THE USE OF ROCK BOLTS IN THE SUPPORT OF MINE OPENINGS

by

Felipe de Lucio

A Thesis Submitted to the Faculty of the

COLLEGE OF MINES

In Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1962

STATEMENT BY THE AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department, or the Dean of the Graduate College when in their judgement the proposed use of the material is in the interests of scholarship. In all other instances however, permission must be obtained from the author.

SIGNED: Felipe de Luis

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

H E Krumlauf
H. E. Krumlauf
Professor of Mining Engineering

June 11, 1962
Date

ACKNOWLEDGEMENTS

The author wishes to thank Professor Harry E. Krumlauf, Professor of Mining Engineering at the College of Mines, University of Arizona, for the guidance and advice offered to the author in the writing of the present thesis. For indirect contributions to the thesis, the author wishes to express his gratitude to: S.T. Hurlbut, Chief Research Engineer, The Anaconda Co.; T.A. Lang, Manager, Betchel Corp.; V. Bilyeu, Mine Superintendent, Utex Exploration Co.; G.W. Allen, Mining Products Engineer, Republic Steel Corp.; E.R. Olson, Mine Manager, Rio Algom Mines Ltd.; L. Frost, Chief Mining Engineer, Dominion Steel and Coal Corp. Ltd.; J.C. Durham, Safety Engineer, Sunshine Mining Co.; J.A. Izzard, Product Engineer, Sheffield Div., Armco Steel Corp.; B.L. Bradley, The Colorado Fuel and Iron Corp.; A.V. Cripps, Holman Bros. (Canada) Ltd.; J.H. Sanford, Manager, Ohio Brass Co.; H. Aram, Mining Manager, Dowty Mining Equipment Ltd.; A.K. Howe, Staff Engineer, Sika Chemical Corp.; Gutehoffnungshutte.

TABLE OF CONTENTS

CHAPTER 1

HISTORY AND INTRODUCTION

Rock Bolting History.

Since the days of the caveman, timbering has been the conventional means of support for underground openings. Other supports such as artificial pillars, masonry arches, steel and concrete structures have also been used, but the differences between them were only in the material they were made of since all worked under the same principle: the use of the compressive and sometimes bending strength of the material to resist the load exerted by the rock.

Rock bolting introduced a new theory in the field of underground support: support by suspension and reinforcement of the rock around the opening.

The origin of rock bolting is obscure and, as most innovations, had a period of development before full-scale usage was attained. The principle of reinforcing the material with the purpose of giving it a greater strength has been practiced for many centuries, but the use of rock bolts as will be defined in this thesis is not older than fifty years. Nevertheless, most of the applications before 1935 were occasional and mostly unsuccessful efforts to support the roof of underground openings by suspension.

Some of the early experiments in rock bolting date back to World War I. In Ober-Schlesien, Prussia (now Poland) rock bolts were used in collieries. In 1917 the Pocahontas Fuel Company installed rock bolts in its Sagamore mine in Virginia, USA.

It is generally agreed that in the late nineteen-thirties the St. Joseph Lead Company, at its mines in Southeastern Missouri, USA, initiated the use of rock bolts in a systematic way. The Anaconda Copper Mining Company used rock bolts as early as 1939 in its Belmont Mine in Butte, Montana, USA. Aunor Gold Mines (Canada) reported having used rock bolts since 1940.

In general it can be said that the systematic use of rock bolts, as a means of underground support, started with World War II. During the war and the following years the scarcity of steel hindered further development. It was not until 1947 that the United States Bureau of Mines became interested in rock bolting as a safety measure for coal mining and initiated a methodic study of the subject. This effort of the United States Bureau of Mines plus the availability of steel stimulated the acceptance of rock bolting in industries dealing with the support of subsurface openings.

Although metal mining gave birth to rock bolting, it was, however, in coal mines, due to the structural geology of their deposits, that the technique first found broad reception. It was only in the early nineteen-fifties when metal mines started to use rock bolts extensively. Originally rock bolting was used entirely in development headings and haulageways, but now it is used in almost every place where timber is suitable. Furthermore, it may be employed where other supports are impractical.

It can be said that after mechanization and better drilling, rock bolting is the third great change in post-war underground mining.

Definition.

Since the development of rock bolts took place simultaneously in different locations, different names have been used to define the same device, such as "rock bolt," "roof bolt," "sky hook," "roof pin," "suspension timber," and "anchor rod." The term "roof bolt" has been in more common use and is widely accepted because the first applications were in coal mine roofs. But with the increasing use of this type of support in other underground mines and even in surface workings, the word "roof" has become inappropiate.

Of all the previously mentioned terminology "rock bolt" is the one which gives a closer idea of the nature of the support and this term will be employed throughout this thesis. For briefness it will sometimes be referred to as the "bolt."

A rock bolt is a bar, generally made of steel, that has an anchoring unit at one end and a bearing and tightening device at the other. It is anchored in a drill hole of the same kind used in blasting.

The rock bolt is placed in the drill hole and the anchoring unit is expanded against the walls of the hole with the purpose of fixing one end of the bolt to the rock. The other end projects outside the hole. With the tightening device this end of the bolt is fixed against the surface of the rock.

The tightening device, besides fixing one end of the bolt, provides the means to apply tension to the bolt bar which lies between the two fixed ends. The pre-applied tension in the rock bolts mekes them unique among rock supports. While conventional supports use compressive and sometimes bending strength to support rock, rock bolts employ tensile strength.

Rock bolts in actual practice can be classified into two major categories: One, the slot and wedge type; and the other, the expansion-shell type. These two types account for over 95 per cent of the rock bolts used today. The remaining 5 per cent is a combination of bold innovations not yet in common use, and of special bolts designed for specific usage. Eventhough these last named bolts vary broadly in nature and usage, in the present thesis they will be grouped together under "Miscellaneous Rock Bolts."

CHAPTER 2

THE SLOT AND WEDGE TYPE OF ROCK BOLT

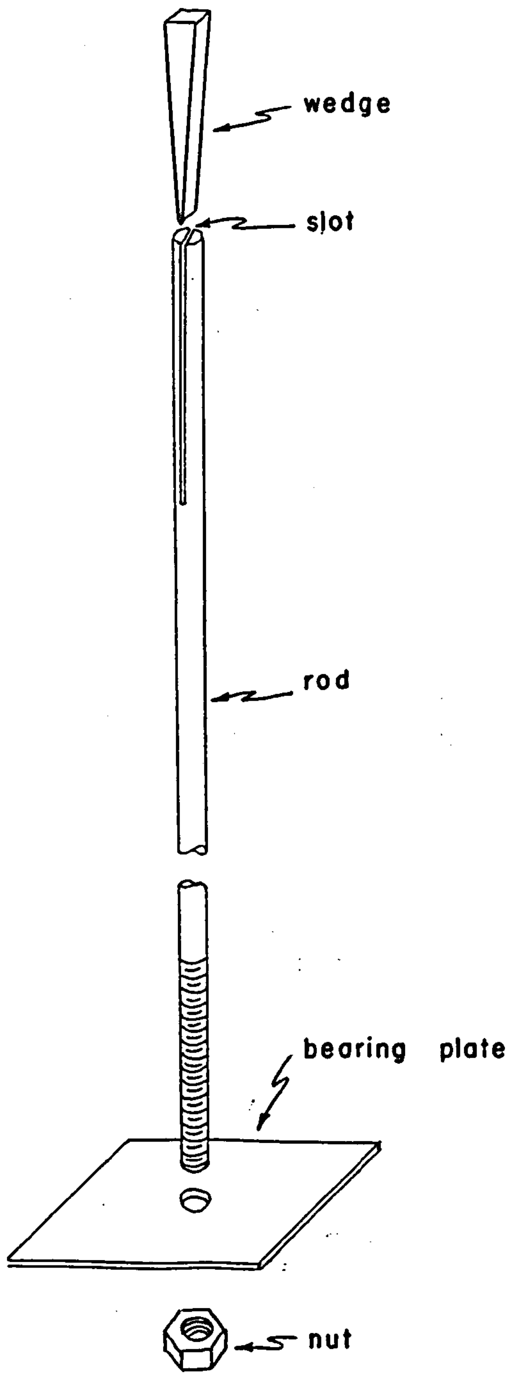
Description.

The slot and wedge type of rock bolt is a steel bar of circular cross section slotted at one end and threaded at the other. On the slotted end it carries a wedge and on the threaded end a nut and a bearing plate(*). (Please note figure 1).

The rock bolt is placed in a drill hole, with the wedge partially inserted in the slot, until it reaches the bottom of the hole. With a rock drill or other percussion machine the bolt is hammered from the threaded end which projects out of the drill hole, forcing the wedge into the slot. Since the wedge is of greater thickness than the slot, on its way in it spreads the prongs of the bolt against the walls of the drill hole. As the hammering continues, the prongs at each side of the slot plough a groove in the rock. (Please note figure 2). In this manner the inner end of the bolt is fixed into the rock. On the threaded

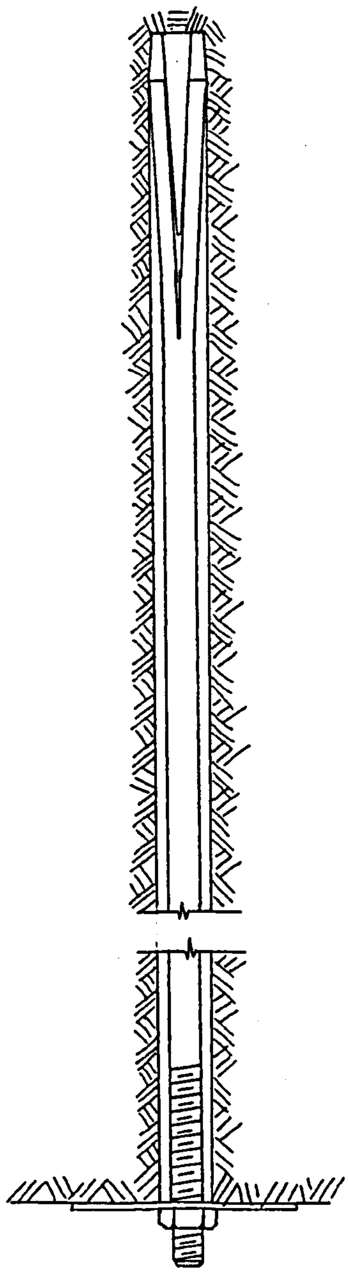
---

(*) It will be noted here that these are the essential parts of the rock bolt. Various other devices are used for particular applications and will be described later on in the chapter "Pattern, Application and Accessories."



SLOT & WEDGE ROCK BOLT

FIGURE 1



INSTALLED SLOT & WEDGE BOLT

FIGURE 2

end the bearing plate is inserted and the nut is tightened. With a torquing machine the nut is tightened to a prescribed torque. With the tightening of the nut two aims are attained simultaneously. First, fixing the other end of the bolt to the rock; second, tensioning the shank of the bolt between the nut and the anchored prongs. The tension in the bolt causes compression in the rock and this is one of the self-supporting effects which rock bolting induces in the rock mass.

Kinds.

The differences in design in the slot and wedge type of rock bolt are limited to the type of thread and the method of making the slot.

The thread can be cut or rolled. (Please note figure 3). When the thread is cut, material is removed giving giving the threaded part of the bolt a smaller effective area. For a 1" rod with class 2 NC (National Coarse) thread with 8 threads per inch the reduction in tensile strength due to the thread cut is 23 per cent. Roll threading, the formation of a thread by rolling the steel through grooved dies that imprint the thread form in the steel, increases the physical properties of the steel by cold-working the metal. The rolled threads should have a stress area equal to the cross sectional area of the shank; thus, the tensile strength in the threads will be the same as in the shank.(*) It is concluded then that for equal nominal diameters a rock bolt with cut threads has 77 per cent of the tensile strength of one with rolled. Improved physical properties in the rolled threads may lower the above figure.

The slotted end of the bolt can be flame-cut, sheared or forged. (Please note figure 3). The flame-cut slot is theoretically the weakest since material is removed during its fabrication, leaving the slotted portion of the bolt with a smaller effective area. The following is a summary of the results obtained independently by the Anaconda Copper Mining Company (1)(**) and the Virginia Polytechnic Institute (41), after extensive testing with slot and wedge bolts. Quantitative results of these tests are not shown because the broad varianve among them did not permit an indicative average. The order in which they appear below is the order of performance, i.e.: the first has the highest strength.

(*) Stress area is the area of an imaginary circle whose diameter D is given by:

$$D = \frac{d' + 3d''}{4}$$

d': outside diameter of the threads
d": inside diameter of the threads

The stress area is used for computing the tensile strength of threaded bars.

(**) Numbers in parenthesis refer to the bibliographical list at the end of the thesis.

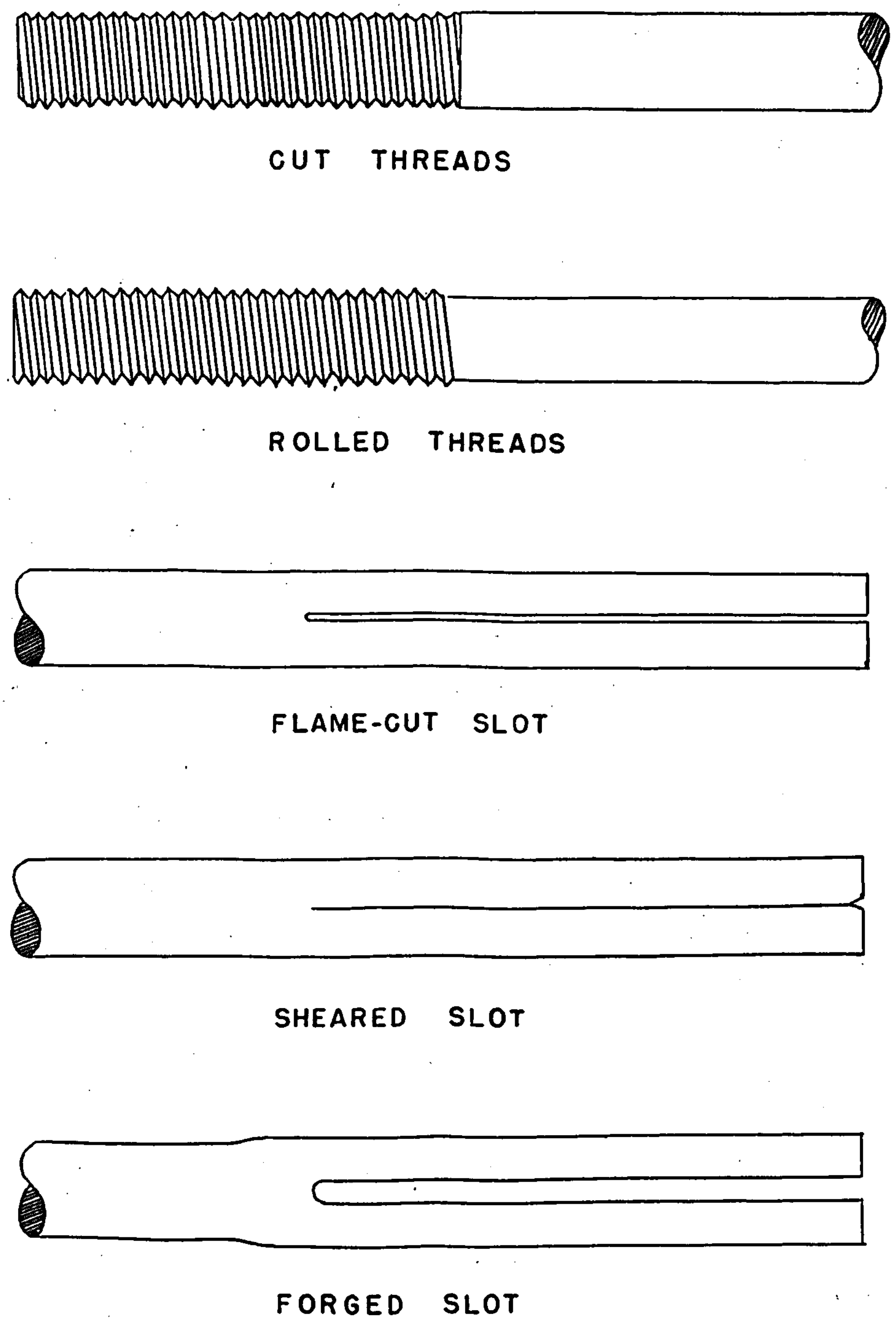

CUT THREADS
ROLLED THREADS
FLAME-CUT SLOT
SHEARED SLOT
FORGED SLOT

FIGURE 3

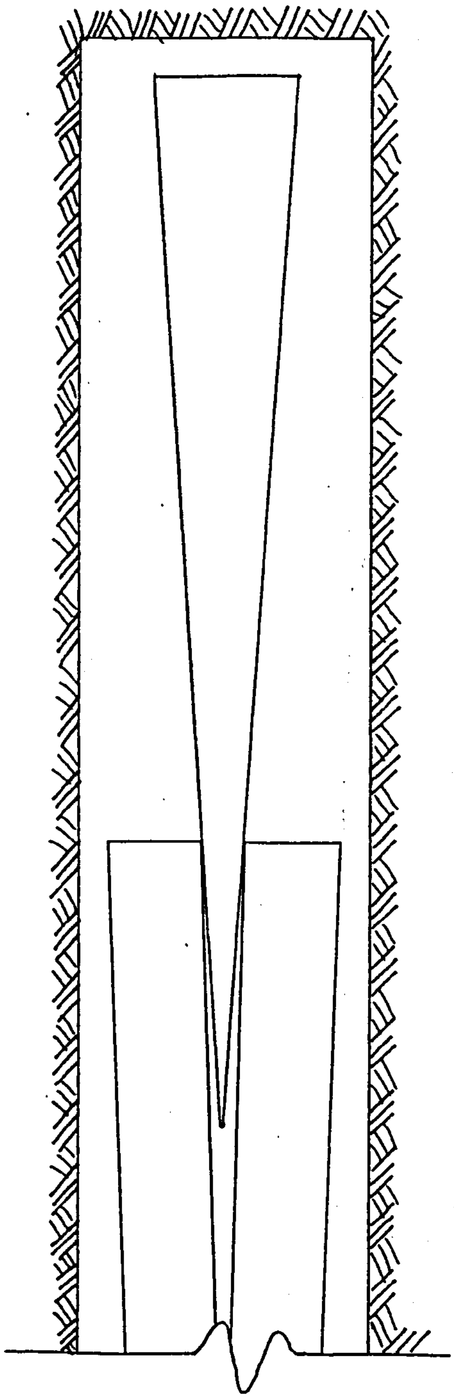
Anchoring Strength	Tensile Strength
1.- Forged Slot	1.- Sheared Slot
2.- Sheared Slot	2.- Flame-cut Slot
3.- Flame-cut Slot	3.- Forged Slot

Anchorage.

In practice a rock bolt fails when the anchor cannot be kept fixed in place and slips or when the yield point of the steel is reached. Generally the former occurs first so the study of the anchorage behaviour of a rock bolt is paramount.

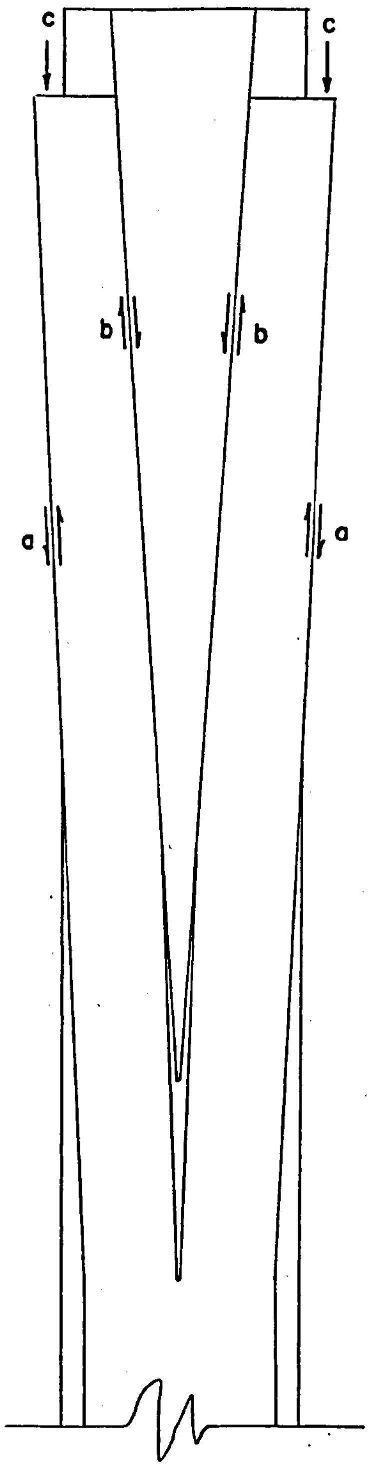
When a slot and wedge type of rock bolt is inserted in the drill hole, before the hammering takes place the picture is as shown in figure 4. When the hammering starts and the bolt is being driven home two movements occur simultaneously. One is a longitudinal movement of the prongs towards the bottom of the hole; the other is a diametrally spreading of the prongs against the walls of the hole because of the wedge action. If these movements are to take place, a groove must be ploughed in the rock or the rock and the bolt steel must be deformed or both. When either or both of these results occur, the bolt is anchored when it cannot be driven further because the sum of the following forces exceeds the driving force: (Please note figure 5)

a) The frictional force between the prongs and the walls of the hole.



WEDGE IN SLOT BEFORE DRIVING

FIGURE 4



WEDGE DRIVEN INTO SLOT

FIGURE 5

b) The frictional force between the wedge and the slot.

c) The reaction caused by the bearing of the bolt on the rock at the top of the groove.

Of these forces, (a) and (b) oppose movement either for withdrawal or insertion of the anchor part of the bolt. A smoothening of the surfaces concerned would decrease the frictional resistance opposing insertion, but would also ease withdrawal of the bolt when under load. Attempts have been made to increase the friction force (a) at withdrawal with a smaller increase at insertion by serrating the outer sides of the prongs but without success. (Please note figure 6-a). However, serration of the slot and wedge surfaces do increase the frictional resistance at withdrawal with slight increase at insertion. (Please note figure 6-b).

Force (c) on the other hand, opposes movement only at insertion. If the top of the bolt were chamfered to a semi-cone point, the driving resistance resistance would be lessened leaving more of the driving force to be used in compressing the rock laterally. This extra compression increases the friction force (b) and provides for a better anchorage.

When the anchoring of the bolt does not plough a groove in the rock, the expanding prongs compress the rock in the walls of the drill hole. In this case the relative

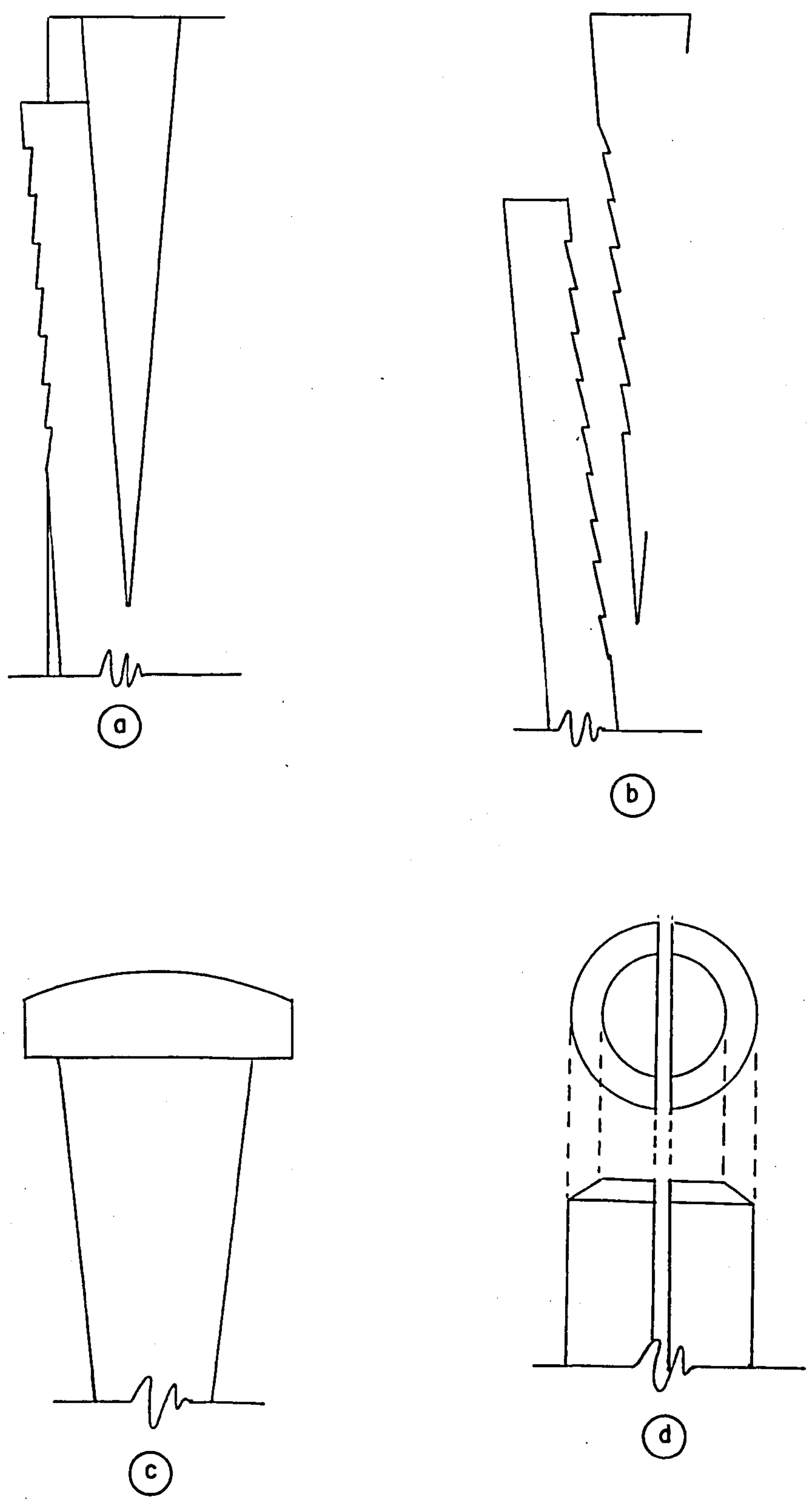


FIGURE 6

dimensions of the drill hole and of the anchorage assembly must have certain proportions as given by the formula:

$$E = \frac{w + d - t - D}{D}$$

E: diametral strain or expansion of the anchorage assembly.

D: diameter of the drill hole, in inches.

d: diameter of the bolt,in inches.

t: span of the slot, in inches.

w: thickness of the thick end of the wedge, in inches.

If E is 0.15 or greater, loads in tension up to 20,000 lbs can be supported in 95 per cent of the cases; and up to 30,000 lbs in 80 per cent of the cases. This means that if the above dimensions are selected in order to give an E value of 0.15, a satisfactory anchorage will be obtained. This formula holds true for hard and fairly intact rock such as granite or quartzite. For softer or badly altered rocks, such as shale or ore, the formula does not apply.

In rocks with poor compressive strength, slot and wedge bolts cannot be anchored because the top of the wedge compresses the rock at the bottom of the drill hole. When this happens, part of the driving force is used in sinking the wedge in the rock leaving little force to spread the prongs. With partial expansion of the prongs a satisfactory anchorage is impossible. When such rocks are encountered, slot and wedge bolts cannot be employed. Some of the European manufacturers of rock bolts design their wedges with a wider and rounded head in order to lower the unit pressure and spread the force over a larger area. (Please note figure 6-c).

When tension is applied to the rock bolt by tightening the nut, anchorage movements take place. The first result of tensioning is to relief force (c) in figure 5, that is, the force exerted by the top of the prongs on the seat of the groove. As tension increases, the compressive force between the prongs and the grooves also increases. This results in an elastic enlargement of the grooves which causes a minute outward movement of the bolt. It should be noted that this movement is due to the elastic compression of the rock at the grooves and not to a slip between the prongs and the grooves.

If the rock at the anchor is weak under compression and shear, it will not stand the force exerted by the prongs. In this case, instead of an elastic enlargement of the rock at the grooves, there will be a plastic deformation of the rock. A slip will be started between prongs and rock. The dynamic coefficient of friction is smaller than the static one, so smaller resistance will be offered to the slip. The sliding continues until tension is lost and by this time the drill hole is badly deformed and anchorage is impossible. When such conditions are encountered, the slot and wedge type of rock bolt is inapplicable.

It is interesting to note that the preceding failure process follows the same pattern when a properly anchored bolt is subject to excessive loading. As load builds up on an installed rock bolt, the effect is the same as if the nut was being tightened. If the rod is strong enough to transmit the load, the anchor will start to fail in the same way as explained above.

Holding Capacity.

The capacity of a rock bolt to stay in place and withstand loads exerted on it depends on several factors. In the case of slot and wedge bolts these factors are:

a) Diameter of the bolt.

b) The type of slot and thread.

c) Relation of the drill hole diameter to the wedge thickness.

d) Excellence of the installation.

e) Kind and condition of the rock at the anchor.

a) It has been customary practice to use a rod 1" in diameter for the slot and wedge bolt. This diameter has proved to be the most satisfactory one. It stands loads in tension, within the elastic portion of the steel, up to 29,000 lbs. Smaller diameters are not recommended since the fabrication of the slot would seriously weaken a smaller bolt. Also, a rod of smaller area would not be rigid enough to transmit, without buckling, the percussion used in driving. Bolts with a bigger diameter are unnecessary since failure at the anchor generally occurs at loads under the yield point of a 1" bolt. For all rock bolts, the ideal diameter is one which gives the bolt a tensile strength equal to the anchoring strength.

b) The advantages and disadvantages of rock bolts with different types of slots and threads were given on page 8.

c) The relation of the drill hole diameter to the thickness of the thick end of the wedge is influential in anchorage performance. In the softer rocks the best anchorage is obtained with maximum expansion of the prongs in order to plough deeper grooves in the rock. The harder rocks are not ploughed but compressed and expansion over a certain limit will not compress the rock and the prongs further. Drill holes $1\frac{1}{4}$" in diameter and wedges 7/8" thick are the most common dimensions used in every type of rock where the slot and wedge bolts are applicable. Nonetheless, when segregation is desired for different ground conditions the following table may be helpful:

Kind of Ground	Wedge Thickness	Hole Diameter
soft	5/8" - 7/8"	1 1/8" - 1 1/4"
medium	7/8" - 1"	1 3/8"
hard	1"	1 1/2"

The above table is intended to give only an approximation, for the exact dimensions can only be defined by pull-tests for each ground condition.

d) The process of installation is of special significance. In the last part of the chapter a recommended installation procedure will be described.

e) The decissive factor in the anchorage capacity of a rock bolt is the kind and condition of the rock at the anchor. Rocks vary greatly in composition and properties and even the same rock can have the same properties in different locations. For this reason it is impossible to classify rocks according to their anchoring strength. Up to now, the only definite way to determine the anchoring strength of a rock is by experimentation. Organized tests must be done before a bolting program is undertaken and the first installations should be done on a trial and error basis.

As a rule, slot and wedge bolts anchor best in hard rocks such as granite, basalt or gneiss. In rocks of medium hardness such as limestone or sandstone, anchorage is still satisfactory. It is in the soft rocks such as weak shales, wet sulphide ore, breccia or coal that a good anchorage is doubtful. It is worth noting that a hard rock when badly weathered and/or fractured can behave as a soft shale. Also, in a sandy compact shale an anchorage as strong as one in sandstone can be possible.

Installation Procedure.

Installation of the slot and wedge type of rock bolt requires three distinct operations: 1) drilling the hole, 2) driving the bolt, and 3) tightening the nut.

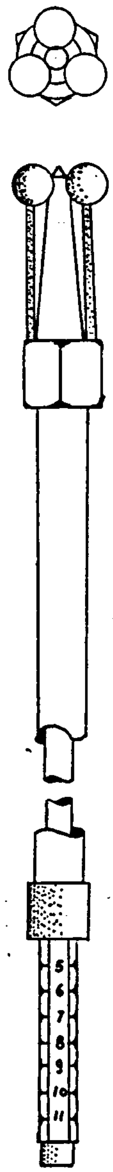
1) The drilling of the hole is the same operation as that done in drilling holes for blasting, with extra care given to the diameter and length of the hole.

It was previously mentioned that for a 1" bolt the most desired hole diameter is $1\frac{1}{4}$". This should be the diameter of the last 8" of the hole since the bolt will be anchored there. On account of the abrasiveness of the rock the bit loses gauge during the drilling. For detachable steel bits drilling in hard or medium hard rocks, a new bit loses 1/8" gauge per 12" of hole length. In drilling holes for rock bolts the drilling of all the hole, except the last 8" or preferably foot, should be done in the conventional way of starting with larger bits and ending with smaller ones. The gauge of the bits used for drilling this last part should be such that the beginning of the last foot of hole will have the desired diameter ($1\frac{1}{4}$" in most cases). The last foot should be started with a new $1\frac{1}{4}$" bit so at the bottom of the hole the gauge will be 1/8" smaller, that is 1 1/8" in diameter. This uniform narrowing will not hinder the insertion of a 1" bolt, moreover, it will provide for a better anchorage. An example can best illustrate this drilling:

Supposing a 5' hole is to be drilled in hard rock in which a slot and wedge bolt is to be placed. At the beginning of the fifth foot the gauge should be $1\frac{1}{4}$". Bits are generally changed at 2' intervals, therefore, the third foot should be started with a $1\frac{1}{2}$" bit (1/8" narrowing per foot is $\frac{1}{4}$" every 2'; $1\frac{1}{4} + \frac{1}{4} = 1\frac{1}{2}$). The first foot should be started with a 1 3/4" bit for the same reason.

Tungsten-carbide insert bits do not lose gauge as fast as steel bits, so the holes drilled with them are of constant diameter, without taper. With a $1\frac{1}{4}$" carbide insert bit a 6' hole can be started and finished with $1\frac{1}{4}$" gauge. For this reason they are recommended, when available, for drilling rock bolt holes.

Improper drilling habits and changes in the rock formation will cause variations in the hole diameter, generally making oversize holes. Usually these variations go unnoticed until they begin to hinder bolting progress. Thus, only extreme variations from proper hole size are noticed. When the causes of improper hole diameter are known to exist,



HOLE GAUGE

FIGURE 7

or when an extensive bolting program is to be initiated, the use of a hole gauge is recommended.

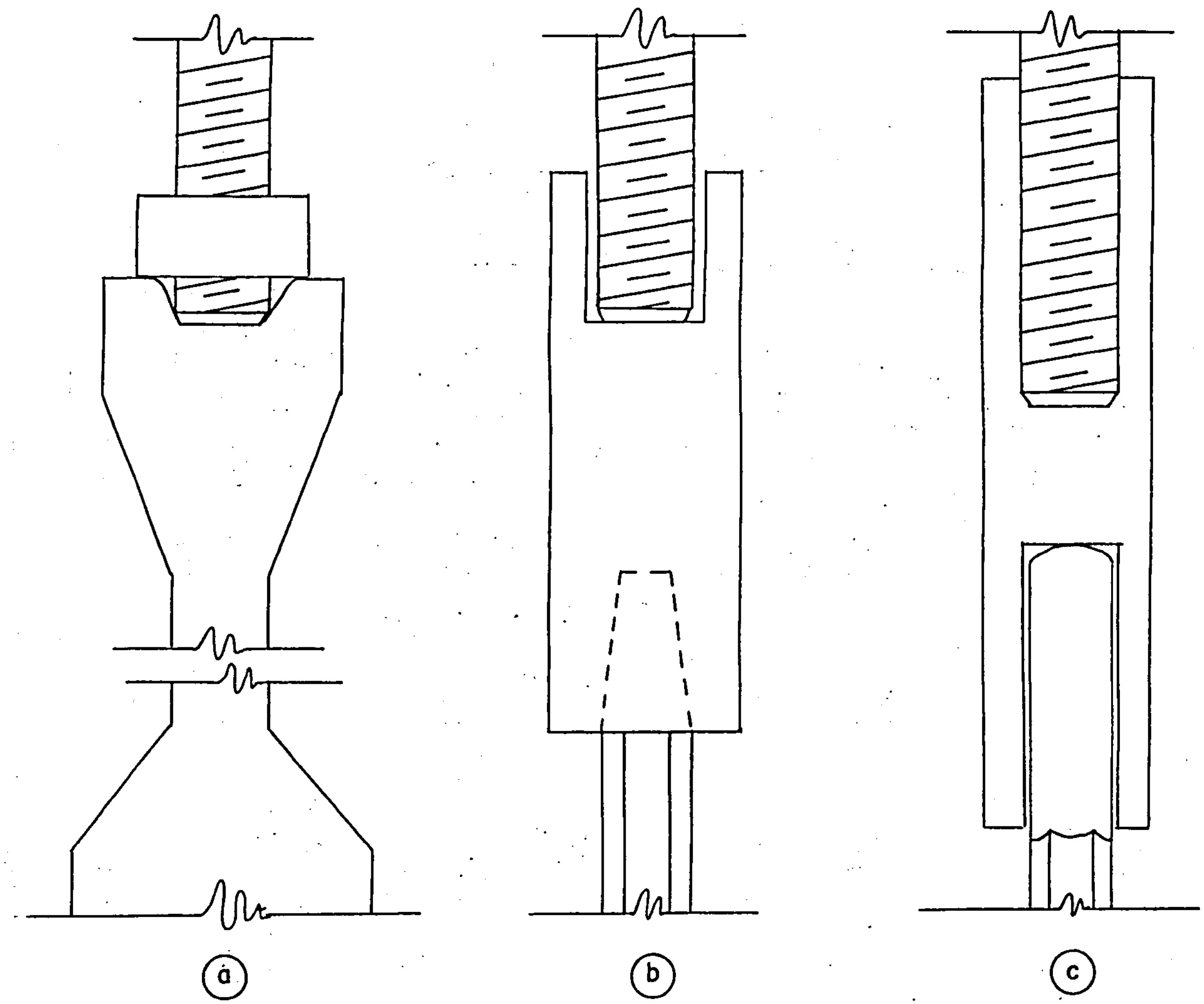
The hole gauge is a fairly simple instrument as can be seen in figure 7. The upper end of the gauge consists of three balls supported by equally spaced wire springs from a ferrule on the end of a tube. These balls surround a conical plunger. The plunger is attached to one end of a rod which passes through the tube. Upward motion of the rod causes the plunger to bear against the balls, forcing them outwards against the sides of the hole. The lower end of the rod is calibrated to read hole diameters in 1/16" increments.

The length of the drill hole is of special significance when using the slot and wedge type of rock bolts. Since this bolt is anchored when it reaches the bottom of the hole, the length of the hole should be at least 3" shorter than the bolt length in order that a portion of the threaded end will remain out of the hole for tightening the nut. Holes should not be too short since part of the unthreaded portion of the bolt may remain outside of the hole and tightening cannot be done. The safest depth of hole is one which leaves half of the the threaded part outside the hole and half inside. This can be measured by placing a bolt without wedge into the hole.

Any machine capable of drilling a hole in rock can be used for rock bolting. Since most bolting is done overhead, or at angles approaching the vertical, stoper drills are most commonly used. Sinker type drills with pneumatic legs give best drilling flexibility. For drilling the small diameter holes used in rock bolting a small-bore, lightweight drill is recommended. Since the clearence of mine openings in the majority of rock bolting applications is limited, short-leg drills are helpful. For driving the bolt best resuslts are obtained if the air pressure at the drill is not less than 75 psi (preferably 85 - 100 psi), and when the hammer strokes are between 2 - 3,000 per min.

2) After the hole is drilled the wedge is inserted in the slot just far enough to hold it in place. The rock bolt is then placed in the hole. The same rock drill used in drilling the hole is used to drive the bolt. To connect the end of the bolt with the rock drill different driving tools may be used. All of them consist essentially of a piece of steel stock, called a "driving dolly", that is recessed at one end to fit the bolt and recessed at the other end to receive a piece of drill steel which fits the chuck of the drill. The most common types of driving tools are shown in figure 8. Type a) receives the bolt with the nut partially run into the threads. It does not use a piece of drill steel but a short and thick stem which fits into the drill's front end in place of the chuck. Without the chuck the rotation of the drill steel is eliminated. This

DRIVING DOLLIES FOR SLOT & WEDGE BOLTS



Approximate Scale 1:2

FIGURE 8

type of dolly has two drawbacks. One is the removal and replacement of the chuck for each bolt which is an obvious inconvenience. The other is the driving with the nut on because the hammering will sometimes deform the nut and threads. Type (b) has the piece of steel welded to the dolly. At the other end of the dolly a cylindrical hole accomodates the threaded end of the bolt. When machines without a mechanism to stop rotation are used, slippage is allowed between the dolly and the bolt. This type of driving tool has inconveniences too. The rotation of the dolly on the threads of the bolt may damage the threads and make it impossible to tighten the nut. Also, the welded bond will eventually break because the hammering of the drill. Type (c) has given the most satisfactory results. At one end, the dolly is threaded to fit the bolt. At the other end, a cylindrical hole accomodates a piece of drill steel which is rounded at the tip to permit slippage. Nonetheless, some of the rotation may be transmitted to the dolly. Since the rotation of the drill is counterclockwise, the bolt may be partially unscrewed from the dolly. To prevent this, dollies are made of hexagonal steel stock so they can easily be held fast with a wrench. A little grease between the drill steel and the dolly will assure a good slippage.

The drill steel in types (b) and (c) and the stem in type (a) may have any length to suit local conditions, but usually are 10" to 20" long.

Driving is done with drill throttle fully open until movement of the bolt stops, usually after about 30 seconds of driving.

3) After driving has been completed the driving tools are removed. A bearing plate is then placed over the bolt and against the rock. A nut is then screwed by hand until it touches the plate. Care should be taken to provide a good bearing between the plate and the rock.

The nut can be square or hexagonal. Hexagonal nuts are stronger than square ones, but since both are strong enough to break the 1" bolt, either one may be used. Bearing plates generally are square steel plates 6" x 6" x 3/8". The principal function of the plate is to provide a flat and even surface against the nut. The area of the plate is of no importance except when the ground is so weak that a small plate might squeeze the rock, but if such is the case it is probable that that ground cannot be supported with rock bolts.

When applying tension to rock bolts it should be kept in mind that the initial tension plus any load that will build thereafter should not reach the yield point of the steel. If the yield point is reached during installation or with a small subsequent load, the bolt will elongate and deform permanently. This elongation will allow the rock to move with little hinderance making possible an eventual fall of rock. The yield load for a 1" bolt is generally over 28,000 lbs, but because of varying steel quality and under-nominal diameters it could be as low as 20,000 lbs. If bolts are pre-stressed to 10,000 lbs this will leave another 10,000 lbs of margin for any load to build up. In practice slot and wedge bolts are tensioned from 8,000 lbs up to 14,000 lbs.

The tension to be applied to a rock bolt of the slot and wedge type can be calculated approximately from the torque that is applied to the nut. The torque-tension relation is expressed in the formula:

$$Tn = \frac{Tr \times 12}{K \times D}$$

Tn: bolt tension, in pounds.

Tr: torque applied to the nut, in foot-pounds.

D: diameter of the bolt, in inches.

K: friction factor.

The friction factor depends on the condition of the threads and mainly on the friction between the nut and the bearing plate. It generally varies from 0.3 to 0.6. With damaged threads it can be as high as 1.0. A common value is 0.35. To attain a tension of 10,000 lbs, according to this formula, a torque of 310 ft-lbs is required.

Eventhough the above formula is theoretically correct, in practice the value of K varies so widely that it makes the formula impractical. The United States Bureau of Mines (37-a) has developed an empirical formula which expresses more realistically the torque-tension relation:

$$Tn = (42.5 \times Tr) - 1000$$

Tn: bolt tension, in pounds.

Tr: torque applied to the nut, in foot-pounds.

The tension will be within ± 2,700 lbs in 90 per cent of the cases. If a tension of 10,000 lbs is desired the required torque is, according to this formula, 260 ft-lbs.

For quick approximation the following formula is useful:

$$Tn = Tr \times 40$$

The friction factor being the decisive element in the torque-tension relation, rock bolt manufacturers have developed a hardened-steel washer to be placed between the nut and the bearing plate for the purpose of reducing the friction. Tests made by the Bethlehem Steel Co. (2) have shown that hardened-steel washers have two useful purposes:

a) With the same torque a higher tension is obtained, generally about twice the tension obtained when the nut bears against the plate.

b) When the same torque is applied to several bolts, a more uniform tension is developed.

To tighten the nut to the desired torque, three tightening machines may be used: 1) hand wrench, 2) impact wrench, or 3) rock drill.

1) Any hand wrench can be used to tighten rock bolts, but certain features are desirable in a wrench used for this purpose. These features are:

a) Sufficient clearence between the handle and the rock face. This clearence should be a minimum of 2" and can be gained with either an offset or a deep socket.

b) Sufficient handle length to develop a torque of 250 ft-lbs. A 48" handle is recommended.

c) A box-type socket to prevent slippage while working from a staging or in high places.

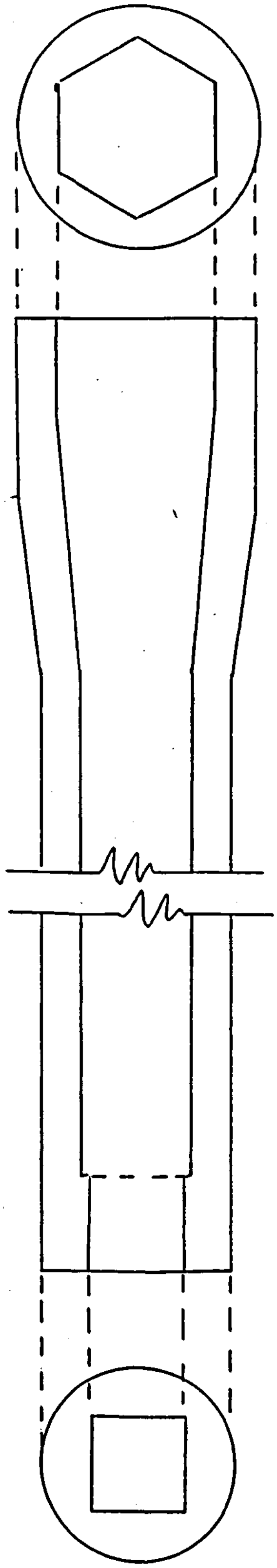
d) A ratchet mechanism to facilitate operation in confined places and for speed of installation.

2) Pneumatic impact wrenches are commercially manufactured for rock bolting purposes. Two special features are desirable:

a) A torque-indicating scale or a calibrating device, so that torque can be measured.

b) A deep socket to accommodate the projecting end of the bolt. This socket may be purchased or forged in the shop from thick walled steel tubing. Figure 9 shows a recommended socket for hexagonal nuts.

Electric torque wrenches available commercially are



IMPACT-WRENCH SOCKET

FOR SLOT & WEDGE BOLTS

Approximate Scale 1:2

FIGURE 9

generally of insufficient capacity for rock bolting.

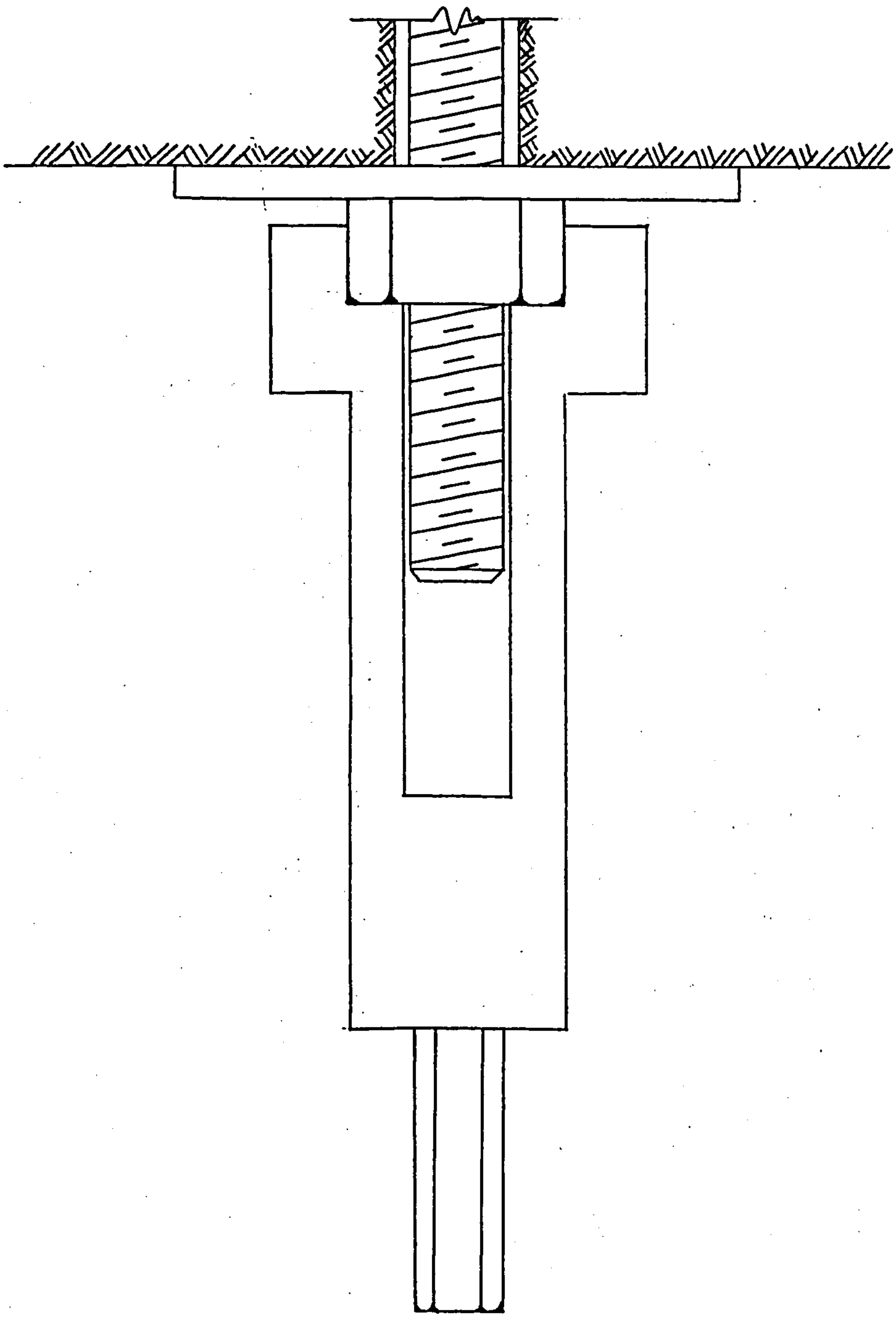
When hand wrenches are used, it should be kept in mind that the dynamic coefficient of friction is less than the static one. Thus, a nut tightened to the specified torque by a series of small angular movements will produce a much lower tension in the bolt than that resulting from a continuous rotation. Impact wrenches give continuous rotation, hand wrenches do not.

3) Although most attempts to tighten nuts with rock drills have been unsuccessful, a few successful cases prove the feasibility of this method. It is beleived that failures were due to low air pressure, the use of low-torque drills and/or defective tightening tools.

The International Nickel Company of Canada Ltd. (7) has had excellent results using a 3 1/8" stoper drill. An average of 300 ft-lbs of torque can be expected from the rotation of this machine when working at 80 psi or over. This average can be increased at least another 100 ft-lbs by using a 3' handle attached to the drill. This handle also serves to resist the torque of the drill. When bolting horizontally, the small-sized airleg drill used does not give sufficient torque for tightening the nut.

Since all rock drills have counterclockwise rotation, bolts tightened with drills must have left-hand threads.

The tool or dolly used for tightening with a rock



DOLLY FOR TIGHTENING SLOT & WEDGE BOLTS WITH A ROCK DRILL

Approximate Scale 1:2

FIGURE 10

drill can be any device that connects the chuck of the drill with the nut. The one shown in figure 10 proved satisfactory at the International Nickel Company of Canada Ltd. Three features should be remembered in the design of this tool:

1) Recessed stem to keep the piston from striking the tool and allow rotational movement only.

2) The depth of the cup to receive the nut should be at least ¼" shorter than the nut thickness to avoid any rotational friction between the dolly and the bearing plate.

3) The bore of the dolly should be deep enough to receive the protruding end of the bolt.

For tightening, one end of the dolly is placed in the drill chuck and the other end fits the nut. The stoper is carefully alligned with the rock bolt and the nut is then tightened, at full throttle, until rotation ceases. To speed the operation, the extension handle on the drill is operated as a ratchet wrench when the drill rotation begins to hesitate. The torque power of the drill at the point where the rotation begins to hesitate should be measured. This should be done before the machine is used to tighten nuts.

In rock bolting it has been customary practice to use header boards between the bearing plate and the rock surface. The purpose is to distribute the bolt load over a larger area where sloughing of the rock face is a problem. The header boards used are generally 12"x30"x3" oak planks.

The relative advantage of the header boards is greatly offset by several and more important disadvantages that are listed below:

1) If the wood is not dry and creosoted it may shrink with a consecuent loss of tension in the bolt.

2) Crushing of the wood around the bolt hole also causes loss of tension. This can be partially improved by using wider bearing plates to distribute the load over a greater area of the header board.

3) If the board is loaded in bending because of uneven bearing with the rock, it may bow and also cause a relaxation of bolt tension.

4) Wood rots with time and looses its compressive strength causing a complete loss of tension in the bolt. Once the header board has failed all the bolt assembly will fail since it cannot be replaced.

For the previous reasons, wooden headers should not be used, except when openings have an expected short life such as in cut and fill stopes in mines.

CHAPTER 3

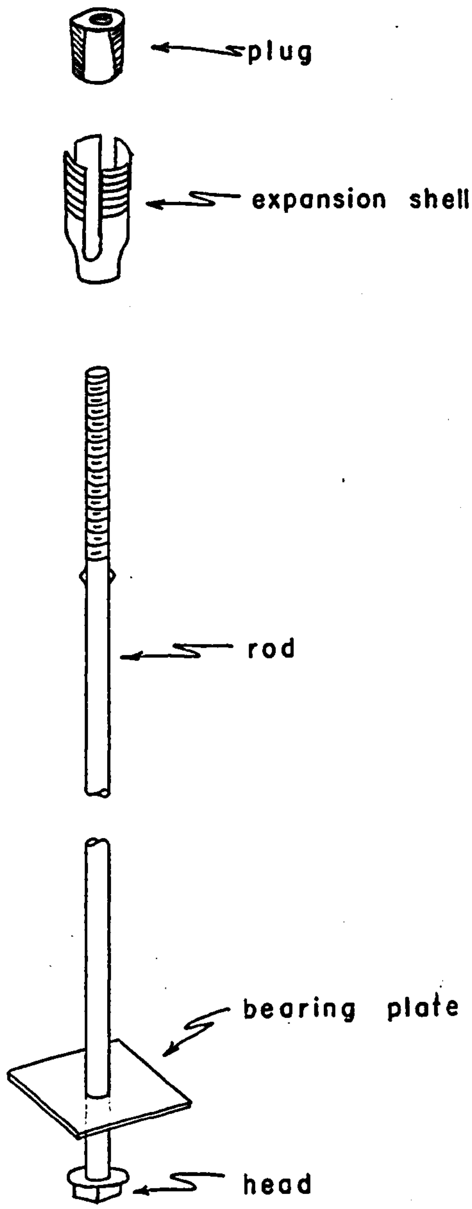
THE EXPANSION-SHELL TYPE OF ROCK BOLT

<u>Description</u>.

The expansion-shell type of rock bolt is a steel, bar of circular cross section, threaded at one end and headed on the other end. An expansion-shell fits on the threaded end and a bearing plate is placed at the headed end. (Please note figure 11). The expansion shell consists of a leaf-type shell and a plug threaded on the inside.

The bolt is placed in the drill hole until only the head with the bearing plate remains out of the hole. With a tightening machine, the bolt is tightened from the head. With the rotation of the shank, the threaded plug moves towards the narrow part of the shell. (Please note figure 12). Since the plug and the interior of the shell are tapered, the wedge-effect causes the leaves of the shell to expand. against the walls of the drill hole. As the rotation continues and the plug cannot be drawn further, the bolt is tensioned between the anchored shell and the bearing plate.

In European mines, a variation of the conventional expansion-shell bolt is used. Its distinctive feature is is the replacement of the headed end with another threaded end, nut and bearing plate; the same as in the slot and wedge bolt.



EXPANSION-SHELL ROCK BOLT

FIGURE 11

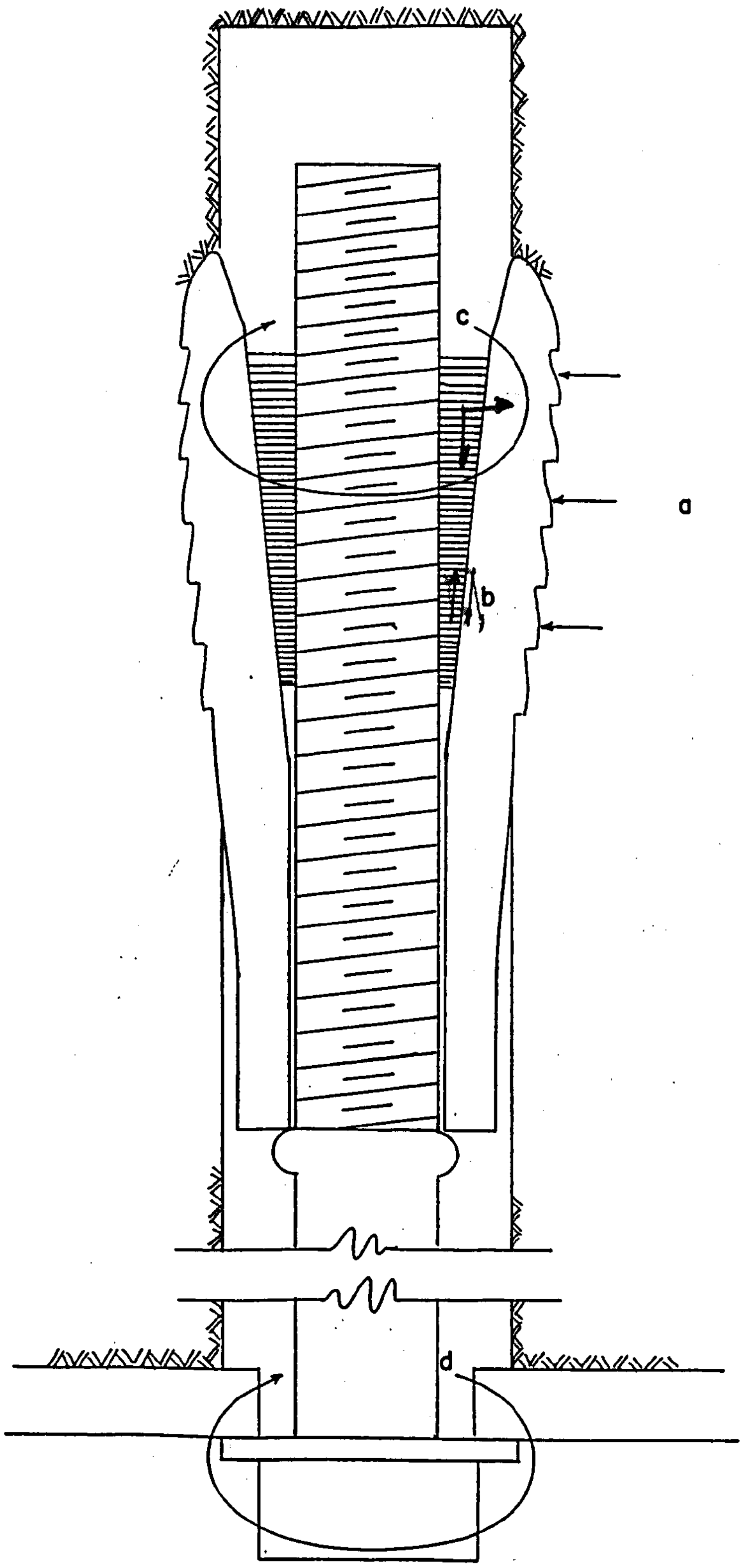


FIGURE 12

In the present thesis when rock bolts are referred to as the expansion-shell type, it is intended to mean the conventional type, except where indicated.

Kinds.

Expansion-shell type of rock bolts are manufactured in a variety of designs, with several details and improvements that makes it difficult to classify them clearly. The differences among them are in the rod diameter and in the design of the expansion shell.

Almost all of the expansion-shell bolts are made in one of the following diameters: 5/8", 3/4" or 7/8". The 3/4" bolt was the first one used with an expansion shell. It was made of this diameter because the expansion shell first used had an average anchoring strength close to the yield load of the 3/4" bolt. A greater diameter would have been useless since failure would still have been at the anchor. A smaller diameter would have lowered the strength of the bolt. Later on, a 5/8" bolt made of high-strength steel was developed. The high-strength steel gave the 5/8" bolt the same tensile strength as the 3/4" bolt made of regular strength steel.

The high-strength 5/8" bolt, for equal tensile strength, has three main advantages over the regular-strength 3/4" bolt:

1) Lower cost per unit, about 95 per cent of the

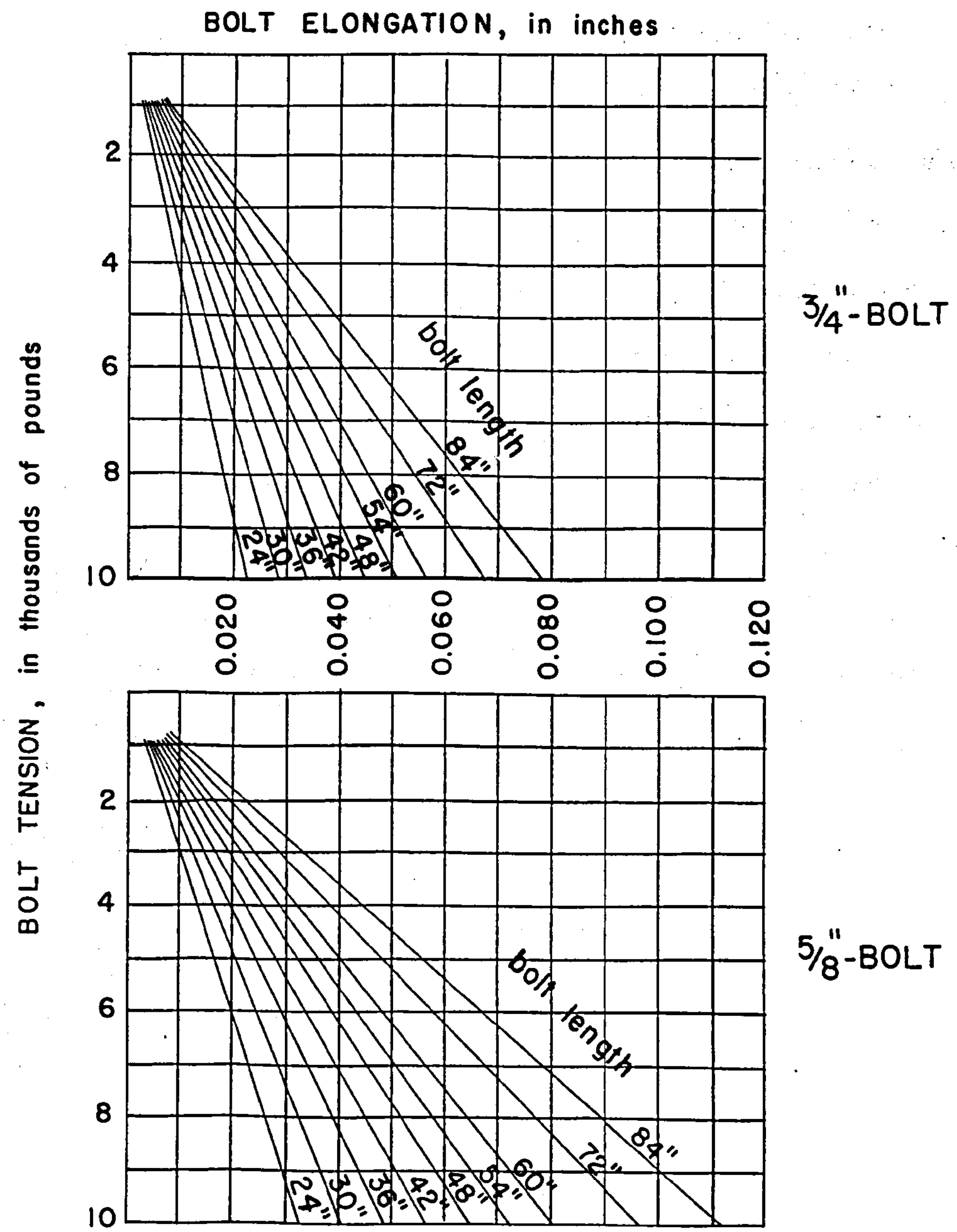
cost of the 3/4" bolt.

2) Lower weight per unit, about 70 per cent of the weight of the 3/4" bolt. Lighter materials result in lower costs of transportation and handling.

3) 42 per cent greater linear deformation than the 3/4" bolt.

This last advantage can best be illustrated with the results obtained by the Ohio Brass Company's laboratory tests (21). The results have been plotted as graphs and are shown in figure 13. Assume that one 48"-long bolt of each size (high-strength 5/8" and regular-strength 3/4") is tightened to an installed tension of 10,000 lbs. Both bolts, of course, show certain amount of elongation under this tension. Suppose that due to an external cause (plastic flow of the rock at the anchor or shrinkage of board headers, if used), movement occurs later which reduces the amount of elongation in both bolts by 0.03". The resulting tension in the 5/8" bolt will be 5,300 lbs; in the 3/4" bolt only 3,600 lbs. The maintenance of bolt tension being a basic element for good rock bolt performance, the advantage of the 5/8" bolt is evident.

With the improvement of expansion shells, higher anchoring strengths were achieved, thus justifying the use of bolt shanks with higher tensile strength. Bolts 7/8" in diameter with extra strong shells began to be used to



BOLT ELONGATION, in inches
BOLT TENSION, in thousands of pounds
2
4
6
8
10
0.020
0.040
0.060
0.080
0.100
0.120
bolt length
24"
30"
36"
42"
48"
54"
60"
72"
84"
3/4"-BOLT
5/8"-BOLT

FIGURE 13

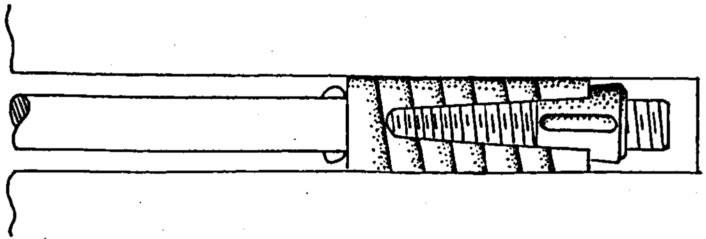
support heavy ground. Also, high-strength steel 3/4" bolts and later high-strength 7/8" bolts were developed. Today, bolts of the three diameters and of both types of steel are used. For the same diameter, the high-strength steel gives about 25 per cent higher tensile strength. The 5/8" bolt made of regular-strength steel and with small shells should be used in rock where the loads are known to be very small and the life of the opening is short. 7/8" bolts, especially those made of high-strength steel, generally have a tensile strength much higher than the anchoring strength of their shells, so their use is seldom justified. The disadvantages of the regular-strength 3/4" bolt has been discussed before, so this leaves the high-strength 5/8" and 3/4" bolts as the most useful for the majority of applications.

The thread in the bolt can be cut or rolled. Advantages of the rolled threads were discussed on page 6.

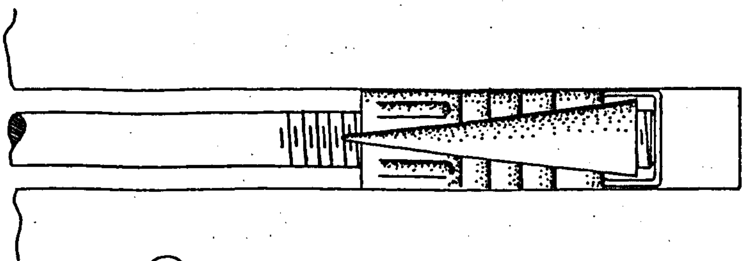
There is a great variety of expansion shells in actual use, but according to the principle by which they provide anchorage, they can be classified into three categories: 1) Standard, 2) Bail, 3) Wedge-nut.

1) The standard type of expansion shell is shown in figures 12 and 14-a. Its parts are a four-leaf shell and a plug threaded in the interior. All shells of this type are similar and vary only in the kind of serrations on the outside of the shell and the shape of the leaves.

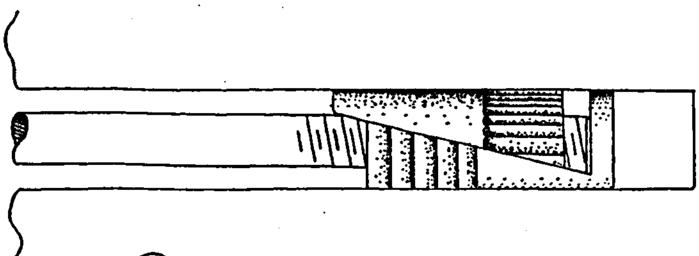
TYPES OF EXPANSION SHELLS



(a) STANDARD



(b) BAIL



(c) WEDGE-NUT

FIGURE 14

The plug is a semi-cone which has either flattened sides to bear against the inside of the leaves or small ribs that fit into the spaces between the leaves.

In the base of the shell there is a hole through which the threaded part of the bolt passes. Since the shell is not threaded, it is held in place until set in the drill hole by one of two means. One type has two pressed ears in the bolt just below the threads that holds the shell in place, and the other has a palnut screwed under the shell base. Both give satisfactory results.

The common feature of all standard types of expansion shells is the conical expansion of the leaves. When the plug is drawn towards the base of the shell the leaves open in the shape of an inverted cone whose vertex is below the shell's base. (Please note figure 15-a).

2) The bail type of expansion shell is shown in figure 14-b. Its essential parts are a two-piece shell, a bail and a plug. The serrations on the outside of the shell generally extend the full length of the shell. Some manufacturers cut a slot at the center of each shell-half thus dividing each half into leaves. The bail passes over the two recesses on the plug and is secured either to the top of the shell or, when slotted shells are used, to the bottom of the shell. Shell and bail are also made in one piece. The bail provides temporary support to hold the shell before set in

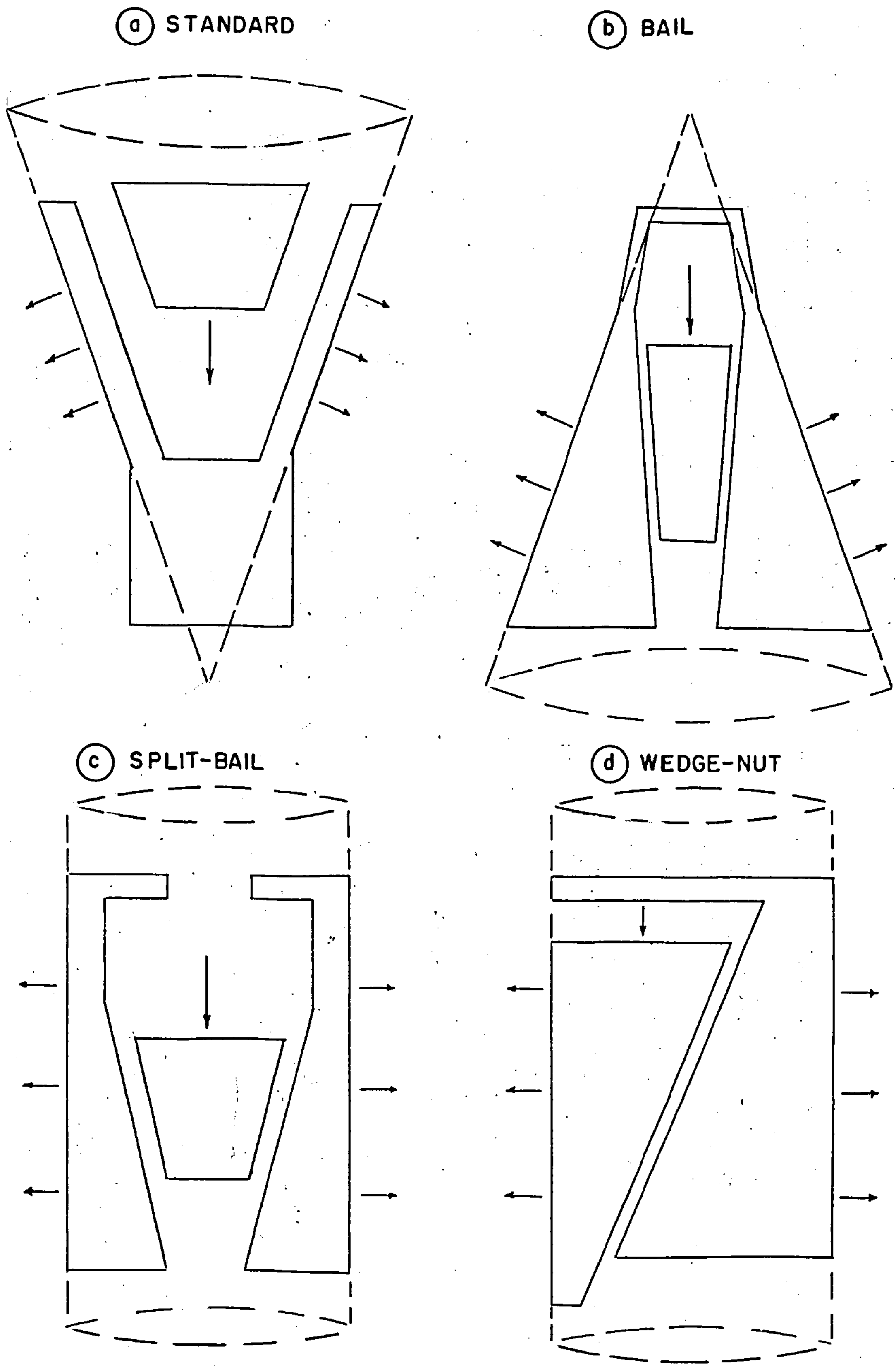


FIGURE 15

the hole, thus not requiring the use of pressed ears or palnut. The plug can be a semi-cone, as the one used with standard shells, or a complete cone.

The bail shell also has a conical expansion, but in the shape of a cone whose vertex is over the shell. (Please note figure 15-b). A special type of bail shell has a cylindrical expansion due to a splited bail. (please note figure 15-c). Until set in the drill hole, this special type of bail shell is held in place with a thin wire ring which breaks during expansion.

3) The wedge nut type of expansion shell is shown in figure 14-c. It is made of a cylindrical shell cut in halves that are arranged diagonally. One of the halves is threaded in the inside and the other is not. The unthreaded half is larger and has a circular base on the top. This type of shell has a cylindrical expansion as illustrated in figure 15-d.

Anchorage Study.

When the rock bolt is placed in the drill hole and is rotated from the head, the whole bolt tends to rotate. However, contact between the expansion shell and the wall of the drill hole prevents the shell from turning. The plug cannot rotate inside the shell, therefore it is drawn onto the threads. Both, the plug and the interior of the shell, are tapered but in opposite directions, thus the wedge action causes the shell to expand. The expansion of the shell causes a deformation in the rock which results in an enlargement of the drill hole at the anchor. The bolt is anchored when the vectorial sum of the following forces equals the tension tension caused by the torque at the head: (Please note figure 12)

a) Compressive force between the exterior of the shell and the walls of the drill hole.

b) Frictional force between the interior of the shell and the exterior of the plug.

c) Frictional force between the threads of the plug and the threads of the rod.

d) Frictional force between the head of the rod and the bearing plate.

The rate of increase of force (a) depends on the compressive strength of the rock. Hard rocks will stand a large force (a) with less deformation than the softer rocks. If a large force (a) is attained with little deformation of the drill hole, anchorage will be weak. If force (a) is extremely small, the shell will expand with little resistance until the plug reaches the base of the shell.

Force (b) has a very small value compare with force (a) and variations in it have no influence in anchorage performance. The frictional force (c) in the threads produces a resisting torque in opposite direction to the torque applied on the head. When the threads of the plug or/and the rod are damaged, force (c) can be singularly large. For this reason the reuse of rock bolts is not advisable, because most of the torque applied at the head will be used to overcome friction at the damaged threads.

Force(d) is by far the greatest resistance offered to rotation. Its magnitude depends on the bearing between the head and the plate and on the nature of the surfaces. When the bolt is not perpendicular to the bearing plate, force (d) is greater. The use of a hardened steel washer between the head and the bearing plate reduces considerably force (d).

After the downward motion of the plug is stopped by the resisting forces, continuing rotation stresses the bolt in tension. Strictly speaking, tension starts before the plug is arrested, but most of this tension is used in producing movement. It is after the plug motion stops that the final bolt tension is achieved. When tension is applied, the shell tends to be pulled downward but is held in place because of three reasons: the friction between the shell and the rock, the bigger diameter of the shell due to expansion, and the grip of the serrations.

If the rock at the anchor is weak under compression and shear, it will not stand the force caused by the downward pull of the shell. The rock will be plastically deformed and sheared and a slip will start between shell and rock. The dynamic coefficient of friction is smaller than the static one, so smaller resistance will be offered to the slip. The sliding continues until tension is lost and by this time the drill hole is badly deformed and anchorage is impossible. If a rock of such weakness is encountered it can be said that rock bolts cannot support it. The preceding description of anchorage failure follows the same pattern when a properly anchored bolt is subject to excessive loading. As the load builds upon an installed rock bolt, the effect on the anchorage is the same as if the head was being tightened.

Holding Capacity.

Several factors determine the capacity of a rock bolt to stay in place and withstand loads exerted upon it. For the expansion-shell type of rock bolts the factors are the following:

a) Kind of steel and diameter of the rod.

b) Tightening device of the bolt.

c) Type of expansion shell.

d) Drill hole diameter.

e) Excellence of installation.

f) Kind and condition of the rock at the anchor.

a) The tensile strength of a steel rod depends on the diameter of the rod and the kind of steel of which it is made. When made of regular strength steel, typical loads that rods of various diameters can support within the proportional stretch of the steel are:

5/8"	12,200 lbs
3/4"	16,800 lbs
7/8"	23,000 lbs

When high-strength steel is used the values are about 25 per cent higher.

b) When the rock bolt is being tightened, torque is required to overcome friction between the head and the bearing plate, and in the threads. The resisting torque in the threads produces an equal an opposite torque in the rod. The combination of tensile stress and shearing stress (caused by the torque) makes the bolt yield at a lower tensile load than when in pure tension. The greater the torque the lower the tensile load at yield. For this reason a special expansion-shell type of rock bolt is provided with a non-torque tightening device. Instead of a head this bolt has a threaded end. The bolt is placed in the drill hole leaving part of the threads out of the hole. A small square head, with ½" of threads in the inside, is screwed on the end of the bolt and used for rotating the bolt to expand the shell. After the bolt is anchored, the head is removed and a bearing plate is placed over the bolt; a nut is then tightened to the desired torque. The advantage of this bolt is that tension is attained without twisting the shank, so for equal conditions this bolt can support higher loads than the regular headed one.

A 3/4" bolt tightened by torque can yield at loads as low as 10,300 lbs; while the same bolt tightened in tension only will rarely yield below 14,000 lbs. Rock bolts that are tightened without torque are usually preferable.

c) The type of expansion shell used will influence anchorage performance. It was mentioned before that when a bolt is tensioned, the shell is kept in place by: the friction between shell and rock, the bigger diameter of the shell due to expansion, and the grip of the serrations. The friction depends on the nature of the rock and the area of contact. The longer the shell the bigger the contact area, but also the bigger the tension needed to expand the shell; this is why extra long shells are not advantageous. The wedge-nut and the split-bail(*) types of shells have the greatest area of contact per unit length, the bail type has the next greatest area and the standard type has the least area. The tension required to expand the shell varies directly as the area of contact. The amount of free expansion

---

(*) The split-bail shell is the variation of the regular bail type which has a splited bail. It is shown in figure 15-c.

(expansion outside the drill hole) in the shell depends on the angle of taper and the thickness of the plug. The best angle has been found to be 6 degrees. The thickness of the thick end of the plug depends on the relative dimensions of each shell, but it should be such that with maximum expansion the shell will be 3/16" wider than the drill hole diameter. This is not absolute and in some rocks thicker plugs may give better anchorage, this can only be determined by experimentation.

When the same tension is applied to the different types of shells, the bail type has the highest expansion force because the moment arm increases as the plug is drawn onto the threads. In the standard type the moment arm decreases with the run of the plug. This characteristic of the bail type is advantageous because the resistance of the rock to expansion increases as the plug is drawn onto the threads. It is in the last instances of the expansion process that most expanding force is needed. The split-bail and wedge-nut types do not have a moment arm, therefore the expanding force is uniform throughout the expansion process.

d) The diameter of the drill hole is greatly influenced by the design of the shell; different manufacturers recommend different hole diameters. It is difficult to relate hole diameters with types of shells unles shells are catalogued according to the manufacturers. The following table gives the most common diameters used according to the bolt diameter and the type of shell:

Bolt Diameter	5/8"	3/4"	7/8"
Type of Shell	Drill Hole diameter, in inches		
Standard	1 1/4	1 3/8	
	1 5/16	1 1/2	
	1 3/8	1 5/8	
Bail	1 3/8	1 3/8	
	1 1/2	1 1/2	
Split-bail	1 1/2	1 5/8	1 5/8
	1 5/8		
Wedge-nut		1 9/16	

Of all the above figures the most used in standard and bail types is 1 3/8" and in split-bail type 1 5/8". For the softer rocks, better anchorage is obtained with smaller holes and for hard rocks better anchorage is obtained with larger holes.

It is said that variations in hole diameter of 1/16" can have detrimental effects on anchoring strength, if such is the case the only sure way of determining the best hole diameter is by testing.

e) In the last part of the chapter, a recommended installation procedure will be described.

f) Anchorage strength is ultimately determined by the kind and condition of the rock at the anchor. Rocks vary broadly in composition and properties and even the same rock can have different properties in different locations. Hence, a classification of rocks according to their anchoring strength is useless. The only positive way of determining the anchoring strength of a rock is by testing. Organized tests must be done before a bolting program is undertaken and the first installations should be done on a trial and error basis.

In a generic sense, it can be said that the expansion-shell type of rock bolt anchors best in soft and medium hard rocks. By soft it is meant shales or coal and not unconsolidated material.

Installation Procedure.

Installation of the expansion-shell type of rock bolt requires two distinct operations: drilling the hole and tightening the bolt.

The drilling of the hole is done in the same way as explained for the slot and wedge bolts. The only difference is in the diameter of the hole that is generally bigger and depends on the type of shell used. The length of the hole is of no importance since anchorage is not obtained by striking against the bottom of the hole. The only precaution is to make the hole at least 3" longer than the bolt length. Longer holes are a waste of drilling time but will not hinder anchorage.

Before placing the bolt in the drill hole, a bearing plate is passed over the threaded end of the bolt and then the shell and plug are installed. When using standard expansion shells, the leaves should overlap the plug by ¼" before insertion of the bolt. On the other types, the plug or wedge should be threaded onto the bolt three or four turns. To save handling and installation time, shells and plugs can be purchased assembled on the bolts. In these cases, bearing plates with a T-hole are slipped over the head of the bolt after the shell has been inserted in the drill hole.

Once the bolt is inserted in the drill hole and the plate is bearing flush against the rock surface, a few turns of the head will expand the shell ehough to keep the bolt in place. This is particularly useful when rock bolts are being installed overhead, because the bolt need not be supported while attaching the tightening machine.

When applying tension to rock bolts it should be remembered that the initial tension plus any load that will build up thereafter should not reach the yield point of the steel. Various advisable tensions to be applied to the different sizes of rock bolts are shown in the table below:

		Average Yield Load in lbs	Installed Tension in lbs	Required Torque, ft-lbs
5/8"	(a)	11,000	5,000 - 7,000	105 - 150
	(b)	15,000	6,000 - 8,000	125 - 170
3/4"	(a)	15,000	6,000 - 8,000	150 - 200
	(b)	22,000	6,000 - 8,000	150 - 200
7/8"	(a)	22,000	11,000	300(c)
	(b)	30,000	15,000	400(c)

(a) Regular-strength steel.

(b) High-strength steel.

(c) These torques should be obtained with non-torque tightening devices and using hardened-steel washers.

The United States Bureau of Mines (37-b) dtermined the tension-torque relation for 3/4" bolts. It is the empirical formula shown below:

$$Tn = 39.8 \times Tr$$

Tn: tension in the shank, in pounds.

Tr: torque applied to the head, in foot-pounds.

The tension will be within $\pm$ 2,880 lbs in 90 per cent of the cases with torques up to 200 ft-lbs. When torques over 200 ft-lbs are desired, tightening should be done with non-torque tightening devices.

Tightening can be done with: hand wrench, impact wrench or rock drill. The process and tools used are identical to those described for slot and wedge bolts.

CHAPTER 4

SPECIFICATIONS FOR ROCK BOLTING

The committee on Roof Action of the American Mining Congress, Coal Division, has recommended dimensions and specifications for rock bolting materials. The following is a summary of the recommendations submitted to the industry as mining standards(*).

Steel Specification: All mine rock bolts shall be made of open-hearth or electric furnace steels according to Tentative Specification for Carbon-Steel Bars subject to Mechanical Property Requirements, American Society of Testing Materials (ASTM), Designation A-306, latest issue.

Bars from which rock bolts are made shall have the following tensile properties:

	Regular-strength	High-strength
Tensile Strength, psi	60,000 min.	80,000 min.
Yield Point, psi	30,000 min.	40,000 min.
Elongation, min. in 8" length	17 pct	12 pct

Threads: All threads shall accept a Class 2 "go" ring gauge.

(*) The recommendations do not include 7/8" bolts.

Bolt diameter	1"	3/4"	5/8"
Length of threads, min.	5"	3 3/4"	3 3/4"
Threads per inch	8	10	11

Bolt Head Markings: The length in inches shall be marked on each bolt head. All 5/8" high-strength bolts shall be marked with a five point star of approximately ¼" in size. All 3/4" high strength bolts shall be marked with a triangle of approximately ¼" in size. Each bolt head shall be marked to identify the manufacturer.

Expansion Shells: Material for expansion shells and plugs shall conform to the requirements of ASTM specification for Malleable Iron Castings A-47 latest issue, grade 32510, or shall be forged steel with a maximum sulphur content of o.23 per cent.

Wedges for Slot and Wedge Bolts: Wedges may be made of steel or cast malleable iron in accordance with the following:

Steel Specification: Same as for regular-strength bolts, namly; open-hearth or electric furnace steels in accordance with ASTM designation A-306, latest issue.

Cast Malleable Iron Specification: Material for malleable iron wedges shall conform to the requirements of ASTM specification for Malleable Iron Castings A-47, latest issue,

Grade:32510

Length: 5½" Min., 6" max.

Width: 3/4"

Thickness: 3/4" or 7/8" or 1". Tapered to chisel point of 1/16" maximum thickness.

<u>Slot in Slot and Wedge Bolts</u>:

Width: 1/8" max.

length: 6" min.

<u>Nuts</u>: American standard regular square unfinished nut or American Standard heavy hexagonal nut with following dimensions:

Hexagonal:	1 5/8" x 1"	tapped 1"
Square:	1 1/2" x 7/8"	tapped 1"

<u>Bearing Plates</u>: Any open-hearth or electric furnace steels suitable for punching and shearing may be used. If Bessemer steels are used the carbon content shall be 0.15 per cent maximum and the manganese content shall be 1.00 per cent maximum. Thickness is optional, except that plates under 5/16" bearing directly against the rock shall be embossed.

<u>Angle Washers, Ties and Channels</u>: These products shall be made of open-hearth or electric furnace steels, in which the following shall not be exceeded:

Carbon:	0.40 per cent.
Phosphorus:	0.04 per cent.
Sulphur:	0.05 per cent.

CHAPTER 5

MISCELLANEOUS ROCK BOLTS

Under the name of Miscellaneous are grouped all the rock bolts which do not fit into the two major classifications studied before. Most of these bolts are designed for specific usage. Even though the bolts studied in this chapter do not cover all the bolts used today for support purposes, each one introduces a new principle.

Wooden Rock Bolts.

The use of wooden rock bolts came into use during the Korean War when steel was scarce. Very few applications of wooden rock bolts are known and almost no research has been done with them. The scanty information available comes from one or two former users of which the Day Mine in Idaho, USA, is the most important.

Wooden rock bolts usually vary from 1 5/8" to 2" in diameter and have approximately the same tensile strength as a 1" steel bolt. They are made from any straight-grained wood on a dowel-making machine such as the type used in mines for making loading sticks. The wood is treated to resist decay. The driven end is left square for 6" to 10" and each end is slotted for about 12" with slots at right angles to each other. Wedges of wood, about 16" long by 1 5/8" wide with a butt end 1" thick, are inserted in the slots.

The hole for a wooden rock bolt is drilled about 1/8" larger than the bolt diameter and a few inches shorter than its length. Driving is done with a drill and a dolly which fits over the wooden bolt in much the same way as with a steel bolt. If a head board is used, a hole is drilled in it to pass the bolt. The head board of any desired length and about 3" thick is pushed against the rock and the outer wedge in the bolt is driven with a jack. Excessive length is then cut off.

The material cost for wood bolting is considerably less than for steel bolting. A wooden bolt costs approximately 25 to 30 per cent of an equivalent steel bolt. Wooden bolts are more easily damaged by blasting and they are not as suitable for use as auxiliary hangers of pipe and conduits as steel bolts. Their life is usually less than that of steel bolts.

The main application for wooden bolts is in wet ground. The ability of the wood to absorb moisture causes it to expand, making contact with the sides of the hole along all the length of the bolt. However, weakness in shear and bending limits the use of wooden rock bolts.

Perfo Bolt.

The Perfo bolt consists of perforated steel half-sleeves that are filled with mortar, tied together, and inserted in a drill hole. A steel bar is then pushed through the sleeve forcing the mortar through all the perforations and filling the entire hole. In order to prestress the bolt in tension a regular rock bolt may be used instead of the steel bar and tension is applied after the mortar has hardened.

The diameter of the drill hole, of the bar, and of the Perfo sleeve are selected so that the mortar volume will fill the hole solidly when the bar is driven to refusal.

Special advantages offered by the Perfo Bolt are:

a) Distributed anchorage. The steel bar is fully embedded along its entire length.

b) High shear resistance. The solid grout provides high resistance to shear forces and vibrations. It is very effective in areas subject to secondary blasting.

c) Long life. No slippage, corrosion, or necessity for maintaining tension.

d) Simple installation. Installation does not require close drilling tolerances or complicated equipment as when regular rock bolts are injected with cement after installation.

Rock bolts afford a better support if installed immediately after blasting, therefore an accelerator should be added to the mortar to cause quick setting. A Perfo Bolt can support a load of 12 tons one day after installation. To offset the natural shrinkage of concrete an expanding compound is added to the mortar.

The Perfo Bolt is the last alternative to be used when the ground is too fractured or too soft to anchor conventional bolts.

Foran Bolt.

The Foran Bolt is anchored in a drill hole by the expansion of a short length of rubber hose slipped over the bolt end. Expansion is achieved by turning a compression nut against the end of the hose, thus shortening the length of the hose and expanding it against the inside wall of the hole. A special tubular wrench is needed to slip over the protruding end of the bolt and engage the compression nut near the bottom of the drill hole.

Anchorage obtained with the Foran Bolt does not compare favorably with conventional rock bolts.

Dowty Bolt.

The Dowty Bolt is a recoverable rock bolt used where temporary support of small loads is needed. It is especially useful in coal mines when recovering coal.

The Dowty Bolt consists of a hollow tube through which a steel rod passes. At one end of the rod is a rubber head connecting the rod with the tube. Longitudinal movement of the rod, inside the tube, presses the rubber head and expands it laterally. At the other end of the bolt an elaborate device provides the pull of the rod to expand the head and anchor the bolt. A nut is used to tension the bolt. A cam handle, that can be operated from a distance with a rope, releases compression in the rubber head, thus recovering the bolt.

The low anchorage obtained with the Dowty Bolt limits its use to short-life openings or where loads are small.

CHAPTER 6

THEORY OF ROCK SUPPORT WITH ROCK BOLTS

The essential features of rock bolts which distinguish them from conventional supports are: One, The employment of the tensile strength of the material instead of the compressive strength; two, prestressed installation.

The portion of the rock which lies between the anchor and the bearing plate is compressed by applying tension to the bolt. In doing so, the bolt reinforces the rock and developes a structural entity in much the same way as steel bars do in prestressed reinforced concrete.

When sets of conventional supports, such a timber, steel ribs or concrete structures, are installed in an underground opening the surrounding rock has to move outwards an appreciable distance before any load builds up. This movement, even in small amounts, weakens the overlying rock and increases the load. Rock bolts, being installed with an initial tension, prevent any movement of the rock, therefore the load supported is considerably less. This is why it is of utmost importance to install rock bolts as soon as possible after blasting.

Solely for the purpose of explaining why rock bolts do work, some elementary principles of rock mechanics will be presented in the present thesis. No attempt is made to prove or discuss these principles that have been thoroughly treated in geomechanics literature.

The principles which explain the succesful application of rock bolts as means of ground support are:

1) Suspension.
2) Beam Building.
3) Arch Reinforcement.
4) Friction Increase on Shear Planes.
5) Elimination of Horizontal Tensile Forces.
6) Stabilization of Fractured Rock.

When rock is supported with rock bolts more than one of the above principles is present. According to stress analysts other principles, not fully investigated, enter in the complex scheme of rock support. For the purpose of the present thesis only the above six principles will be described briefly.

Suspension.

Rock is supported by suspension when loose pieces of rock are pinned and secured to solid ground. This is the poorest way to employ a rock bolt since its essential features of prestressed installation and reinforcement of the rock mass are not used. Here, the bolt acts as a hook only which has to support the entire weight of the largest piece that may become loose. (Please note figure 16-a). Moreover, a big boulder cut through by a drill hole will be weak enough to split in two and fall. For loosened pieces of rock it is always advisable to have them "barred down," never pinned.

There is a special case where rock bolts do give satisfactory results when holding rock by suspension.

It is the case frequently found in collieries, where the flat roof consists of a thin bed of soft laminated shale which underlies a hard bed of sandstone or other competent rock. In this case, rock bolts suspend the weak bed from the hard one. (Please note figure 16-b). The reason behind the success in this particular case is the presence of another principle: that of beam building which will be explained below.

Beam Building.

The principle of beam building is particularly useful when mining bedded formations such as coal, potash or uranium deposits. The methods for mining these deposits include tabular openings with long-spanned flat roofs. The layers of sedimentary rock of which the roof is made acts as a simple beam supported at both ends. Rock is particularly weak under bending stresses and if it is jointed transversely, as it generally occurs, this weakness is accentuated.

Rock bolts tie layers together and prevent slippage between them with a consequent reduction in beam deflection. Individual layers tied up in this manner form a monolithic beam which is self supporting and does not depend on suspension from a formation above it. (Please note figure 16-c).

Arch Reinforcement.

Reinforcement can be applied to an arched underground opening such as tunnels, cross-cuts, drifts, etc. This principle is particularly applicable in igneous or metamorphic rocks where the back does not break to a natural smooth plane and must be carried in an arch for maximum strength.

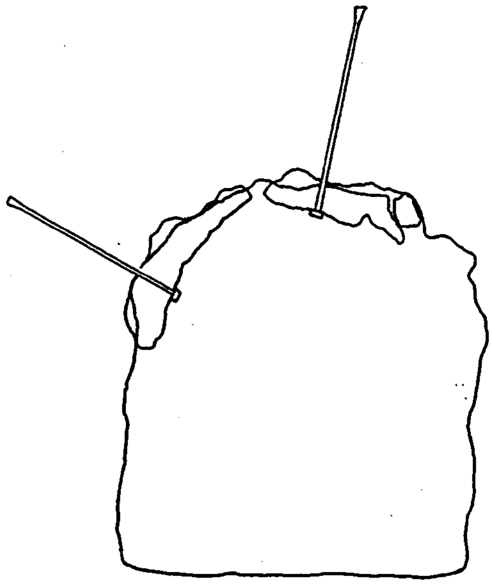
With conventional tunnel-driving methods, blasting crushes the rock within a certain cross section. Outside of this section the rock is fractured and shattered but held in place for a time. Further blasting, exposure to the air and other agents open fractures causing the rock at the exposed surface to cave into the opening. If this process is not arrested it continues until the entire opening is filled with rock. By rock bolting the upper perimeter of a tunnel, the fractured or sloughing zone is compacted and made self-supporting. (Please note figure 16-d).

Friction Increase on Shear Planes.

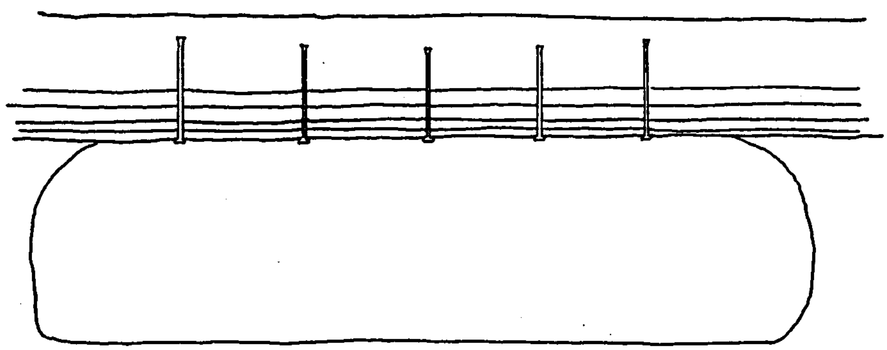
Vertical or steeply dipping walls of stopes, shafts and other large underground openings must often be reinforced to prevent spalling. When stoping steep tabular veins, mainly those of hydrothermal origin, it is common to find in the walls natural shear planes parallel to the vein. When the supporting ore is removed, the hanging wall, and sometimes the footwall, will slip downwards. Bolting these walls increases the friction in the shear planes and also gives the rock a higher tensile strength. (Please note figure 16-e).

Elimination of Horizontal Tensile Stresses.

In an underground opening of tubular shape, as a tunnel or drift, the stresses around it vary from compression at the ribs to tension at the roof and floor.

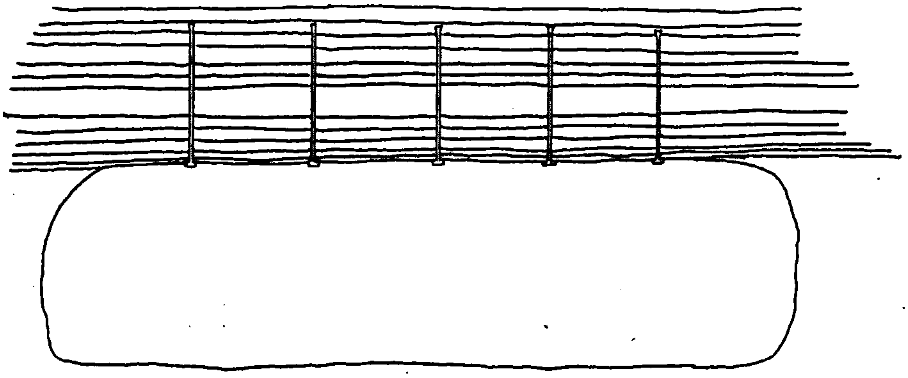


(a) SUSPENSION

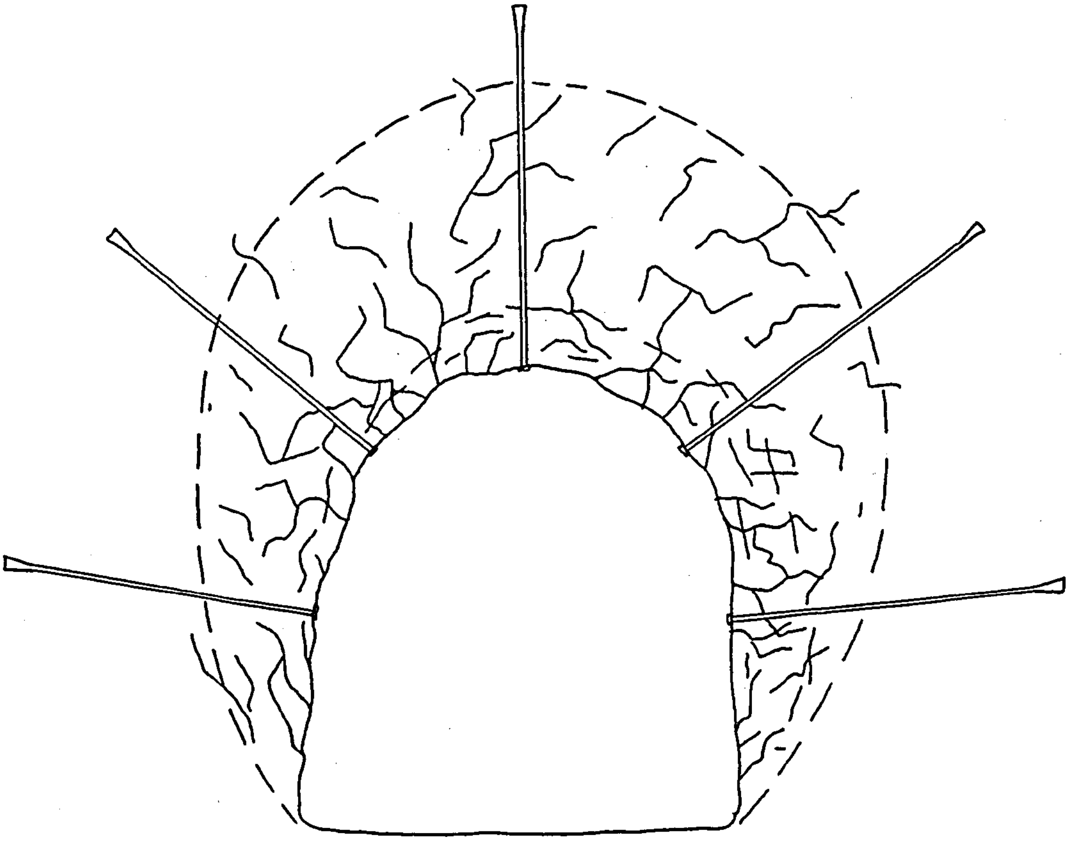


(b) STRATA SUSPENSION

FIGURE 16

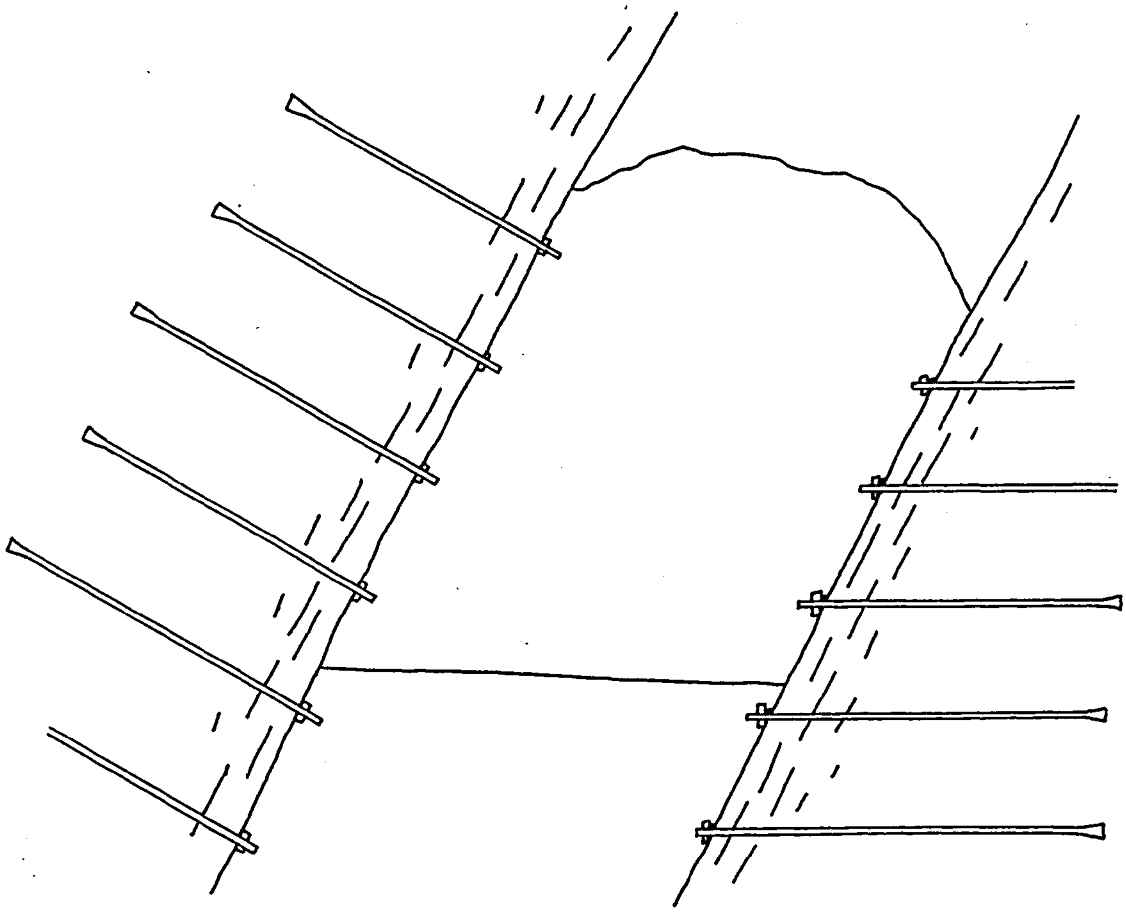


(c) BEAM BUILDING



(d) ARCH REINFORCEMENT

FIGURE 16 (cont.)



(e) FRICTION INCREASE ON SHEAR PLANES

FIGURE 16 (cont.)

Rock is weak in tension and if jointed can be assumed to have no tensile strength. Under these circumstances the rock in the roof of an opening will not transmit tensile stresses and cracks will appear until individual blocks cave in. When rock bolted, a zone of radial compression is created around the opening by the tension in the bolts. A Poisson's ratio effect makes the compressed material to tend to expand laterally. As this tendency is restrained, compression is induced at right angles to the direction of the bolt, thus eliminating the initial tensile stresses. Tensile stresses in the floor are unimportant since loose blocks will not fall.

If the rock is bolted before the cracks appear, it can be made self-supporting. If bolting is delayed, the rock will be supported by simple suspension and the bolts will have to resist much higher loads.

Stabilization of Fractured Rock.

Rock may be broken into numerous slabs, blocks or irregular interlocking fragments. Rock in this condition may be a product of natural effects (jointed granite, breccia, shear zones, etc.) or it may be due to blasting. When due to natural effects the crushed zone will normally extend far away from the opening's perimeter; if due to blasting, it will not extend further than the tunnel radius. In the former case, the rock can be supported efficiently if the interlocking fragments are big enough to provide an anchorage for a rock bolt. In the latter case, it is only neccessary that the rock bolt be anchored in the uncrushed zone.

In either of the above cases, rock bolts will compress the fractured rock and make it self-supporting in much the same way a mansonry arch can withstand vertical loads.

When bolting any kind of rock, a low-tension zone developes between rock bolts. If the rock is not crushed, the low magnitude of the tension is harmless. When crushed rock is bolted, a fall-out of a small amount of material between bolts can easily start ravelling the whole mass due to the movement of certain key fragments which, although carrying little or no load, may start a run if removed. In order to prevent the first fall-outs a flimsy support is needed between bolts, such as thin chicken wire.

CHAPTER 7

PATTERN, APPLICATION AND ACCESSORIES FOR ROCK BOLTING

Where large areas are to be supported by rock bolts, it is necessary to design a general pattern of bolting rather than to bolt only where the engineer or inspector considers it might be needed. Up-to-date geological information correlated with pull-test data regarding the properties if the rock will enable a systematic bolting program to be designed, including length of bolts, angle of bolts to free surface, spacing of bolts and use of rock bolting accessories. The use of a pattern in bolting enables the installation crews to work systematically and makes for easy and convenient checking of the bolts after installation. These advantages far outweigh the cost of the few extra bolts that might be installed.

Rock bolts are used in almost all kinds of mines and construction work. Today rock bolts are employed in underground metal mines for sill development, stoping, raises, and shafts; in coal mines and other tabular openings; in construction tunnels and in surface construction projects. In the present chapter rock bolt applications will be classified, according to the pattern and accessories used, in five categories; horizontal tubular openings, stopes, tabular openings, shafts and surface workings.

Horizontal Tubular Openings.

By horizontal tubular openings are meant those underground workings of approximately cylindrical cross-section and whose long axis is horizontal and much longer than the other axes. In this category are included: drifts, cross-cuts, tunnels, haulage-ways, etc.

When rock bolts are used in tubular horizontal openings they generally support rock by two principles; arch reinforcement and elimination of horizontal tensile forces. In very particular instances they can stabilize fractured rock and/or suspend loose boulders.

The variables to consider when designing a rock bolting pattern for horizontal tubular openings are: row pattern, row spacing, bolt length and angle of bolt to the rock surface.

Rock bolts are installed in planes perpendicular to the long axis of the opening. Each plane is named a row and the spacing between rows is the row spacing. For rock bolting purposes, the cross-sections of the horizontal tubular openings can be grouped in three classifications: flat, arched and circular.

With flat cross-sections the row pattern is shown in figure 17-a. The spacing of the bolts depend on the load on the roof and the tensile strength of the bolt used. For 1" slot and wedge bolts, the bolt spacing varies from 3ft. to 5ft., for 3/4" regular expansion-shell bolts form 1½ft. to 3ft. Where sloughing of the walls is a problem, one or more bolts may be placed in the ribs. The row spacing varies between 3ft and 6ft. It is not advisable to have all rows with the same pattern since the thrust caused by the anchor in the rock can create a vertical plane of weakness along the length of the opening. To provide for this, it is recommended to have two patterns and use them alternately, so that no two consecutive bolts will be in the same allignment.

For flat tunnels, the length of the bolt should be at least one half the width of the opening; making those bolts close to the vertical one foot longer than the others. If the ribs are bolted, bolts 4ft long are sufficient.

Generally bolts should be installed perpendicular to the rock surface since the strength of the bolt varies inversely with the angle to the normal. Bolts at an angle with the normal should be used only when the geological structure of the roof justifies it. Inclined bedding formations may be better supported with bolts normal to the bedding plane than to the rock surface.. Special angle washers are used for non-perpendicular bolts so the nut or head will bear flush against the surface.

When openings have an arched cross-section, the row pattern is fan-shaped. (Please note figure 17-b). The lowest bolt is installed at about hip height. Bolt spacing is from 3ft to 5ft. The length of the bolts should be at least as long as the tunnel radius, with longer bolts at the top and shorter at the ribs. Here too, the bolts should be perpendicular to the rock surface.

When openings have a circular cross-section, the row pattern is a ring of bolts installed radially around the perimeter with the lowest bolts at the horizontal. (Please note figure 17-c). Bolt spacing is from 2ft to 5ft and row spacing is from 3 ft to 6ft. All bolts have the same length which should be at least as long as the tunnel radius. Bolts should be normal to the surface.

When rock tends to break and cave between rows of bolts, steel rock-ties are useful. They are made of steel tie sections of any desired length. They are pressed against the rock under the bearing plate by one bolt of two or more consecutive rows. War surplus landing mats were also used instead of rock-ties. They are thin plates of steel with punched holes. When rock tends to cave in small pieces between every bolt, as when stabilizing fractured rock, wire mesh is used just to hold small pieces in place. This last practice is very common when tunnels are to be concreted since the wire mesh provides for a better bond.

Stopes.

Stoping methods in which rock bolts are used are cut and fill, square sets and shrinkage. With these methods, the openings within the stope have a relatively short life, therefore rock bolts support the opening until filled. Generally, only the hanging wall needs to be rock bolted, but for steeply dipping veins with "false walls" footwalls and the ore itself are sometimes bolted.

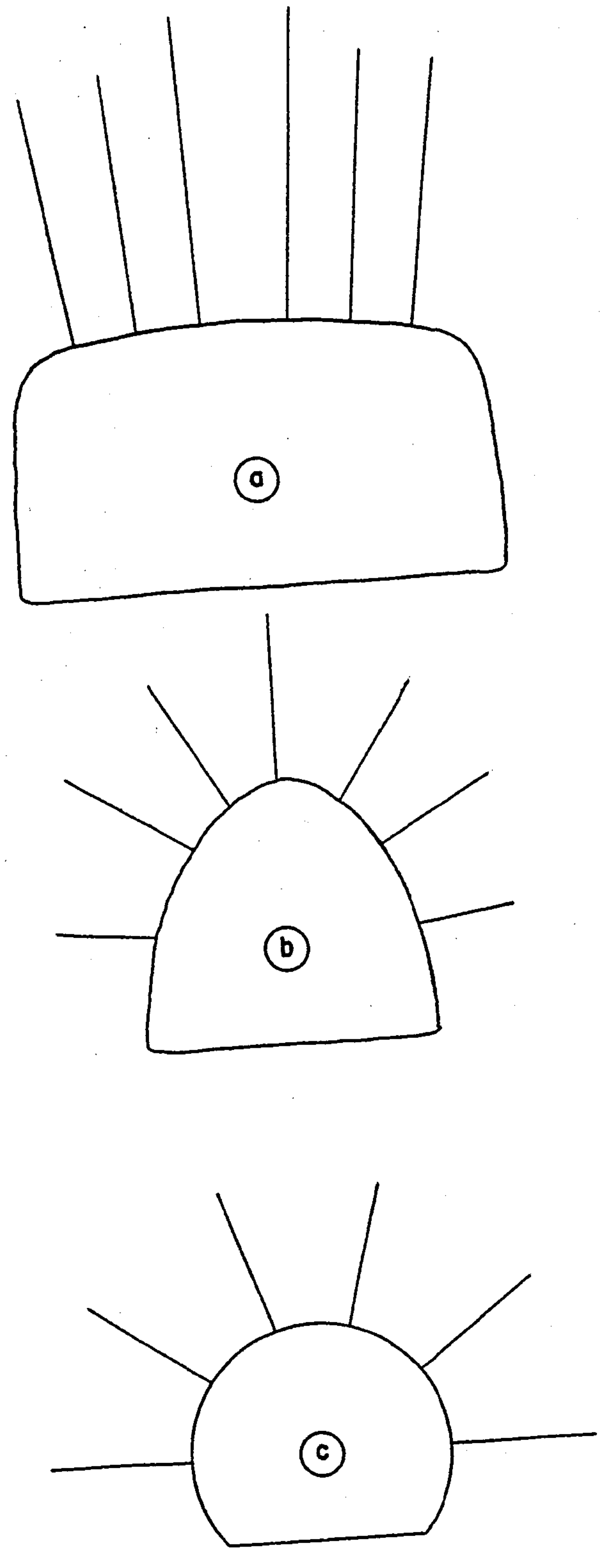


FIGURE 17

In stoping, rock bolts support the ground by increasing friction on shear planes.

The most common pattern used to support the walls is a rectangular grid where the bolts are spaced 5ft. horizontally and 4ft. vertically. This spacing may vary according to the competence of the rock. Bolts should be long enough to anchor in non-sheared rock, bolts 6ft. to 8 ft. generally reach solid ground. In the hanging wall, bolts should be installed perpendicular to the wall, but in the foot wall it is better to place them horizontally to prevent sliding of "false walls."

Rock bolting the ore in the back of stopes makes possible the breaking of larger rounds and permits bigger heights between fill and ore. The pattern consists of installing vertical bolts through the ore and anchoring them in the hanging wall. If the vein is vertical, the bolts may be placed at an angle to reach the wall. Bolts are lost after blasting the round.

Some stopes that normally would be mined by cut and fill, when rock bolted, can be mined by the more economical method of shrinkage stoping. Also, some veins which normally must be mined by square sets, when rock bolted, can be mined by cut and fill.

Tabular Openings.

By tabular openings is meant those underground workings in which two dimensions are much bigger than the vertical dimension, as is the case in coal mines and other bedded deposits.

Coal mines are characterized by wide flat roofs of sedimentary rock in layers.

In coal mines, rock bolts support the roof by the principle of beam building and by the principle of suspension from a stronger stratum. The pattern used is a series of parallel rows perpendicular to the mining advance. All bolts are installed normal to the roof.

Where there is a thick competent stratum in the roof, bolts should be long enough to anchor in such stratum. When the roof is made of thin layers, the problem is more complex. The United States Bureau of Mines (24) has developed a formula to compare the amount of support provided by different bolting systems in thin bedded roofs. The formula is based on the principle that stratified roofs fail under bending stresses and the ultimate purpose of any support is to decrease the bending strain. The formula is as follows:

$$D = 0.265\,(bL)^{-\frac{1}{2}} \left[\frac{NP(h/t-1)}{w}\right]^{1/3}$$

D: decrease in bending strain due to rock bolting, as a decimal fraction of the bending strain in the unbolted roof.

N: number of bolts per row across the opening. (Equidistant spacing of the bolts is most satisfactory).

P: bolt tension, lbs.

h: bolt length, inches.

T: bed thickness of the roof rock, inches. (For a roof composed of beds of different thickness, T is the average thickness).

w: unit weight of the rock, lbs/cu in.

b: spacing between rows , inches.

L: span or width of the opening, inches.

The limits beyond which the formula is not applicable are:

Maximum L: 1066 in. (89ft)

Minimum b: L/12

Maximum N: 12

Maximum P: 17×10^{-8} EL

(E: Young's modulus for the rock. Normally = 4×10^{6} psi)

Maximum h: 3L/8

Minimum T: L/64

If the value of D obtained in the preceding formula is substituted in the formula below

$$RF = \frac{1}{1-D}$$

the so called reinforcement factor (RF) is obtained. A bolting system with a higher RF gives better overall support. In most coal mines an RF between 2 and 3 is fairly easy to obtain, higher values are difficult to obtain.

When changes in local conditions demand a change in one of the variables, other variables can be changed and still maintain a safe reinforcement factor. A typical case is when rock falls between bolts due to transverse fractures in the strata. To arrest rock falls, the number of bolts per row, N, can be increased and the bolt length decreased.

Shafts.

Rock bolts used in shafts have the purpose of increasing friction on shear planes and of suspending loose slabs. Since shafts need to accomodate hoisting facilities, they are usually either timbered or concreted.

With timbered shafts, rock bolts are placed perpendicular to the walls in the center of the squares formed by the timber sets. The bolt length is normally 6ft. Sometimes slot and wedge bolts are used like anchor bolts from which to hang timber sets.

When shafts are to be concreted, rock bolts are installed in parallel horizontal rings . Horizontal and vertical spacing is generally 2ft to 3ft. Bolts are always perpendicular to the surface and are about 6ft long. Alternate rings should offset each other at consecutive rows, so no two adjacent bolts are in the same vertical plane.

Surface Applications.

Two main applications of rock bolts in surface workings are: to improve ground conditions for foundations and to stop rock slides in slopes.

When improving foundations, rock bolts are of the slot and wedge type with lengths from 8ft to 20ft. They are generally cemented.

In railroad or highway cuts, bolts are generally installed where needed. Visual inspection of weak zones determines the places where rock bolts are needed. The length of the bolt is designed according to the depth to solid ground. Where cuts are done in ravelling rock, wire mesh is used to protect the project from falling boulders. Rock bolted slopes can be made much steeper, thus saving excessive excavation.

CHAPTER 8

COST OF ROCK BOLTING

The unit cost of rock bolts depends greatly on the manufacturer. When slot and wedge bolts are made in a mine shop their cost is, of course, less than when purchased commercially. This lower cost usually offsets the shortcomings found in shop-made bolts.

Rock bolt prices, for the same manufacturer, vary according to the type of bolt (slot and wedge or expansion-shell), the diameter of the bolt, the length of the bolt, the type of expansion shell, the steel quality and the quantity of bolts purchased. In the table below is shown an average price rate for regular-strength bolts bought in bundles of over 500 pieces. The prices are f.o.b. factory, USA, for 1960 in US dollars.

	Slot and Wedge	Expansion-shell		
Bolt Length	1"	5/8"	3/4"	7/8"
5'	1.70	1.00	1.20	1.30
8'	2.40	1.50	1.70	1.90

The prices include wedge, nut and bearing plate for the slot and wedge bolt; they include shell, plug and bearing plate for the expansion-shell bolt.

The length of the bolts usually augments in 6"-increments and the prices vary more or less proportionally with the length. High-strength bolts sell at prices about 5 per cent higher.

The cost of rock bolting, when applicable, is generally less than any other kind of support. In particular cases other supports may be cheaper. In the next two pages are shown the cost of supporting a typical tunnel section with steel ribs and lagging and with rock bolts and channels. The dollar values are of 1954, but the relation between them can be considered constant. In the following page, there is a tabulation of the cost of roof support in coal mines when using timber and when using rock bolts. The data for this tabulation was compiled by the United States Bureau of Mines (37-c) in 1961.

EXAMPLE OF THE COST OF TUNNEL SUPPORT WITH STEEL RIBS AND LAGGING

Dimensions: 9' nominal diameter (excavated section).

Criteria: 4", 13 lbs, H-section sets at 5' centers.

Materials	No.	Dimensions	Quantity		Unit Cost	Cost
Steel set	1	4"x4"	21' @ 13 lbs	273 lbs		
Splice & base plates	4	6"x6"x3/8"	@ 4 lbs	16 lbs		
Tie rods & nuts	6	5/8"x5.1'	31' @ 1 lb	31 lbs		
			Total steel	320 lbs	$0.25	$80.00
Lagging		2"x5'		60 fbm		
Collar braces	6	3"x4"x5'	30' @ 1 fbm	30 fbm		
Blocking		Miscellaneous		10 fbm		
			Total timber	100 fbm	$0.35	$35.00
				Total Cost		$115.00

or $23 per linear foot

EXAMPLE OF THE COST OF TUNNEL SUPPORT WITH ROCK BOLTS AND CHANNELS

Dimensions: 9' nominal diameter (excavated section).

Criteria: 5' bolts, slot and wedge type, 5 bolts per row, $3\frac{1}{2}$' row spacing.

Materials	No.	Dimensions	Quantity		Unit Cost	Cost
Channels	5	4"	$17\frac{1}{2}$' @ 5.4 lbs	95 lbs		
Rock bolts	5	1"x5'	@ 14 lbs	70 lbs		
Washers	5	3"x3"x3/8"	@ 1 lb	5 lbs		
			Total steel	170 lbs	$0.25	$42.50
				Total Cost		$42.50

or $12.50 per lienear foot

COMPARISON OF SUPPORT COSTS IN COAL MINES

Mine	Timber: Tons per manshift	Timber: Cost per ton, dollars: Labor	Timber: Cost per ton, dollars: Supplies for roof support	Timber: Cost per ton, dollars: Total	Rock Bolts: Tons per manshift	Rock Bolts: Cost per ton, dollars: Labor	Rock Bolts: Cost per ton, dollars: Supplies for roof support	Rock Bolts: Cost per ton, dollars: Total
1	42.3	0.602	0.347	0.949	51.3	0.491	0.293	0.784
2	32.9	0.725	0.238	0.963	37.3	0.667	0.197	0.864
3	21.5	1.128	0.222	1.350	27.2	0.907	0.231	1.138
4	15.0	1.636	0.142	1.778	17.3	1.334	0.202	1.536
5	15.6	1.552	0.266	1.818	20.8	1.16	0.258	1.418
6	14.0	1.736	0.284	2.020	21.0	1.158	0.247	1.405
7	11.5	2.17	0.294	2.464	13.9	1.793	0.260	2.053
8	34.8	0.714	0.102	0.816	35.4	0.696	0.300	0.996
9	28.7	0.876	0.347	1.223	29.2	0.865	0.452	1.317

CHAPTER 9

COMPARISON OF TIMBER SUPPORT WITH ROCK BOLT SUPPORT

Advantages of Rock Bolts over Timber.

1.- Reduces the required excavation in tunnels by approximately 30 per cent.

2.- Timber supports efficiently only at the vertices of the sets.

3.- Timber availability is prone to a bigger number of hazards: forestation, plagues, weather, etc., which makes its supply less dependable.

4.- Rock bolts may be applied to any shape of excavation, while timber sets have a definite pattern and the shape of the opening must often be shaped to conform with this pattern.

5.- Rock bolts can be installed a few feet from the breast of a drift, while timber, in some cases, has to be kept several yards away to protect it from blasting. This is especially important in heavy ground where immediate support is necessary.

6.- In large excavations that are to be concreted, the protruding end of the bolts provide better bonding facilities for the concrete.

7.- Less storage requirements and greater ease in handling.

8.- Elimination of fire hazards.

9.- Less maintainance and longer life.

10.- Smoother surface in airways offers less resistance to ventilation.

11.- Timber is relatively compressible and its foundation may subside. This permits movement of the roof with a consequent increase in the supported load.

12.- Shorter installation time.

13.- Bolting usually does not interfere with the mining cycle.

14.- Lower cost in most cases. Even when timber is cheaper, the difference is very small.

15.- Less labor required for installation.

16.- Openings can be widened easier.

17.- Lessens rock burst probabilities.

Advantages of Timber over Rock Bolts.

1.- Rock bolts do not warn of increasing loads on supported rock and falls are generally sudden.

2.- Some rocks with unsatisfactory anchorage cannot be supported with rock bolts.

3.- Some rocks have a plastic behavior and when under pressure squeeze slowly into the opening. These rocks cannot be supported with rock bolts.

4.- In competent ground where occasional support is needed, timber is much more economical than rock bolts.

CONCLUSIONS

Rock bolting is a new technique for the support of rock in underground openings. Most of the applications have been developed empirically and have followed previous timbering methods. Some testing has been done, but most of it has been directed to specific conditions.

Future research to be done on rock bolting is recommended to be focused on the following aspects:

1) To determine the relative anchoring strength of the different kinds of expansion shells available on the market.

2) To determine the role that each detail of design plays in the anchorage of the expansion shell. It is believed that some details in the design of the expansion shells contribute little, if any, to the anchorage process. Experimentation can point out which features contribute most to the anchoring strength of the bolt and how these features can be improved.

3) To relate the late developments made in the study of stress distribution around mine openings with the patterns used in rock bolting. This will contribute to a more efficient support and to a saving in support materials.

4) To develope a safe and practical indicator to warn of the presence of excessive loading on rock bolted

openings. Electrical strain gauges can accurately measure such changes, but the instrumentation needed is too expensive and the methods used too complex for routine applications. Rubber compression pads and helical springs have contributed to the solution of the problem, but are only partially successful.

BIBLIOGRAPHY

1-Anaconda Copper Mining Co.
"Rock Bolting." Bulletin 31. February, 1956.

2-Bethlehem Steel Co.
"Bethlehem Mine Roof and Rock Bolts." Catalogue 485.

3-Bowie, Robert F.
"Special Roof Bolt Applications." Mining Congress Journal. January, 1954.

4-Burchell, H.J.
"Rock Bolting." The Canadian Mining and Metallurgical Bulletin. October, 1955. Montreal.

5-Colorado Fuel and Iron Corporation.
"Installation Procedure. Slot and Wedge Type. C F & I Rock Bolts."

6-Cumming, J.D.
"New Rock Bolting Devices." Ontario. March, 1961.

7-Dewey, J.H.
"Roof Bolting at the International Nickel Co." The Canadian Mining and Metallurgical Bulletin. September, 1955. Montreal.

8-Foster, W.B.
"Rock Bolting at Sunshine." Mining Congress Journal. July, 1953.

9-Gibson, A.V.
"A Practical Look at Progress in Roof Control." Mining Congress Journal. December, 1960.

10-Gutehoffnungshutte
"GHH Roof Bolting." November, 1953. Strekrade, Germany.

11-Humphrey, J.L.
"Steel Bolts in Mine Roof Support." Mining Engineering. May, 1956.

12-Huston, E.F.
"How to Install Roof Bolts." Coal Age. June, 1954.

13-Ingersoll-Rand
"The Application of Rock Bolting to the Roof and Sides of Rock excavations." Ingersoll-Rand., Form 4155.

14-Kravig, C.N.
"Rock Bolting Practices at Homestake." Mining Congress Journal. August, 1960.

15-Kroc, H.W.
"Kiruna Cements All Rock Bolts in Holes by Injecto Method." Mining World. August, 1960.

16-Lang, T.A.
"Theory and Practice of Rock Bolting." Society of Mining Engineers of AIME. Preprint No. 61-A-u35. 1961.

17-Lock Washer Industry
"Lock Washers Indicate Roof Bolt Tension." Mining Congress Journal. 1960.

18-Mahood, G.P.; Dempsey, J.B.; Robertson,A.K.; Sanford, J.H. and and Thomas, E.M.
"Specifications for Roof Bolting Materials." Mining Congress Journal. July, 1956.

19-McGuire, C.E.
"Roof Bolting Slusher Drifts at Climax Molybdenum Co." Climax Molybdenum Co. March, 1955.

20-McKelvey, R.G.
"Roof Bolting at Lamaque." The Canadian Mining and Metallurgical Bulletin. September, 1955. Montreal.

21-Ohio Brass Company.
"Haulage Ways." September, 1956.

22-Olds, E.B.
"Use of Rock Bolts with Bearing Sets in the Crescent Shaft of Bunker Hill and Sullivan Concentrating Co." January, 1956.

23-O'Leary, V.D.
"Changes at Mountain Con." Mining Congress Journal. March, 1956.

24-Panek, L.A.
"Analysis of Roof Bolting Systems Based on Model Studies." Mining Engineering. October, 1955.

25-Panek, L.A.
"Anchorage Characteristics of Roof Bolts." Mining Congress Journal. November, 1957.

26-Perez, H.T.
"Tunneling Costs Drop Way Down when Bolts Hold up Tunnel Roof." Construction Methods and Equipment. March, 1952.

27- Pollish, L. and R. N. Breckenridge.
"Rock Bolting in Metsl Mines of the Northwest." Mining Engineering. July, 1954.

28- Pynnonen, R.O. and R.L. Bernard.
"Supervision in Roof Bolting." Skilling's Mining Review. February, 1961.

29- Schmuck, H.K.
"Theory and Practice of Rock Bolting." The Colorado School of Mines Quarterly. Vol. 52, No. 3. (Date not given.)

30- Schmuck, H.K.
"How Western Mines Use Metallic Fabric Lagging for Support Between Roof Bolts." Mining World. November, 1956.

31- Schmuck, H.K. and D. R. Silgestrom.
"Rock Bolts...applications in Construction." Western Construction. January and February, 1960.

32- Schmuck, H.K.; Crow, W.L.; Goslo,C.E. and Holkstad, H.M.
"Rock Bolting in Non-Carboniferous Mines." Colorado Fuel and Iron Corp. January, 1956.

33- Smith, A.T.
"Rock Bolting in Practices at Brittania." The Canadian Mining and Metallurgical Bulletin. September, 1955. Montreal.

34- Teal, J.K.
"Roof Bolting Practice at Kerr-Addison." The Canadian Mining and Metallurgical Bulletin. September, 1955. Montreal.

35-Thomas, E.
"Rock Bolting." The Canadian Mining and Metallurgical Bulletin. September, 1955. Montreal.

36-Thomas, E.
"Rock Bolting Finds Wide Application." Mining Engineering. November, 1954.

37-United States Bureau of Mines
a) Report of Investigations No. 4967. May, 1953.
b) Report of Investigations No. 5080. October, 1954.
c) Information Circular No. 8024. 1961.

38-Union Pacific Railroad
"How to Stop Slides in Rock Cuts." Railway Track and Structures. November, 1954.

39-United States Steel Corp.
"Investigations in Bolted-Roof Falls at T C& I Coal Mines." Coal Age. October, 1955.

40-Woodruff, S.D.
"Rock Bolts." Western Construction. July and August, 1954.

41-Wojciechowski, J.J. and C. T. Holland.
"Some Aspects of Roof Bolt Action in Coal Mine Roof." Mineral Industries Journal. December, 1956.

42-Wuerker, R. J.
"Testing of Roof-Bolting Systems in Concrete Beams." Mining Engineering. June, 1953.

43-Zelenkov, S.E.
"Mining Practice at the Kokomo Unit of the American smelting and Refining Co." Mines Magazine. April, 1951.