March 9, 1971 J. M. WHITING 3,568,450

METHOD FOR COUNTERSTRESSING IN SITU ROCK FOR SUPPORT OF UNDERGROUND OPENINGS

Filed May 28, 1969 6 Sheets-Sheet 1

PRIOR ART

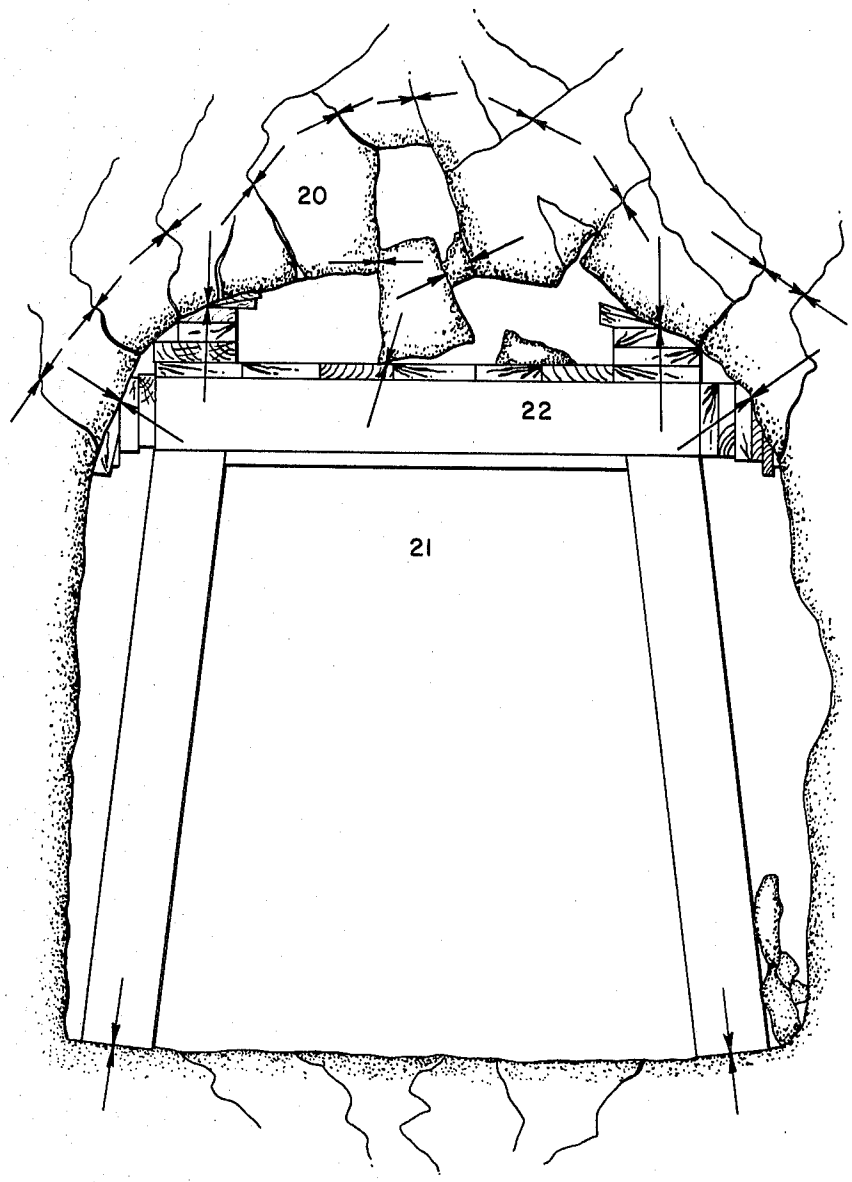


FIG. 1

INVENTOR
JERRY M. WHITING

Robert Ellsworth Lee
ATTORNEY

March 9, 1971 J. M. WHITING 3,568,450
METHOD FOR COUNTERSTRESSING IN SITU ROCK
FOR SUPPORT OF UNDERGROUND OPENINGS
Filed May 28, 1969 6 Sheets-Sheet 2

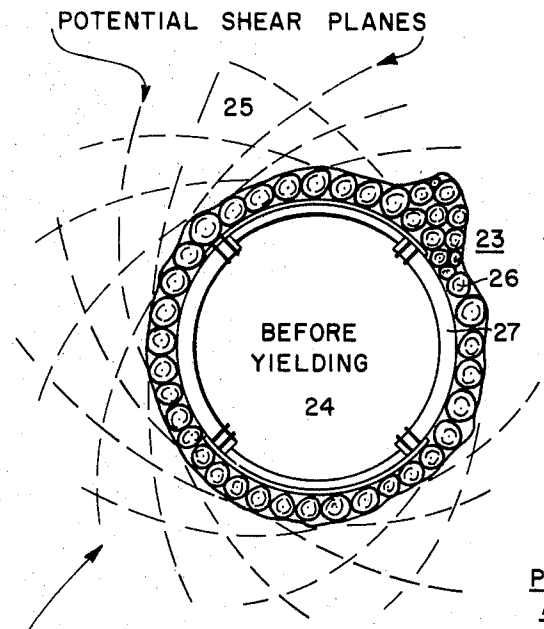


FIG. 2A

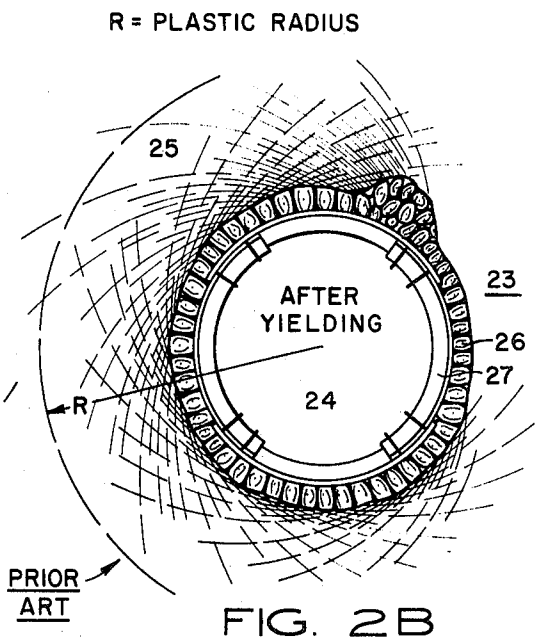


FIG. 2B

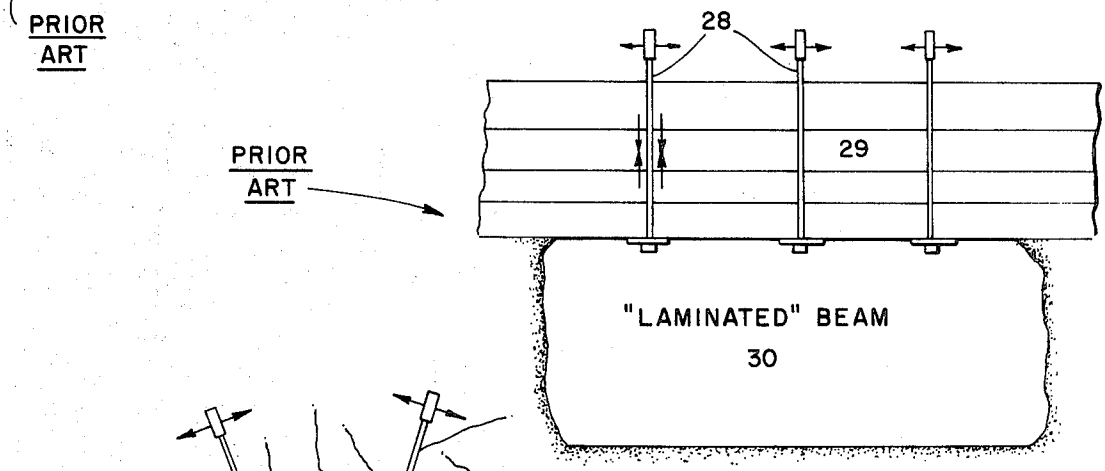


FIG. 3

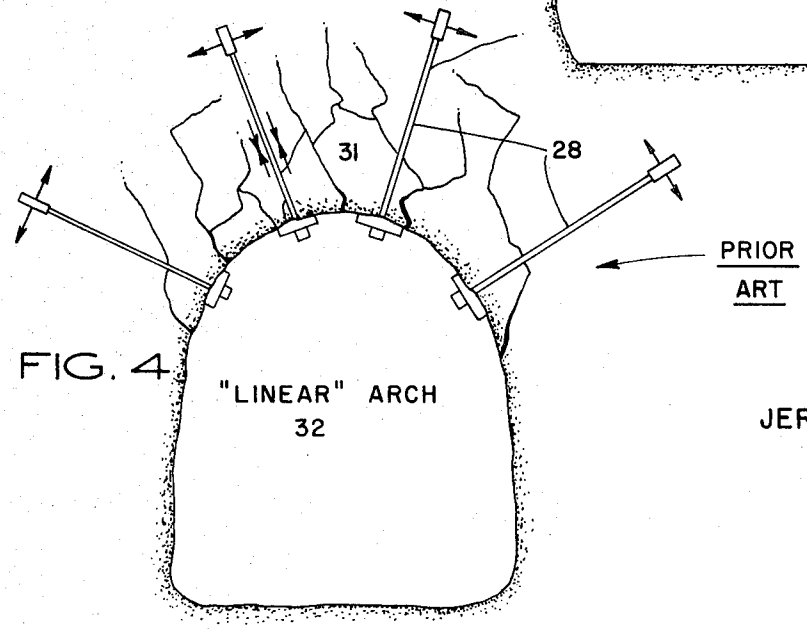


FIG. 4

INVENTOR
JERRY M. WHITING

Robert Ellsworth Lee
ATTORNEY

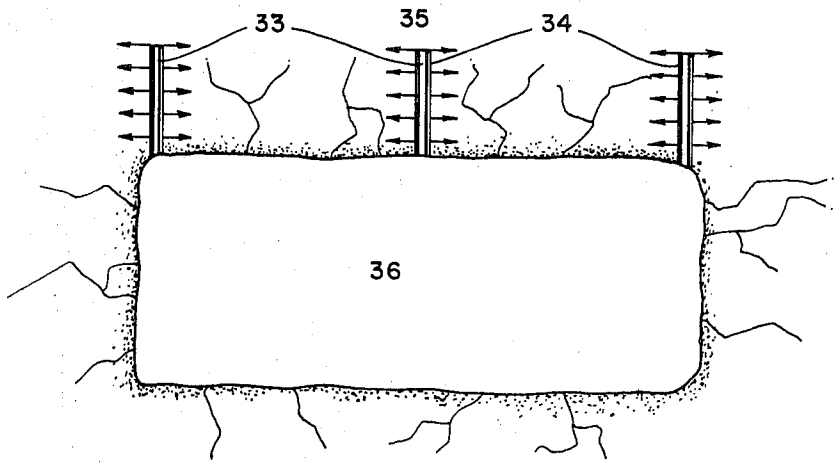


FIG. 5

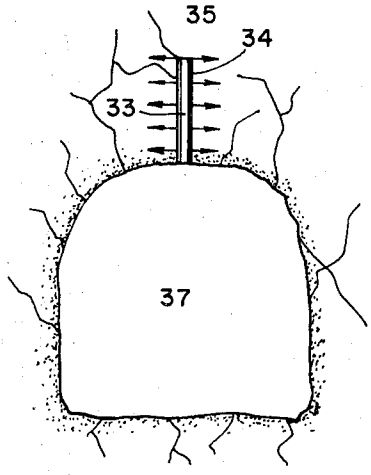


FIG. 6

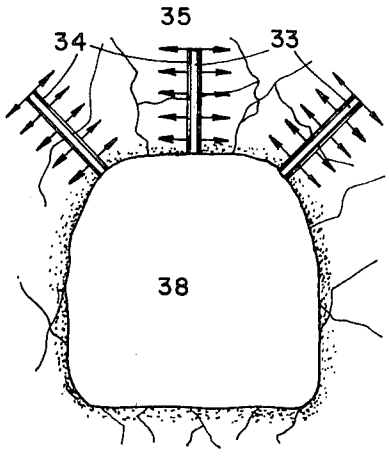


FIG. 7

INVENTOR

JERRY M. WHITING

Robert Ellsworth Lee

ATTORNEY

March 9, 1971 J. M. WHITING 3,568,450
METHOD FOR COUNTERSTRESSING IN SITU ROCK
FOR SUPPORT OF UNDERGROUND OPENINGS
Filed May 28, 1969 6 Sheets-Sheet 4

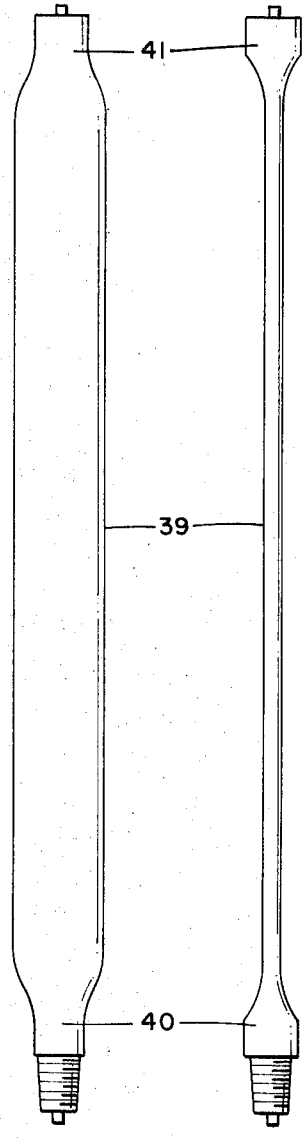


FIG. 8

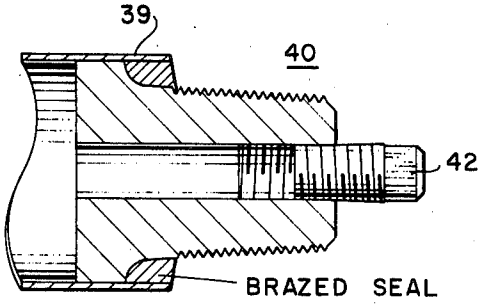


FIG. 9A

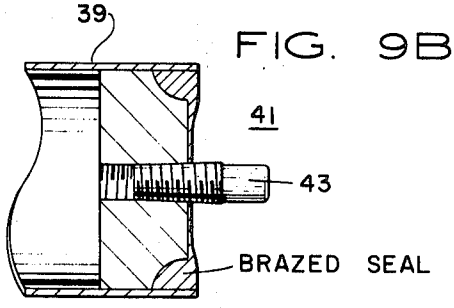


FIG. 9B

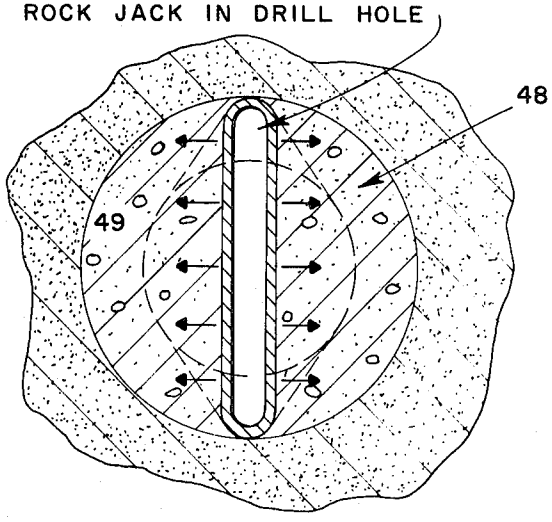


FIG. 10

INVENTOR
JERRY M. WHITING

Robert Elsworth Lee
ATTORNEY

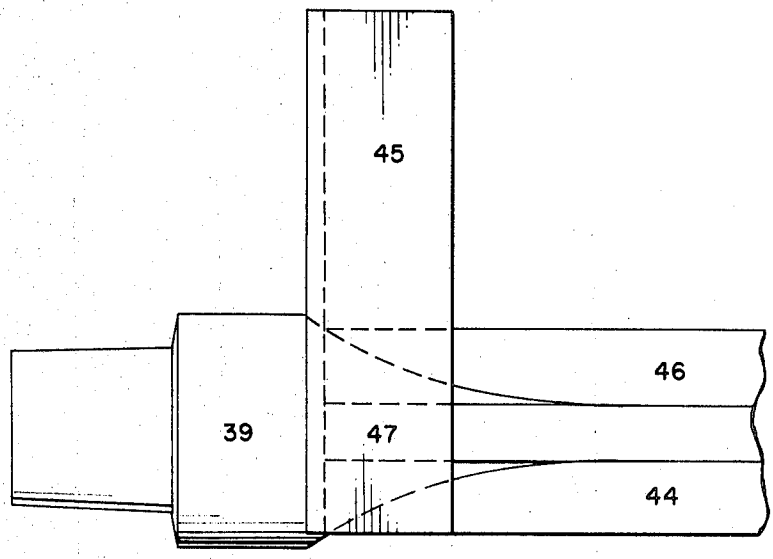


FIG. 11A

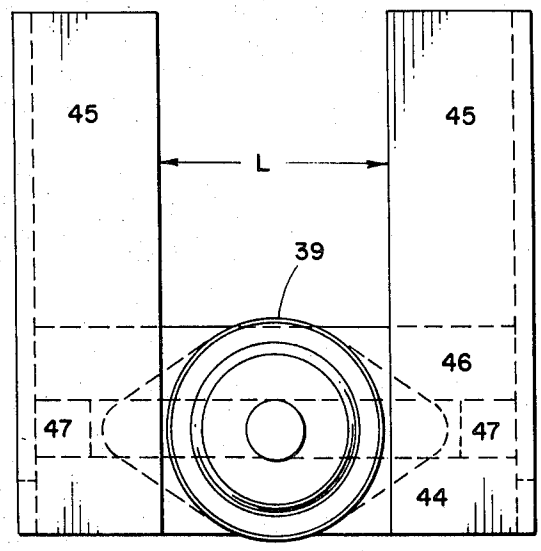


FIG. 11B

INVENTOR
JERRY M. WHITING

Robert Ellsworth Lee
ATTORNEY

March 9, 1971 J. M. WHITING 3,568,450
METHOD FOR COUNTERSTRESSING IN SITU ROCK
FOR SUPPORT OF UNDERGROUND OPENINGS
Filed May 28, 1969 6 Sheets-Sheet 6

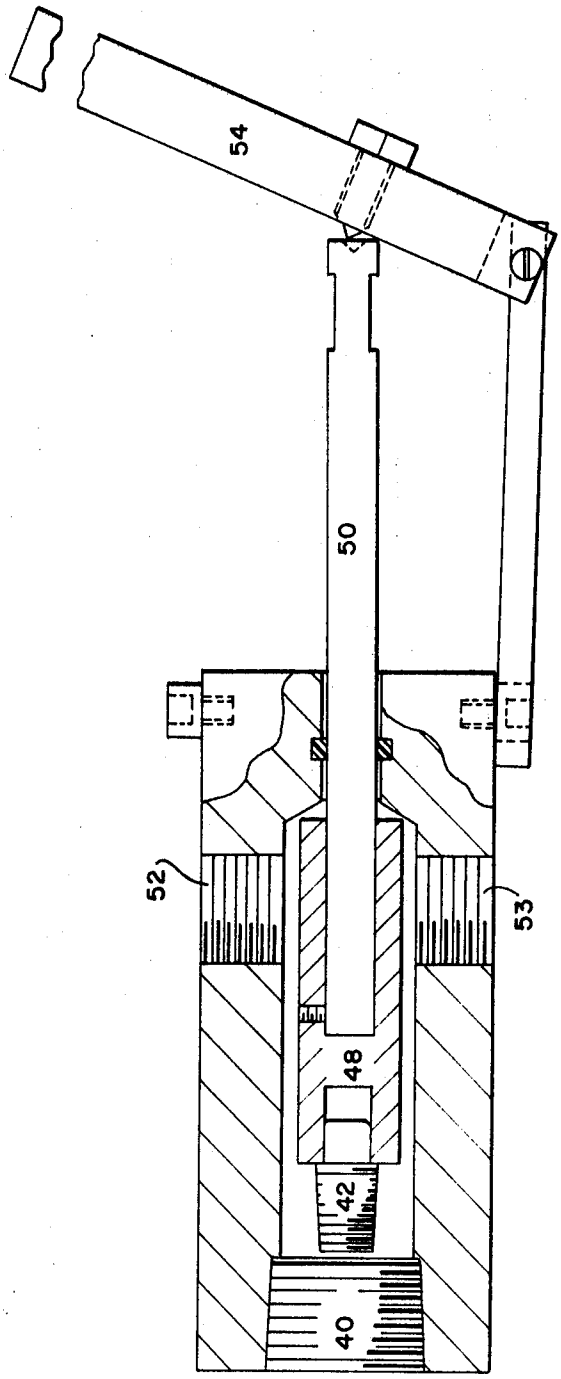


FIG. 12

INVENTOR
JERRY M. WHITING

Robert Ellsworth Lee
ATTORNEY

United States Patent Office 3,568,450 Patented Mar. 9, 1971

3,568,450

METHOD FOR COUNTERSTRESSING IN SITU ROCK FOR SUPPORT OF UNDERGROUND OPENINGS

Jerry M. Whiting, Dallas, Tex., assignor to Atlantic Richfield Company, a fractional part interest

Filed May 28, 1969, Ser. No. 828,513
Int. Cl. E21d 21/00
U.S. Cl. 61—45 4 Claims

ABSTRACT OF THE DISCLOSURE

In rock surrounding an underground excavation which must have a man-made support system to ensure a required degree of structural stability and which is subjected to certain stress conditions, an inflatable device or rock jack is inserted into a drill hole or slot in the rock. The rock jack is inflated slightly by fluid pressure to take up any space between the jack and the in situ rock and is subsequently pressurized to the limit of its capability. High compressive force is transmitted to the rock, thus creating compressive stress in monolithic rock and increasing confinement of and friction between proximal blocks of rock which are separated by narrow fractures, tension cracks, joint planes or similar structural defects. Such action maintains or increases the natural capability of the rock to support itself and to remain stable by utilizing the inherent compressive strength of the rock.

BACKGROUND OF THE INVENTION

The invention pertains to mining and particularly relates to supporting underground openings.

Rock below the surface of the earth is under stress. The magnitude of the stress often becomes appreciable at depths where mining operations are carried out. The origin of this "inherent" stress has been the subject of research for several years. Many causes have been suggested. The most important are outlined below:

(a) The uniform inward pull on the earth's crust by the force of gravity creates both vertical and lateral stresses on rock at depth. Thus, a two-dimensional section of the earth's crust can be likened to a circular steel ring subjected to external radial forces. In place of the external load, however, it is the weight of the rock itself which creates the radial (vertical to an observer) component. The weight of the overlying material tends to compress the rock, and when squeezed in a vertical direction, the rock tries to expand laterally. This expansion is resisted by the surrounding rock so that some magnitude of compressive lateral stresses are present on any confined volume of rock at depth.

(b) Deformation of the earth's crust accounts for "inherent" stress at some localities. Folding and faulting are evidence of intense stress buildup. Stresses which have remained stored in the elastic deformation of the rock or which are the result of presently active faulting may be present in some portions of the earth's crust.

(c) Expansion during crystallization or recrystallization during cooling of magmas or metamorphic changes have been suggested as a cause for "inherent" stress.

It should be clearly pointed out that "inherent" stress at a particular underground location may be caused by any combination of these factors. For this reason, attempts to compute "inherent" stress at certain depths by using only the weight of overlying material as a basis have often proved to be grossly inaccurate. Some mines in the Alps, for example, have accumulated data which show that the greatest portion of "inherent" stress encountered there is caused by active tectonic movement. Nevertheless, the weight of overlying material plays the prime role

in producing "inherent" stress at most subsurface locations.

When an opening is made in a material which is under stress, there results an internal rearrangement of the stress distribution which creates a stress concentration in the proximity of the opening. The stresses immediately adjacent to the opening may change from compression to tension, or may increase or decrease in magnitude several times. The resulting distribution depends on the shape and orientation of the opening, the original ("inherent") stress distribution, and Poisson's ratio of the rock.

Stress concentrations caused by discontinuities were not known for many years after the start of structural and machine design. Even after the phenomenon was recognized and applied to machine design, it was many years before anyone realized the structural similarity of a rivet hole in a piece of metal and a circular opening in the earth's crust.

The difference between the "inherent" stress and the resulting stress after an opening has been formed in rock may be referred to as "induced" stress. It is of prime importance in ground support and rock pressure problems. Woodruff succinctly states:

> "The realignment and concentration of pre-existing stresses during excavation of underground openings appears to be the most important single factor tending to destroy the structural stability of rock around an opening."

(Woodruf, Seth D., "The Causes of Structural Deterioration of Rock Around Mine Openings," Engineer of Mines Thesis, University of Idaho, Moscow, Idaho, 1956, pp. 1–88.)

The above fact should be considered in light of the fact that the tensile and shear strengths of most rocks are only about 4 percent and 10 to 15 percent, respectively, of the rock's compressive strength. Because of this anistropic behavior of rock, the presence of minor tensile stress and moderate shear stress is far more important than compressive stress in determining the stability of an opening.

Tensile stress may not be present on the periphery of all openings; but it will often be present at some period in the history of an opening in sufficient magnitude to cause tensile cracks if one of the principal stresses, which can be at any orientation, exceeds the other (assuming analysis of a two-dimensional cross-section) by a ratio of about 3 to 1 or more. Woodruff (ibid.) comments on such a situation as follows:

> ". . . the maximum stress at the periphery of an opening is a compressive stress tangent to the periphery. This stress is located at the ends of the horizontal axis [where the vertical exceeds the horizontal stress by a sufficient ratio] in the case of circles and ellipses, and at the corners in the case of rectangular openings.
>
> Most important, from the standpoint of opening stability, are the tensile and shear stresses. The maximum tensile stress occurs at the ends of the vertical axis . . . [where the vertical exceeds the horizontal stress by a sufficient ratio]. Significant shear stresses for the circular opening occur at the sides . . ."

Thus, physical failure of an opening takes place because of excessive "induced" stresses; these may be shear, compressive, or tensile. However, shear and tensile stress are the most critical if they are present in sufficient magnitude; this possibility is very likely in many situations and depends on the ratio of principal stresses which are acting on the rock adjacent to the opening. In a stress field where the horizontal stress equals the vertical stress, a compressive stress is present around the entire periphery. However, where only a uniaxial stress is present, a tensile stress concentration is created in a zone centered about the axis of the stress. (Obert, L., Duvall, W. I., and

Merrill, R. H., Design of Underground Openings in Competent Rock, U.S. Bureau of Mines Bulletin 587, 1960, pp. 1–17.)

Fundamental as it may appear, it should be emphasized that gravity acts on any rock in the overhead portion of an opening which has been loosened or displaced by tensile fracturing and/or shearing. The material overhead, therefore, constitutes the greatest potential safety hazard. Walls and ribs may crush, slab off, slough and even allow the back (roof) to converge on the opening. Floors may crack and some times heave. But, troublesome as these failures may be, they cannot compare with sudden uncontrolled roof failures. In summary, therefore, the most troublesome features attending ground failure are low tensile strength of rock and roof or back failures.

Any opening in a medium under stress creates "induced" stresses by its very existence. Nothing can be done to prevent "induced" stresses (compressive, tensile, and shear stress concentrations) from appearing at the periphery. Rather, there are three alternative approaches:

(a) Artificial supports can be used to hold broken rock in place after it has cracked due to excessive "induced" stresses. This has been, and still is, the most widely used solution in mining. It requires little knowledge of stress-strain phenomena because each particular solution is mainly a question of economics.

(b) A second approach is to create "induced" stresses which are beneficial (or least destructive) to the stability of the opening by planning the location, shape, size and orientation of the opening. Most of the emphasis in the engineering field of rock mechanics to date has been toward this type of solution.

(c) A third approach has scarcely been touched upon in research or practical work thus far; that is, to prevent or change undesirable "induced" stresses by use of some mechanical device. This method is most analogous to prestressing concrete structures, a technique that is widely applied in the construction industry. (Lin, T. Y., Prestressed Concrete Structures, John Wiley and Sons, Inc., New York, N.Y., 1955, pp. 1–79.) It would supplement the second approach and have the marked advantage of not having to make the mining sequence or plan tailored to the openings. Often there is no choice as to where an opening should be located, or how it should be oriented; and the desirable shape structurally may be undesirable from a production viewpoint. It is the third approach that is the subject of this invention.

The concept of modifying "induced" stresses mechanically so that their effect on the stability of an opening is minimized was reported by J. J. Reed during the 1956 Symposium on Rock Mechanics. ("Mine Openings Stabilization by Stress Redistribution," Quarterly of the Colorado School of Mines, July 1956, pp. 65–97.) What Reed did was to reduce high compressive tangential stresses and resultant high shear stresses at the periphery of an opening in an isostatic stress field by mechanically inducing compressive stresses some distance from the opening.

The greatest number of rock failures, however, are encountered in openings located in a nearly uniaxial stress field where tensile stresses or strains tend to cause fracturing and subsequent displacement of pieces initiates failure of the overhead supporting rock structure. Thus, in most instances, the need is to counteract tensile stresses or strains by increasing, as opposed to reducing, compressive stress (rock confinement) sufficiently to enable natural structures such as "linear arches" or "Voussoir arches" to develop the shear stresses such that they are capable of resisting. (Woodruff, Seth D., Methods of Working Coal and Metal Mines, vol. 1, Pergamon Press, London, 1966, pp. 282–287.)

The present invention is an extension of the above concept. It was reduced to practice and successfully proved by the inventor while he attended graduate school.

(Whiting, Jerry M., "Counterstressing Rock for Ground Support," Ph.D. Thesis, Stanford University, Department of Mineral Engineering, June 1968.)

SUMMARY OF THE INVENTION

As described below, rock bolts create a moderate compressive force (i.e. 10,000 lb.) normal to the rock surface which helps hold rock units in position. A new method has been found, however, in which a high compressive force (i.e. 150,000 lb. or more) is transmitted tangential to the rock surface in those portions of the opening, particularly in the roof or back, which are subjected to "induced" tensile stress or strain. Such a method is designated as "counterstressing in situ rock," and accomplishes one or more of the following useful results:

(a) Absorbs "induced" tensile stress, thus delaying or eliminating tensile fracturing and consequent reduction of the particle-to-particle fraction which maintains shear strength.

(b) Increases the effective shear strength of the rock by increasing the lateral confinement of the rock.

(c) Increase the lateral compressive stress components in a "linear arch" or "Voussoir arch" by pressing together the proximal blocks of rock comprising such a structure and maintaining sufficient lateral thrust on abutment regions to hold such a structure in place.

(d) Preserves the structural integrity of the rock by forcing every unit tightly together into a single structural unit.

(e) Eliminates or reduces the amount of rigid supports such as sets, props, and the like, that are used, or increases spans and recovery.

One practical device for affecting counterstressing of in situ rock is a "rock jack." A rock jack is simply an inflatable, fluid pressure maintaining, high strength sheet metal container which is inserted into a drill hole or prepared slot in the rock. Any air space between the jacks' faces and the rock is filled with relatively unyielding solid material such as hardened grout, cement, concrete, or epoxy resin. The jack is filled with similar material in a fluid, unhardened condition and is subsequently pressurized to the limit of its capability, somewhere between 3500 or 5000 p.s.i. or higher, depending upon its design.

During pressurization, the jack expands slightly while taking up normal yields of materials and cracks between proximal blocks of rock. The total compressive force transmitted to the rock is the product obtained by multiplying the area of the face of the jack by the contained pressure per unit area. For example, 2⅜-inch wide by 28-inch long jacks have been tested and found to exert a total force more than 150,000 lb. at 3500 lb. per sq. inch. A jack's effectiveness in accomplishing the results listed above is directly related to the total force it is capable of exerting and maintaining up to the limit of the surrounding rocks' capacity to withstand such force. Thus, care is taken to have the jack filled with material which will undergo minimum shrinkage (and, hence, cause minimum pressure reduction upon hardening.

No method of ground support is a cure-all, including this invention. Experienced men must identify rock and stress conditions which indicate counterstressing is an appropriate technique. In general, those conditions will be similar to those where the now familiar method of rock bolting can be successfully applied, excluding thinly bedded strata which may buckle upon application of high tangential compressive force. Blocky, brittle rock, particularly where the blocks are sufficiently large to encase entire rock bolts and, consequently, where there is some danger of apparently properly bolted rock masses falling out of place, seems to offer an ideal area of application. In most situations, it is envisioned that rock bolts and rock jacks would be used together to provide the best possible support for high value openings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings.

FIG. 1 illustrates the prior art rigid set method of supporting an underground opening.

FIGS. 2A and 2B illustrate the prior art yieldable set method of supporting an underground opening.

FIGS. 3 and 4 illustrate the prior art method of supporting an underground opening by using rock bolts.

FIGS. 5, 6, and 7 illustrate the counterstressing or rock jack method of supporting an underground opening according to the present invention.

FIG. 8 shows side elevations of a rock jack of the type used by the inventor.

FIGS. 9A and 9B are drawings of the inlet and outlet ends of the rock jack shown in FIG. 8.

FIG. 10 is a schematic drawing illustrating the positioning and expansion of a rock jack in a drill hole.

FIGS. 11A and 11B are drawings of a frame to aid in forming rock jacks.

FIG. 12 is a drawing of a valve which allows rock jacks to be plugged while under pressure.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Besides eliminating the opening altogether as is done by hydraulic or rock fill, there are only three general types of artificial supports when one stops to consider how all of the many adaptations function: (a) rigid, (b) yieldable, and (c) rock bolts.

The rigid method of support is illustrated in FIG. 1. The total elastic deformation of rock **20** around subsurface opening **21** is so slight that a few small voids in the blocking absorb all of the initial movement before any appreciable load is transmitted to support means **22**. During this slight movement of the rock, stress concentrations develop which exceed the structural capacity of the rock; the rock breaks; and it comes to bear against the beams and blocking. Therefore, rigid sets, stulls, posts, props, and similar supports only hold broken material in place. They do not utilize the compressive strength of the rock except by holding the broken pieces in position so that a few pieces may bear against one another and form a sort of loose "linear arch" or "Voussoir arch" as indicated by the force lines.

Rigid supports are only economical or effective where the burden of broken material does not exceed the strength of the support. Thus, it can be stated that they generally support the static load of a very limited amount of overlying material.

Yieldable supports **23**, such as depicted in FIGS. 2A and 2B, perform a very specialized function. When opening **24** is created in rock **25** which is subjected to high magnitude, nearly isostatic stress conditions, high tangential compressive stresses develop at its periphery. If the high shear stresses which result exceed the rock's shear strength, the rock fractures at the edge of the opening and progressive breakdown is initiated. Yieldable supports **23** comprised of wood lagging **26** and sectional steel arches **27** resist displacement of the fractured rock and provide a radial confining stress as the fracturing expands into opening **24**. This radial confining pressure helps maintain a natural rock arch around opening **24** and reduces the distortion of rock **25** beyond the plastic radius R. Therefore, a shear stress is maintained within the unfractured rock some distance from the opening which is below the rock's strength.

A pertinent point is that rigid sets (FIG. 1) would have the same effect. However, the enormous force which can be caused by the convergence of the broken rock causes early buckling and consequent loss of rigid supports. Yieldable supports (FIGS. 2A and 2B) are designed to relieve their load when a maximum load is reached (when properly installed) and thus they last longer. Often convergence of the rock stops before the sets' total yielding capacity is used up.

Referring to FIGS. 3 and 4, rock bolts **28** perform still a third distinct function. (Lang, T. A., "Theory and Practice of Rock Bolting," AIME Transaction, vol. 220, 1961, pp. 333–348.) Bolts **28** are inserted into drill holes and expanded to tie many small units together into a single stronger unit, FIG. 3, or hold structural units of rock in place, FIG. 4. Thus, in FIG. 3, "laminated beams" of overlying strata **29** are formed over opening **30** and, in FIG. 4, "linear arches" of fractured or jointed blocks of rock **31** are formed over opening **32**. Therefore, material which would become further disarranged and fall out of place, or have to be supported by sets, props, etc., is maintained in position by forces acting perpendicular to openings **30** and **32**.

The success of yieldable supports (FIGS. 2A and 2B) and rock bolts (FIGS. 3 and 4) in holding ground previously requiring much more extensive and expensive methods results from the unique way these supports function. Both enable the rock to help support itself. Thus, they carry only a portion of the load that would ultimately bear upon a conventional rigid support system (FIG. 1). Of these prior art techniques, rock bolting (FIGS. 3 and 4) best utilizes the strength of rock. A rock bolt, though, provides a rather limited force, which is directed normal to the rock surface, i.e. parallel to the axes of each rock bolt, to hold rock units together, and even the slightest slippage of its anchorage often sharply reduces or eliminates its support capability.

The method of the present invention is illustrated in FIGS. 5, 6, and 7. Inflatable devices **33**, referred to hereafter as "rock jacks" or "flat jacks," are inserted into holes or slots **34** drilled in rock **35** about the periphery of underground openings **36**, **37**, and **38**. Rock jacks **33** are inserted radially into holes **34** in the roofs of mine openings **35**, **36**, and **37**, primarily in the overhead quadrants thereof. They are spaced at sufficiently close intervals to create a region of compression which is sufficient to counteract the tensile stress in rock **35**. When jacks **33** are pressurized, high compressive forces are transmitted to the rock in a direction generally lateral or tangential to the surface (face) of openings **36**, **37**, and **38**, as indicated by the lines of force. The result is that proximal blocks of rock are pressed tightly together, increasing and/or maintaining the frictional contacts between rock particles so as to increase the rocks' capability for resisting structural breakdown. This counterstresses the rock and greatly improves stability.

A predetermined tangential compressive force such as may be desired can be achieved by increasing the pressure within the jacks, making the jacks longer and/or wider, or by increasing the number of jacks. A rule of thumb is to arrange multiple jacks so that their spacing is equal to less than about three times and, preferably, less than about twice the length of one of the jacks. (Two-dimensional photoelastic model studies have shown that the loss in compressive stress one jack length's distance from the center of the jack is about 36 percent.) Desirably, the rock jacks should be at least two or three feet long and should be set 90° to the edge of the opening. Typically, they are pressurized to 3500–5000 p.s.i. (Maximum pressures should be used in order to achieve economy in the number of jacks.)

Rock jacks of the type shown in FIG. 8 are easily made by flattening seamless metal tubing **39** and brazing end plugs **40** and **41** into position. A 2⅜-inch by 28-inch rock jack may be manufactured in the following manner:

Sixteen gage, 1½-inch diameter, seamless steel tubing **39** is cut to length. Inlet end **40**, FIG. 9A, is machined from steel to slip snugly into tube **39**. It is provided with an external ¾-inch pipe thread and its center is tapped and threaded for ¼-inch pipe plug **42**. By slipping inlet end unit **40** past the end of tube **39** for ½ to ¾ inch, a well is formed for brazing a seal. Outlet end **41**, FIG. 9B, is a simple cylindrical plug which is machined from steel to slip snugly into the opposite end of tube **39**. A

fillet is cut on the external outside diameter to provide means for forming a strong brazed seal to the tube. The center is tapped and threaded for ⅛-inch pipe plug **43**. Tube **39** thus fabricated, with inlet and outlet ends brazed into place, is heated to about 1600° F. When tube **39** is uniformly hot, it is flattened on two opposing sides to a thickness of ⅜ inch, resulting in the configuration shown in FIG. 8.

A simple frame, FIGS. 11A and 11B, is used to ensure uniformity and ease in the flattening process. The frame consists of a 3 5/16-inch by 26-inch piece of ½-inch thick steel plate **44** which has been ground off to a large radius curve on the upper side of each end. A 1-inch by 3½-inch angle **45** is welded upright at each corner of plate **44**. The clearance L between the angles slightly exceeds the diameter of tube **39** so that it can be dropped quickly into place. Thereafter, a matching ½-inch steel plate **46** is dropped into position over tube **39**. The assembly is placed between the jaws of a suitable fast acting press (not shown) and the upper plate is compressed to where it contacts ⅜-inch spacer bar **47**.

The resulting rock jack, FIG. 8, has parallel faces about 2⅜ inches wide and 24 inches long, an area of 57 sq. in.

One convenient method of using the rock jack, FIG. 10, is to first encase the entire jack, except the ¾-inch pipe threads of inlet end **40**, FIG. 9A, with high strength concrete (sand and cement). A 2⅜-inch diameter cylindrical mold can be used for this purpose. This step would not be necessary, however, if the jack and drill hole already have approximately the same cross sections. In the latter case, the jack is simply inserted directly into the drill hole without the use of filler material. (Hence, the advantage of drilling holes in the form of slots.) Referring to FIG. 10, 2⅜-inch diameter holes **48** are bored at selected locations in the overhead portion of an underground opening to a depth of 28 inches or more. The rock jacks, sandwiched in a concrete cylinder **49**, are inserted into holes **48**. A valve is then attached which allows the jack to be filled, pressurized, and plugged at peak pressure.

One such valve, developed by St. Joseph Lead Company, is shown in FIG. 12. The valve receives inlet end **40** of the rock jack and provides a means of forcing pipe plug **42** into the inlet while maintaining the full pressure of the pump. Rod **50** holds pipe plug **42** in jaw means **51**. Grout, epoxy resin, or other fluid is introduced via port **52** and forced into the rock jack while port **53** provides an outlet for flushing. When the jack is pressurized to the desired level, lever **54** is actuated to force plug **42** into contact with inlet end **40**. Rod **50** is then turned with a wrench to seat plug **42**. The valve may then be removed from the pressurized rock jack and attached to the next jack to be pressurized.

When the jack is thus filled and the outlet ends tightly plugged, the assembly can be slid into drill hole **48**, FIG. 10, and its faces oriented at right angles to the desired direction of compressive force. Very slight pressurization causes the jack to expand slightly and holds the assembly tightly in position. Once in the proper position, the jack is pressurized to the limit of its capability, i.e. 3500 to 5000 p.s.i., producing compressive forces normal to the face of the jack as shown in FIG. 10.

The total force exerted by the rock jack is determined by the area of its faces and the pressure maintained upon solidification of its grout or epoxy resin contents. For example, a jack with a face area of 57 sq. in., pressurized to 3500 p.s.i., with a 20 percent loss of pressure upon hardening and shrinking of its contents, would exert $57 \times 3500 \times 0.80 = 159{,}600$ lbs.

The forces obtainable can be varied by controlling the the jack length, width (diameter), pressure capability, and percentage loss of pressure due to shrinkage of filler material. Relative to the latter factor, water can be used for medium term installations with no shrinkage problems. For permanent installations, care should be taken in choosing a filler material such as neat cement or epoxy resin, and particularly in filling the jack to avoid air bubbles, so that shrinkage and pressure loss is minimized.

As the rock jack is pressurized, compressive stresses are created in adjacent rock which tend to counteract deleterious tensile stresses or increase lateral confinement and thus the contact between proximal rock blocks or particles. Rock shear strength is determined by the frictional stresses developed between rock particles as shear stresses tend to move these particles in opposite parallel directions. Frictional stresses are proportional to the magnitude of stresses tending to press the rock particles directly together. Thus, the confining compressive normal stresses created by rock jacks tend to maintain or increase the shear resistance of the natural rock structure in overhead portions of underground openings which is supporting its own weight plus possibly some amount of overlying material.

This explains why the roofs of many underground openings will continue to remain in place even after fractures have developed. This phenomenon is attributed to the development of a "linear arch" (or, as some prefer, a "Voussoir arch").

Note that a "linear arch" of fractured rock is held in place by the lateral components which are created as the arch deflects or sags across the open span. If these lateral components are too low, one or more blocks of rock will shear out of place from their own weight and the arch will collapse. Rigid supports such as sets, linings and stulls limit the displacement of pieces in the arch by directly opposing gravitational forces. Prior art devices, such as rock bolts, tie pieces of the arch together and tend to prevent dislocations which drastically reduce the arch's natural strength. Rock jacks, on the other hand, perform an additional vital function: that of substantially increasing the lateral (tangential) compressive stress component which forces the blocks of the arch together into a stabile structural unit and presses this unit against the abutments. FIGS. 5, 6, and 7, as already noted, illustrate typical underground openings which can be counterstressed by rock jacks to increase their stability and are referred to by way of summary.

What is claimed is:

1. A method for improving the stability of underground openings by counterstressing in situ rock comprising drilling a hole normal to the rock face of an opening in the upper quadrant thereof, inserting a rock jack into said hole, filling said jack with a suitable fluid, and pressurizing said jack to a predetermined level, thereby creating a compressive tangential stress in the rock about said opening.

2. A method for improving the stability of underground openings by counterstressing in situ rock comprising drilling a plurality of holes in a plane normal to the rock face of an opening in the roof thereof, inserting a rock jack into one of said holes, filling said jack with a suitable fluid, and pressurizing said jack to a predetermined level, and repeating said procedure for each of the remaining holes, thereby creating a compressive tangential stress throughout the rock structure enclosing said opening.

3. A method for improving the stability of underground openings by counterstressing in situ rock comprising drilling holes of desired depth and orientation into the rock face of an opening, especially the overhead portion, inserting a rock jack into each said hole, adding solid filler material to take up any space between the jack faces and the rock, and filling the jacks with a suitable fluid and pressurizing them to a predetermined limit, thus transmitting high compressive force to proximal blocks of rocks.

4. A method for improving the stability of underground openings by counterstressing in situ rock comprising drilling at least one hole in the overhead face of the opening which is to be stabilized, inserting a flattened metal tubular member into the hole, adding material to

fill the air space between the tubular member and the bore of the hole, and pressurizing the tubular member with fluid so that it expands in volume over substantially all its longitudinal length, thereby transmitting significant compressive forces tangential around the faces of the opening.

References Cited

UNITED STATES PATENTS

2,015,081	9/1935	McElhany et al.	85—65X
3,099,911	8/1963	Turzillo	61—35
3,108,404	10/1963	Lamb	85—65UX
3,301,123	1/1967	Worley	61—45X
3,306,051	2/1967	Howlett	61—45
3,332,244	7/1967	McLean	61—45X
3,345,824	10/1967	Turzillo	61—35
3,349,567	10/1967	Munn	61—45
3,386,251	6/1968	Casagrande	61—35
3,396,545	8/1968	Lamberton	61—45X
3,492,823	2/1970	Lamberton	61—35

DENNIS L. TAYLOR, Primary Examiner

U.S. Cl. X.R.

85—65