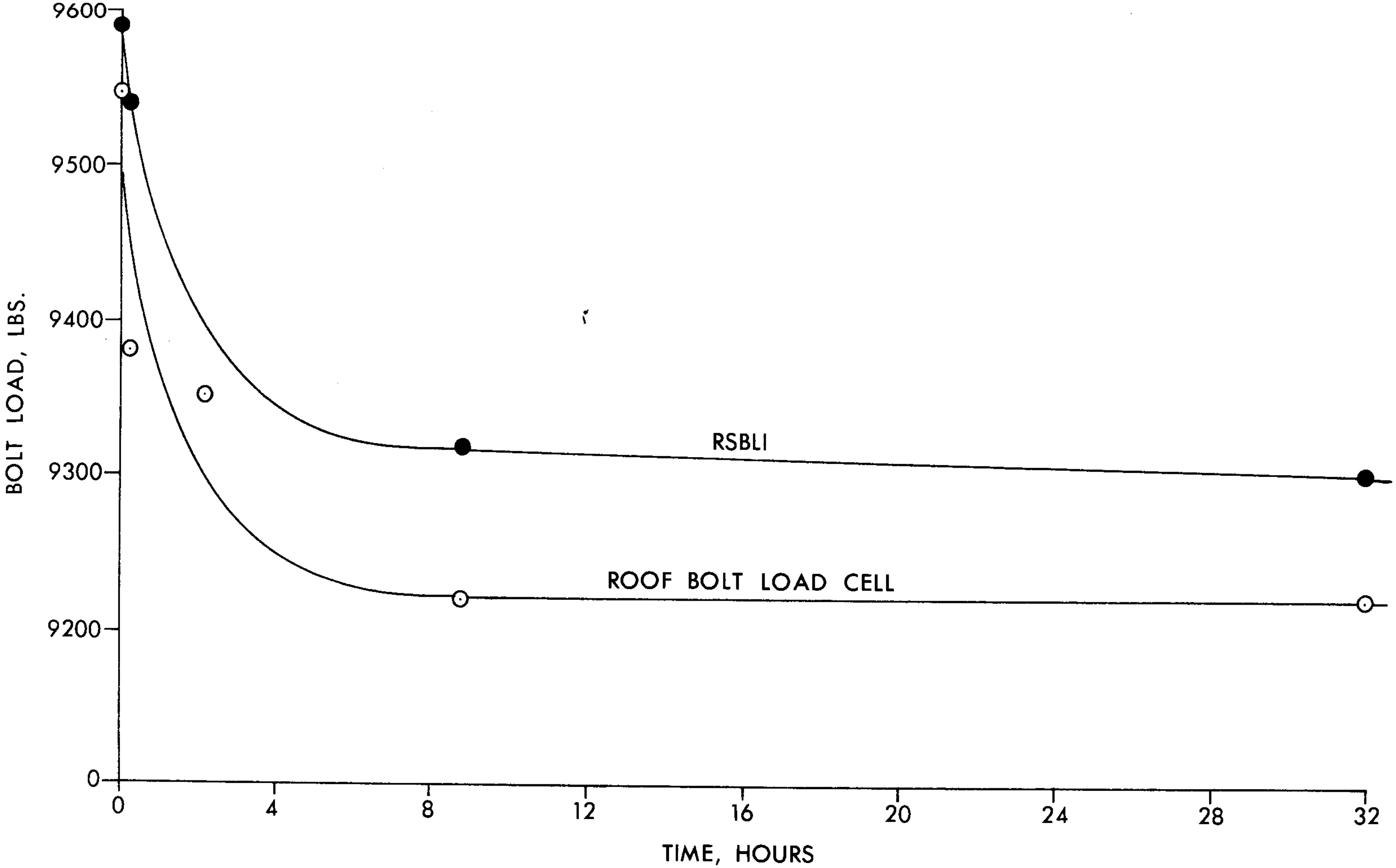


Fig. 12. COMPARATIVE PERFORMANCES OF TWO DIFFERENT BOLT LOAD INDICATORS

C. GENERAL CONCLUSION FROM FIELD AND LABORATORY TESTS WITH RECOMMENDATIONS FOR FUTURE RESEARCH

Field tests revealed that although differential sag measurements can be made very accurately with the equipment designed, bolt load measuring equipment presently available does not combine accuracy with simplicity and economy. Therefore, ring cells were designed, tested, and calibrated and are now ready for underground use. A very fine system for underground instrumentation is now available.

Another underground installation is to be made immediately to test the new system to see if it will perform as well as laboratory tests indicate. With the more sensitive system, better correlations between bolt load bleed-off and differential sag are expected. The effect of various operations in the mining cycle on roof conditions will be determined, especially cutting and blasting. It is recommended that an installation in a continuous mining section be made. It would be important to see if bed separation commences almost instantly upon exposure of the roof or whether it is primarily accelerated by blasting activity.

The ultimate objective, of course, is to minimize or prevent bed separation which leads, usually, to roof failure. However, to date only trial-and-error procedures have been generally utilized to improve on existing roof support systems. Even when apparently successful, there is no scientific proof that the new support system was responsible or whether improvements in natural conditions produced the desired results. With the measuring system described in this report, the effect of changes in roof control procedures can be directly measured. Thus, the new support system can be instantly evaluated, and depending upon the data, can be discarded, modified or continued without change. Thus costly trial-and-error procedures are avoided, and safety is greatly enhanced.

It is anticipated that bolt anchorage efficiency can be greatly improved. Research is now underway to develop improved systems. It is recommended that mechanical anchorage be designed to minimize rock stress concentrations and a better distributed anchorage be achieved, possibly by employing resins.

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