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ROCK ANCHORS IN MINING

A Guide for their Utilization and Installation

D. F. COATES AND R. SAGE

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ROCK ANCHORS IN MINING
A Guide for their Utilization and Installation

by

D. F. Coates* and R. Sage**

ABSTRACT

Rock anchors, i. e., tensioned cables or bars of much higher load capacity than conventional rock bolts, have been used for some time in civil engineering works and in some mining applications. It is expected that their use in mining will become more common. This report provides a summary of fabrication and installation procedures to guide engineers on mining properties.

Selection of anchor types must be related to the mine and to total system costs. Consideration should be given to using high-strength, new steel cables rather than second-hand hoist cable (the higher load capacity and the dominant drilling and installation costs may be significant). There is much to recommend one grouting for the full length of the anchor, with sleeves or grease to allow tensioning after grouting and mechanical assistance at the anchorage.

Certain general rules can be followed in all installations. Percussion-drilled holes are advantageous owing to their rough surfaces for bonding. The actual lengths of holes should be known, and caving and water zones should be grouted. Deviations from straightness should be less than 3 in. in 20 ft. Although manual installation usually is used, a mechanical method for the larger anchors would be valuable. During tensioning, a load-deformation record should include the decrease in deformation on release of the jack load. Safety precautions are particularly important when applying large loads.

Correcting undesirable situations can be time-consuming if the experience of others is not available. For example, inability to insert the anchor for the full length of the hole may require deepening the hole, acceptance of the situation, or re-design of the system with a new hole. An unexpected load-deformation curve obtained during ten-

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Key Words: rock anchors, mining, pre-stressing, stability support.

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sioning can arise from a change in the jack calibration, slippage at the anchor, and other less frequent causes. Failure of the grips during tensioning and failure to release afterwards are not uncommon.

Monitoring may either confirm that the anchors are working as expected or indicate the need for additional support. The two most practical measurements are anchor loads and rock deformation.

ANCRAGES POUR TERRAINS ROCHEUX DANS LES EXPLOITATIONS MINIERES MODE D'EMPLOI ET D'INSTALLATION

par

D.F. Coates* et R. Sage**

RESUME

Les ancrages pour terrains rocheux, c'est-à-dire des câbles ou des barres tensionnés, ayant une capacité de beaucoup supérieure à celle des boulons d'ancrage ordinaires, sont utilisés depuis un certain temps déjà dans les travaux de génie civil, et on s'en sert aussi parfois dans les exploitations minières. L'on prévoit que leur usage deviendra de plus en plus répandu dans ce dernier genre d'application. Le présent rapport résume leurs procédés de fabrication et d'installation à l'intention des ingénieurs miniers.

Le choix des ancrages doit être fait en fonction de la mine et du coût total du système. On doit songer à utiliser de nouveaux câbles d'acier à haute résistance plutôt que des câbles moufleurs d'occasion (la capacité supérieure et les frais dominants de forage et d'installation peuvent être importants). On recommande une cimentation pour toute la longueur de l'ancrage, et des manchons ou de la graisse qui permettraient le tensionnage après la cimentation et qui fourniraient une aide mécanique au point d'ancrage.

Certaines règles générales doivent être observées dans toutes les installations. Les trous obtenus à l'aide d'une foreuse percutante sont préférables parce que leurs surfaces rugueuses permettent une adhérence supérieure. Il faut connaître les dimensions véritables du trou et cimenter les éboulements ainsi que les zones où l'eau s'est infiltrée. Les déviations ne doivent pas dépasser 3 pouces sur une longueur de 20 pieds. Même si, en général, l'installation se fait manuellement, il est préférable d'utiliser des dispositifs mécaniques lorsqu'il s'agit d'ancrages de dimensions importantes. Au cours du tensionnage on inscrira au dossier de la déformation en fonction de la charge, la diminution de la déformation lors du transfert de la charge qui reposait sur le vérin. Les mesures de sécurité sont particulièrement importantes quand il s'agit de charges considérables.

On peut prendre beaucoup de temps à corriger des situations indésirables à cause d'un manque d'expérience. Ainsi, trois choix s'offrent à nous lorsqu'il y a impossibilité d'insérer l'ancre sur toute la longueur du trou: accepter la situation telle quelle, approfondir le trou, ou forer un nouveau trou et repenser le système. Il peut se produire une courbe inattendue de déformation au cours du tensionnage, à la suite d'un changement dans l'étalonnage du vérin, d'un glissement au point d'ancrage, ou pour toute autre raison moins fréquente. Il n'est pas rare que les attaches se brisent lors du tensionnage ou qu'elles ne se déclanchent pas par la suite.

On peut confirmer au moyen de contrôle que les ancrages fonctionnent comme prévu ou qu'il est nécessaire d'installer des supports additionnels. Les deux mesures les plus pratiques sont la charge de l'ancrage et la déformation du roc.

Mots clé: ancrages, exploitation minière, pré-tensionnage, support stable.

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INTRODUCTION

In recent years, rock anchors (i.e., high load capacity cables or bars) have been used in some underground mines to retain roofs and walls. They have been used for some time for tying down dams, stabilizing underground excavations for turbines and powerhouses, and for retaining rock slopes. It is probable that more use could be made of rock anchors in mining.

Engineering staffs, isolated on mining properties, do not normally have easy access to a technical library and so are not able to make full use of the experience of others when planning stabilisation using rock anchors. Consequently, this report has been prepared to provide some guidance on the practical details of fabrication and installation that are appropriate in mining. Examples are given of rock anchors in construction and in mining and of the difficulties that have been encountered.

The design of a rock-anchor system is a complex process requiring a knowledge of site geology, rock properties, groundwater conditions, and mining plans. Consideration of all these factors is beyond the scope of this report; however, a bibliography of publications dealing with some aspects of design is provided.

The rock anchor consists of a tensioned steel cable or bar in a borehole in a rock. The ends of the anchor are fixed to the rock, and the rock mass adjacent to the hole is compressed by the tension in the anchor. This tension is intended to improve the rock mass properties. In addition, the associated high-pressure grouting is often beneficial (1). The bar type of rock anchor differs from the conventional rock bolt primarily in its greater length, strength, and load.

As shown in Figure 1, there are several areas of use for rock anchors in mining. Underground they may be used to retain either roofs or walls when either the extra length or strength of an anchor makes it preferable to a rock bolt. Anchors may be used to compress a rock pillar horizontally, increasing the vertical load capacity of the pillar. In open pits, rock anchors may be used to retain loose blocks in the slopes, or to create pressure on joints or faults in order to prevent slips.

Figure 2 shows a cable rock anchor. The cable anchor consists of several strands, up to 12 or more, of high-tensile steel; each strand consists of steel wires wound together. A typical strand can contain 7 wires each 0.16 in. in diameter. The strands that make up the cables are tied together at intervals, often using a specially made spacer to keep the strands in the same relative positions. The far end of the cable may be fitted with a nose cone to guide the cable into its hole.

The cable is usually anchored in the rock by grouting the far 10 ft with either Portland cement mortar or resin; mechanical anchorages* have also been used. The cable has one or two ducts, usually of plastic tubing, which are used to deliver the grout. At its collar end, the anchor requires a steel bearing plate and a wedge-and-cone anchoring device that grips the cable as it is tensioned and prevents slip back into the hole. Wedge-and-cone anchors and tensioning jacks can be obtained from manufacturers of pre-stressed concrete equipment.

Figure 3 shows a solid-bar rock anchor. The general principles are the same as for the cable anchor; the anchorage usually consists of either a nut and washer, which establish a strong anchor point before the borehole is filled with grout, or a patented mechanical anchorage. At the surface, the wedge and the cone can be used, although a nut which is tightened against the bearing plate while the bar is held in tension by a jack is probably more convenient.

The bearing plate for both types of anchor is preferably bedded on either mortar or concrete to give an even bearing surface on the rock.

Both solid and cable anchors can be installed in either up or down holes. The cable is flexible, can be transported easily underground and is more easily installed if working space is limited. Weight for weight, cable anchors are stronger than solid, due to the very high strength of the wire used in the cable strands, and they can be made up in any length; the solid anchor, over, say, 40 ft long, must be made from several lengths joined by couplers. The solid bar, however, requires little site fabrication and is easier to handle and push into a borehole.

There are many important aspects of rock anchor fabrication and installation which should be appreciated before their use is attempted. These include the grouting techniques, pro-

* Terms used are defined in the glossary (p. 26).

tection of the bar or cable from corrosion and damage before and after installation, methods of checking and monitoring the anchor load, and safety precautions. These will be discussed in the following sections of this report, but first a description of some previous rock anchor installations will be given.

PREVIOUS ROCK ANCHOR INSTALLATIONS

Hydro-Electric Projects

Rock anchors have been used in hydro-electric projects to strengthen rock abutments, resist uplift and overturning forces, and retain the roofs of underground power houses.

The strengthening of the Cheurfas Dam, Algeria, is one of the earliest examples of the use of rock anchors. Thirty-seven cables, 183 ft long and of 2200 kips* capacity (large even by today's standards) were used to tie the masonry dam down to the underlying sandstone. The anchors were placed eccentrically in the dam to provide resistance against the overturning force of the water. The principles involved are illustrated in Figure 4, and a fuller description can be found in Reference (2).

The rock foundations to the Muda Dam in Malaysia consist of massive quartzite with thin, nearly horizontal mudstone beds. The resistance to horizontal sliding of the dam on the mudstone beds was inadequate; rock anchors were used to increase the normal stresses across these beds and thus increase the frictional sliding resistance. Two hundred and five anchors were used, each of 600 kips working capacity. The layout of anchors in a typical buttress and the location of the mudstone beds is shown in Figure 5 (3).

Extra intake structures were provided at the Wanapum Dam, U.S.A., to allow for future generating capacity. The empty installations, however, would not have been stable when submerged, and so they were tied down to bedrock by cable anchors. Thirteen anchors, 70 ft long, were used; each anchor had a maximum capacity of 2600 kips; 16-inch-diameter holes were required for the anchors. A full-scale pull-out test was conducted on the dam site (4).

The Libby Dam, U.S.A. is a concrete gravity dam. The left abutment is of thinly-bedded argillite, with jointing varying from less than 3 in. to more than 6 ft. During construction, part of this

* 1 kip = 1000 lbs force.

abutment failed by sliding, so rock anchors were installed to ensure the stability of the remaining rock. Ninety rock anchors of 400 kips working load were used to achieve the desired stability. Because of the difficulty of access to the installed anchors, a system of remote reading hydraulic load cells was installed. The effectiveness of the anchoring was demonstrated by the steady load that was maintained in the monitored anchors (5).

The Hongrin Powerhouse, Switzerland, required a 90-ft-high by 450 ft by 100 ft excavation in a fractured, clayey limestone. The roof and walls were reinforced by 700 rock anchors, 40 ft long and up to 300 kips capacity, which were generally installed overhead. The anchor layout is shown in Figure 6 (6).

Highway Cuts

The cutting of an access road to the Cethana Dam, Tasmania, meant undercutting bedding planes in a previously stable rock slope. Half-a-dozen potential slope failures were recognized along the road, one of which did occur. The others were stabilized by rock anchors, up to 50 ft long, of 250 kips working capacity. The design of the support took into account the features of the actual failed slope. The rock anchors were used to increase the resistance to sliding. Figure 7 shows a plan and a section through a typical potential rock slide (7).

The work at Windy Point, Australia, is particularly interesting because the rock slide involved was in the stage of progressive failure. The slide was moving up to one inch a day and approximately 200, 000 tons of rock was moving; 45 rock anchors (average working load of 375 kips) and a system of horizontal drain holes successfully arrested the movement.

The formations in the slide area consist of extensively-jointed sandstone beds which dip towards the sea at about 27° and contain two silty clay beds. There is evidence of past rock slides in the area. The slide discussed here was apparently triggered by the cut made for the coastal road. Figure 8 is a section through the slide that shows the silty-clay beds and the anchor and drainage layout.

The calculations for the anchors were based on the fact that the slide was on the point of moving along one of the silty clay layers. The factor of safety against sliding was raised to 1.15 by increasing the forces resisting movement. The rock anchors both provided a direct force to resist sliding and increased the normal stress on the plane of sliding, thus increasing the frictional resistance to sliding (8).

Mining

At a Canadian salt mine, production is from an 80-ft-thick bed, underlain and overlain by dolomite strata. Five-foot rock bolts have been used to provide roof support, but measurements with instrumented boreholes have shown that these bolts are usually anchored in salt which is likely to move as mining progresses. For roof support over an underground mill, it was therefore decided to use cable anchors that would be anchored in stable ground (9).

Figure 9 shows a typical cross section of the mill gallery. The borehole measurements of roof movement and experience with past roof falls were used to delineate a zone of unstable material. The cables were designed to exert a vertical force equal to the weight of the unstable material. For convenience, the cables were all substantially the same length, 30 ft.

The length of anchorage required was determined from pull tests on trial cables with 5 ft, 10 ft and 15 ft grouted anchorages. All three anchorage lengths were able to sustain the maximum cable load of 60 tons ; 10 ft was chosen for actual use.

The cables consist of three 0.6-in-diameter strands, each strand being enclosed in plastic tubing except for the far 10 ft. Initially two plastic tubes were included, one for grouting and one for an air-bleed during grouting. The grout and air-bleed tubes were 5/8" O.D. (approximately $\frac{1}{2}$" I.D.) and the tubes enclosing the strands were 3/4" O.D. (giving approximately 1/32" clearance around the strand). The cable layout is shown in Figure 9.

The 3.5-in. holes for the anchors were drilled by auger and enlarged at the collar to 5.5 in. and then to 12 in. The 5.5-in.-diameter section was used to form a grout seal. This was done (after a patented inflatable seal proved inefficient) by packing as tightly as possible with oakum around the cable and tubes. The 12-in.-diameter section formed a recess for the 1.5-in.-thick mild-steel bearing plate.

Anchorage grouting proved to be a problem. It was found in the first installations that fissures in the salt could cause loss of grout, as shown by the appearance of grout elsewhere, and failure to form the anchorage. Two grout tubes were finally used. Grouting was stopped after an initial placement until the grout had set. The second tube was then used for an additional injection.

Occasionally, however, even this practice did not produce an adequate anchorage, and some cables could not be fully tensioned.

Tensioning was done by pre-stressing one strand at a time. The cable load on final locking was 55 tons. One hundred and eighty-five cables were installed; 6 have been fitted with load cells to measure changes in load in the cable. These six cables showed a decrease in load of about 20%, due largely to creep in the rock salt, before reaching a steady state. Thus, the long-term load in each cable is about 40 tons.

Since 1960, solid steel rock anchors, 22 ft. long, have been used underground in a Canadian copper mine to control hanging wall spalling, which was causing serious dilution. The use of rock anchors followed attempts to stabilize the wall using conventional 8-ft rock bolts, which were unsatisfactory because the zone of spalling extended more than 8 ft into the wall. Figure 10 shows the details of the anchor which substantially reduced the dilution at moderate cost.

The rock anchors were installed at 8-ft spacing with 25 to 35 anchors at each elevation. A 3-in. borehole drilled at a very slight (1^{o}) downwards inclination (for grout retention) was washed clean before inserting the anchor. The bottom anchorage was formed by attaching a nut and washer to the threaded bar and filling the entire hole around the anchor with grout. The anchor was greased to prevent bond between the grout and the bar and so ensure subsequent tensioning. A plastic tube taped to the full length of the bar was used to place the grout. During the grouting the open end of the borehole was lightly packed with rags to centre the bar and prevent loss of grout.

At the collar of the hole, an anchor block fitted with conical grips for anchoring the bar and a 12-in.-square bearing plate were used. The bearing plate was seated on a pad of mortar, being held in place, while the mortar was setting, by the anchor block and anchor cones.

The grout and mortar were made with high-early-strength cement. The bars were tensioned three days after installation to their working load of 50 tons. After tensioning, the excess lengths of the bars, about 2 ft, were cut back to be almost flush with the surface of the hanging wall (10).

Since 1963, more than 1300 cable rock anchors have been used in a second copper mine to reduce or prevent sloughing of blasthole stope backs (11, 12). The cable anchors are made from single lengths of discarded locked-coil hoisting cable, 1.25 in. in diameter. The anchors are installed either from drifts and cross cuts or from the stope itself.

Initially the anchors were fitted at the far end with a pipe, or deadman, 6-in. long and 2.75-in. in diameter; the pipe was attached by pouring Babbitt metal into the pipe around the end of the cable. This pipe was then inserted into a 3-in. borehole and grouted to form an end anchorage. In recent years, however, the deadman has been eliminated; this allows the use of a 2-in. borehole and costs less.

The current technique is to open up the end of the hoisting cable by driving several short spikes into it, to form a strong anchorage after the grout sets. Three to four feet of grout is placed in the far end of the borehole before the cable is inserted. By using a very stiff grout and a grout extruder, this technique can be used satisfactorily in up-holes. The extruder is a length of plastic pipe fitted with a piston. A known amount of grout can be extruded by measuring the movement of the piston. The grout is made from high-early-strength cement.

The cable can be tensioned three or four days after installation. The anchor head is the usual bearing-plate seated on a mortar bed, with an anchor block and cones to secure the cable after jacking. Standard commercial anchor blocks and cones are used. After tensioning, the cable is fully grouted, using a length of copper pipe placed in the mortar bed below the bearing plate. An air-bleed of plastic tubing is also placed in the mortar bed; this runs to the end of the borehole in up-holes but stops below the surface bearing plate in down-holes. The final grout is fluid enough to be pumped conventionally. A typical cable is 40 ft in length including the anchorage and is tensioned to about 40 tons.

The layout for a typical stope is shown diagrammatically in Figure 11, and the anchor details are shown in Figure 12. An average cost of about $2 per ft is reported. The cables have been highly successful in reducing sloughing. Even when the bearing plate is blasted off, the anchor continues to retain the surrounding ground.

In 1969, a trial installation of four rock anchors on a typical bench in an open pit mine was completed. The purpose of the trial was to obtain information on costs and to observe the long-term behaviour of the anchors. The details of the installation have been reported (13).

For the trial, each anchor was different. Three were cable anchors of lengths 33, 110, and 195 ft; these anchors consisted of twelve 0.5-in. strands, giving a working load of approximately 150 tons per anchor. The strands were laid around special spacers giving an over-all cable diameter of 2.75 in. The fourth anchor was a solid steel bar 1.375 in. in diameter, 55 ft long, with a working load of about 50 tons.

The anchors were installed in diamond drill holes inclined downwards at 10^{o} to the horizontal. Two sizes of hole were used, HX (3.98-in.) for the 33-ft and 195-ft cable anchors, and NX (3.5-in.) for the 110-ft cable anchor and the solid anchor. Diamond drilling was chosen because the site investigation required core logging and the use of a down-hole television camera, but it was felt that percussion-drilling would have been acceptable. The anchors were grouted for their end 20 ft and stressed 28 days later. The collar assemblage consisted of the bedded bearing plate, cones, and an anchor block.

In order to monitor anchor behaviour, load cells were fitted between each anchor block and bearing plate. These load cells were removed after nine months by releasing the anchor. The anchors were then retensioned and sealed by filling the boreholes completely with grout.

The trials showed that rock anchors could be manufactured at an open pit mine and installed by mine personnel without particular difficulty. The coupled-bar anchor which was assembled from 20 ft lengths using couplers, proved easier and quicker to install but was much weaker than the cable anchors. Drilling and installation costs formed the largest part of the total expense of the anchors.

Some difficulty was encountered in placing the longest cable anchor; it seemed that the clearance of 0.5-in. all round the anchor was the minimum advisable, at least for long anchors. Because the boreholes had been diamond drilled, it was thought that rougher, percussion-drilled holes would require even more tolerance for easy installation.

FABRICATION

General

Rock anchors must be made from high-strength steel.

The reason for this is that steel, if held under a steady tension, will creep. The phenomenon is noticeable only at high loads, and the amount of extension is limited. In a rock anchor that is given an initial fixed extension, gradual reduction of anchor load occurs in the weeks and months after installation. This loss of load is roughly the same no matter what type of steel is used. For mild steel, which has a comparatively low strength, the loss amounts to practically all the load that can be initially applied to the steel, thereby making mild steel useless for all pre-stressing work, including rock anchors. For high-strength steel, which may be tensioned to eight times the load of mild steel, this loss becomes only a small proportion of the total load.

High-strength or pre-stressing steel is manufactured by most steel suppliers. Hoist cable is made from high-strength steel; this is why old hoist cable has been satisfactory in some rock anchor applications. However, hoist cable is not designed for pre-stressing use, and care should be exercised if hoist cable is used for rock anchors. Weight for weight, the breaking strength of hoist cable is less than that of pre-stressing strand. Some hoist cable contains a fibre core; such cables may have a reduced diameter after stressing and so may slip in the anchor block and cones at the collar. If hoist cable is used, the original supplier should be consulted for strength and creep properties of the cable and for advice on its use as a rock anchor.

For the design of an anchor, it will be assumed that the required load, length and direction are known, usually as a result of calculations for an over-all support system. For a solid anchor, the required size of bar can be found from the supplier's catalogue. The cable anchor can also be chosen from a supplier's catalogue, or the numbers of strands required can be calculated in the manner described below.

There are a few differences found in practice between the various types of rock anchors, apart from selecting either a solid bar or a cable and a particular load capacity.

(1) The method of bottom anchorage can be a grouted anchorage relying on bond between the steel and the concrete, a combination grout and mechanical anchorage, such as a nut on the end of a solid bar, or a purely mechanical anchorage like the expanding shell of a rock bolt.

(2) The extent of grouting in the borehole can be in either one or

two operations, and the hole can be either partly or wholly filled.

(3) The nature of the surface anchorage and jacking procedure can vary.

(4) The attitude of the anchor - up, horizontally, or down - can vary.

(5) Fabrication details, such as whether spacers are used to separate the strands and whether a nose cone is fitted to the bottom of the cable, will differ.

The rock anchor described in this report has a grouted bottom anchorage, aided, in the case of a solid anchor, by a nut and washer on the end of the anchor. The recommended length of grout is 10% of the anchor length, with a minimum length of 10 feet.

It is preferable to place the grout after the cable has been inserted. For the down-hole anchor, this grout tube runs the full length of the anchor, and the amount of grout required to fill only the desired anchorage length can be calculated beforehand. After tensioning, the borehole is filled completely with grout, giving the anchor maximum security and protection.

For the up-hole anchor (more than 5° from the horizontal), although anchors have been successfully installed overhead with only an end section grouted, it is recommended that the anchor again be inserted before the grout is placed, and that grout be pumped conventionally from the collar of the borehole. This means that the entire hole is filled with grout in one operation, grease or a sheath around the strand being used to prevent bond and allow tensioning.

The advantages of grouting the entire length of the anchor are to protect the anchor from corrosion and to provide additional anchorage. In down-holes, damage to the cable, for example from blasting or adjacent excavations, will not mean failure of the entire anchor; the anchor will continue to provide support for its undamaged length. In the up-hole anchor, where bond is prevented for most of the anchor length, these advantages are partly lost, but the tight full grouting will protect the anchor against corrosion and provide some extra anchorage.

Solid anchors, over, say, 30 feet long, usually must be made from several lengths of bar joined together by couplers. These couplers will be of a larger diameter than the bar and, if used in an up-hole, would prevent the tensioning of the anchor, because the grout will effectively prevent movement of the couplers. It is therefore suggested that solid anchors with couplers not be used in up-holes. Horizontal holes should be treated as up-holes for the purposes of grouting.

The anchor head should be any of the several suitable pre-stressed concrete anchorages commercially available. All of these systems are reliable; availability of equipment, size of anchor, and cost will dictate the choice. Some choice can be exercised in deciding either to tension an entire cable anchor or to tension each strand individually; the size of jack and the time of the operation are the variables to consider in this case.

Details of the materials and equipment needed for the fabrication and installation of a rock anchor are listed in the Appendix. The various steps in the design, fabrication and installation of a rock anchor will now be considered in more detail.

Capacity

For the cable anchor, there will usually be a choice of several cable sizes and types of anchor head. Generally, the cable with the fewest strands will be cheapest and simplest to install; for example, a cable with four 0.5 - inch strands has about the same capacity as one with three 0.6 - inch strands, so the 3-strand cable is preferable in this case.

The load capacity depends on the number, size and strength of the strands in the cable. The working load in a strand is typically 60% of the breaking load of the strand, and the number of strands required is found by dividing the required cable capacity by this working load. The calculation will be illustrated by an example. Suppose a cable with a capacity of 250,000 pounds is required; then, if a 0.6-inch strand has a breaking load of 54,000 pounds, the cable will need:

$$\frac{250,000}{0.6 \times 54,000} = 7.6, \text{ or eight strands.}$$

The factor 0.6 in the above calculation is the 60% of ultimate load that is recommended for design purposes. This figure arises in the following way: at loads above about 90% of the breaking point, a strand begins to stretch by large amounts; consequently, 80% of the breaking load is usually specified as the maximum allowable load in the strand at any time. The process of anchoring the strand at the surface after jacking results in some loss of extension and hence of load; a strand if tensioned to the 80% figure, will typically have a load of 70% of ultimate strength after anchoring. The drop from 70% to 60% is due to the creep of the steel. Table 1 shows the capacities and sizes of some typical cable anchors.

The choice of anchor head for a cable anchor, apart from the choice of different suppliers, is basically that between either tensioning the strands separately or all together. Tensioning separately is preferable since the jack required is smaller, is easily portable and can be pumped by hand. Tensioning all the strands together, however, results in a faster operation. It also has advantages when short (less than 30 ft) cables are used because the loss of load on anchoring, which may be critical in a short cable, can sometimes be reduced*. Figure 13 shows typical anchor heads required for the two methods of tensioning. Figure 14 shows the two types of jack required.

The anchor head for a solid anchor is best obtained from a supplier of these special solid steel bars; the supplier will also have the correct jacking equipment.

The length of grouted anchorage actually required for a cable anchor is difficult to analyse. It depends upon the load in the cable, the surface area of the strands, the strength of the grout, the method of grouting, and the strength of the rock. It is also affected by the mechanical bonding which results from the twisted shape of the strands. However, a conservative length, based on experience, of 10% of the cable length with a minimum of 10 feet is usually adequate, particularly for down-holes. If it is suspected that the rock in the anchor zone is weak, fractured, or fragmented, and also for up-holes, a pull test might be appropriate; at least, the anchor length should be increased in this case to a minimum of 15 feet. Long anchors require longer anchorages because it is more difficult to measure a length of grout in the bottom of a long hole and also more difficult to position the anchor accurately. This extra length is provided by the stipulated minimum 10% of the cable length for a grouted anchorage.

The bottom anchorage for solid bars depends on the bearing action of the nut on the grout column, rather than on the bond between the bar and the grout. However, sufficient grout must be provided for the transfer of the anchor load into the rock around the bottom anchorage; a minimum length of 5 feet should usually be used. In each case, the actual length of the anchor must include also the length for jacking - between 2 and 5 feet.

An important part of the design and installation of a rock anchor is the calculation of the extension expected on tensioning. New solid bars and high-strength steel strands are certified as to the load and extension properties of the steel. Strand is usually supplied in reels from which the lengths required for a cable anchor are cut; each reel will have its own certificate.

* see page 18

Figure 15 shows a typical certificate for strand steels; a certificate for a steel bar is similar. The load applied in jacking the anchor, 80% of the ultimate strand strength, is marked on the figure; it lies on the straight line section of the curve. From the chart, the extension of a strand for any load can be determined. For the particular chart shown, a load of 35,000 pounds will cause an elongation of 0.008 inches in a length of 1 inch. Therefore a 25-foot length of strand would stretch by: 25 x 12 x 0.008 = 2.4 inches. In practice, a cable in a hole, owing to rock friction, will elongate less than the theoretical amount.

The expected loss in anchor load due to the installation operation can be calculated. A typical anchoring operation may result in the strand pulling into the hole (draw-in) of 0.25 inches. For the strand considered above, a shortening of 0.25 inches in 2.4 inches would correspond to a loss of load of 35,000 x 0.25/2.4 = 3,500 lbs. This is 10% of the original load. The actual strand load after tensioning would be 31,500 pounds. The shorter the anchor and the bigger the draw-in required for anchoring, the larger is the loss of load on anchoring. The amount of draw-in will be given by the supplier of the cones and the jack; the actual draw-in should be measured and checked against the specified figure.

A cable anchor should be made as far as possible with strand from the same reel, because strands from different reels may have different properties.

Assembly

Solid anchors require little assembling. The bottom anchor and washer must be attached; there will usually be a recommended procedure to avoid damaging the thread and hence weakening the bar. Similarly, couplings must be fitted carefully. The grout tube for the down-hole anchor or an air-bleed for the up-hole anchor must be attached by taping at intervals along the full length of the bar. In an up-hole, the bar, except for the far five feet, must be given a coat of light motor grease during insertion to prevent bond between the anchor and the grout.

Cable anchors should be carefully fabricated, particularly if long and of high capacity, that is, if many strands are used. As a rough guide, an anchor longer than 50 feet and with more than 3 strands should be assembled using strand spacers and with a nose cone fitted to aid insertion. Typical strand spacers and a nose cone are shown in Figure 16. Other anchors can be assembled by merely tying the strands together.

The cable anchor should be assembled in a clean, dry place, preferably using trestles or a table. The required strand length is marked out, including an allowance for jacking. The strand is paid out from the reel and cut into lengths with a high-speed carborundum disc cutter. Flame cutting must never be used, because the heat will severely damage the cable. The strands are taped together or tied with soft iron wire, using strand spacers if necessary; they should be kept parallel to the cable axis.

Tubes for grout and air-bleeding are included in the cable. If spacers are used, there may be a central hole in the spacer through which the tubes can run; alternatively, a spacer with room for an extra strand can be used, and the space used for the tubes. Both tubes should be plastic, of at least 0.5-in I.D.

Up-hole cables, like bars, can be greased to prevent bond on the length of the cable to be tensioned; this would be done after the cable is fabricated to avoid contaminating the anchorage. An alternative to greasing the cable is to sheath the strands individually in plastic tubing, which makes them easier to handle. However, this is more expensive and, for a long cable, may mean fitting the tubing in lengths and then taping the joints. Sheaths must be sealed around the strand at the far end to prevent grout ingress.

During assembly and installation care must be taken not to bend the cable too much (radius below 5 ft for a 12-strand cable). Kinked strands should be rejected. For a long or large cable, the final step is the assembly of a nose cone which can either be obtained from suppliers of pre-stressing equipment or made on site; a suitable cone can be fabricated from light gauge drain pipe. The cone is often welded to a short length of steel rod to assist in attaching the cone to the anchor (Figure 16).

INSTALLATION

General

Percussion drilling for rock anchors is recommended, both for economy and to improve bond between the grout and the rock. The anchor hole should be 1 inch larger in diameter than the assembled cable (approximate cable sizes are given in Table 1, but these should be checked on site). The actual length of hole drilled must be recorded for use in assembling the cable.

Where bad ground or marked loss of water is encountered, drilling should be stopped and the hole grouted for the extent of the affected region. The hole is then re-drilled through the grouted section. There are two reasons for this. First, the loss of water shows that grout would be lost when forming the end anchorage, and second, bad ground, causing caving in the hole, may make cable insertion difficult.

A hole that deviates more than 3 inches in 20 feet should be abandoned. A curved hole may make anchor insertion difficult and can cause problems in tensioning the anchor because of friction on the borehole sides. In drilling long holes, where the diameter of the hole decreases as the bit wears, an allowance for this must be made in the initial hole size. Between completion of the hole and insertion of the anchor, the collar should be plugged, e.g., with rags, to prevent entry of extraneous materials.

In an up-hole, the mouth of the borehole should be enlarged by hand or by over-coring to provide space for packing with oakum. Sometimes individual strands are packed with oakum to prevent leakage between them. Both up-and down-holes require a collar area about 18 in. by 18 in., normal to the axis of the borehole, to receive the bearing plate. This area can either be cut in the rock, or formed with concrete.

Before inserting the anchor, holes should normally be flushed with compressed air or water. Further, it may be useful to test the hole with water to determine whether it is tight enough to contain the grout. For example, loss of water in a down-hole at a rate under gravity greater than 0.03 gallons per linear foot per 10 minutes in a 3.5-inch hole would suggest that the rock should be sealed with grout before the anchor is installed. Alternatively, pumping grout until the pressure builds up may be satisfactory. Measurements of hole diameter with an appropriate commercial instrument may be advisable to prevent loss of time attempting to insert in obstructed holes.

Insertion is usually done manually, which is easier with solid anchors than with flexible cables. Most difficulty will be found with long cables, and many men may be required for the final push. Mechanical assistance can be devised with drill-rod pullers. The true length of the borehole should be marked on the anchor so that the extent of insertion is known. It is possible that loose material in the borehole will prevent some penetration, but the loss of a small amount of depth may not be serious. The consequences of the loss of more than a small amount, say 1 ft per 25 ft of anchor, may require a reappraisal of the design of the entire system of support.

The grout tube for the up-hole anchor is placed only into the mouth of the borehole, which is sealed to prevent grout loss. A plastic tube for air-bleeding is taped to the full length of the anchor; the emergence of grout from the air-bleed shows that the hole is full. The seal at the mouth of the borehole is formed by packing the space around the anchor, air-bleed and grout pipe with oakum and, if necessary, pumping a small amount of grout into the hole to reinforce the oakum seal. In this case, a short, additional grout tube for this seal is advisable. Grout and air tubes can include a section of steel tube at the seal to prevent collapse during packing.

A grout pump is required to place the grout. Pumps may be rented or bought from suppliers of construction equipment. Grout should be mixed using high-early-strength Portland cement, which permits tensioning four days after grouting and reduces grout settlement in the hole (14). Ordinary Portland cement will require two weeks or more before tensioning. An expansion agent is usually added to form a stronger anchorage; additives and directions for mixing can be obtained from suppliers of construction equipment. Aluminum-based additives should perhaps be avoided since there is evidence that these cause hydrogen embrittlement and hence weakening of the steel (14). A recommended grout mix is 4.0 to 4.5 gallons (Imperial) of water per 100 lb of cement, plus the appropriate amount of additive. The grout pressure should not be excessive, owing to the danger of lifting-off surface rock; it may be advisable in some ground to use pressures as low as 30 psi. The amount of grout required to cover the end anchorage length should be calculated in the case of the down-hole anchor. At the same time, it is useful to know the actual length of the grouted anchorage, which can be obtained with a probe rod used to determine the depth to the top of the grout after it has set.

Tensioning

The rock surface at the collar may require preparation for tensioning after placing the anchor and grouting the anchorage. In competent rock, it may be possible to chip the rock square at the mouth of the borehole so that the steel bearing plate can be positioned square to the line of the anchor; the plate is placed on a mortar bed on the rock face. For down-hole anchors, two pipes for the grouting operations are placed in this bed. One pipe is used for placing the grout and extends a little further than the other, which is an air-bleed. Metal tubing should be used for these pipes to avoid collapse in the mortar bed. A surface bearing plate, usually 1 or 1.5 inches thick, is set in the mortar, care being taken to set the plate at right angles to the line of the anchor.

If the rock is weak at the mouth of the borehole, it may be necessary to use a mass concrete anchor block to spread the anchorage forces. Details of such a block are shown in Figure 17. A wooden box or length of plastic pipe can be used over the bar or cable anchor to prevent its being embedded in the concrete. The bearing plate can be cast into the block, though it is usually easier to bed the plate against the concrete with mortar after the concrete has set. High-early-strength cement is recommended for the concrete block to save time. The block must be large enough to transmit all the anchor load to the rock without danger of rock failure.

Anchor tensioning should not be attempted until the grout is fully set. For the solid anchor, the end must be thoroughly cleaned of grease and the tensioning assembly fitted onto the bar. For the cable anchor, the strands are carefully cleaned and the anchor block and cones are fitted over the strands. The jack then is fitted over the strands one at a time or all together, depending on the tensioning procedure used.

The female cone should be cleaned of all dirt and coarse rust and then coated with a thin layer of high-pressure grease. The male cone should be inspected to ensure that there are no projections or sharp edges on the taper.

It is strongly recommended that cable extension be measured during tensioning. The jack is initially pumped to about 500 psi to take up slack in the anchor. The jack may be released if necessary to restore full travel to the ram, but then should be repumped to 500 psi. At this pressure the extension meter on the jack is zeroed. It is usual to pump in load increments and record the anchor extension at these increments to obtain a complete record of the anchor's behaviour during tensioning. Five increments to full load are usually adequate.

The jack will probably have a double-acting ram that automatically seats the cones in the anchor block. On release of the jack, the anchor then anchors itself - though there will still be some draw-in as the grips take up the full anchor load. With some jacks, however, it may be necessary to hammer the cones home before releasing the jack; a driving tool will be provided with the jack. Care must be taken in this case not to use too much force. If many cables are to be tensioned, a motor-driven pump would be advantageous.

The jack or pump should be fitted with a pressure gauge, and a chart for the conversion of pump pressure to jack load should be supplied. The gauge must be checked regularly, preferably daily when in use; often a connection for a second check gauge is provided for this purpose. The jack should also be fitted with a rule or scale for measuring extensions on jacking and draw-in on anchoring. These extensions provide a good guide to the anchor force and so act as a check on the jack. If excessive draw-in occurs, the cable must be retensioned.

If the cable strands are tensioned one at a time, subsequent strands should be tensioned on opposite sides of the cable to give a uniform distribution of load within the anchor. This sequence is continued until all the strands are tensioned.

A record should be kept of the loads and extensions of the anchor throughout the jacking procedure and of the draw-in on anchoring. This information is needed to check the calculated anchor performance and to determine if the anchor is functioning correctly. A form suitable for this purpose is shown in Figure 18. The form shown is for either a solid anchor or a cable anchor where all the strands are tensioned together. When the strands are tensioned individually, a sheet such as this should be used for each strand. The jack and pressure gauge should be recalibrated periodically, i.e., at least once a month during intensive use. A spare jack should be on hand, or at least obtainable on short notice, to avoid delay if the jack or gauge fails.

The amount of load lost on anchoring the strands of a short cable anchor (of the order of 30 feet) can be serious. These losses can be avoided if a jack is used that tensions all the strands together. The anchor is first tensioned and anchored according to the procedure outlined already. After tensioning, however, the jack is fitted back onto the cable together with a special chair which is used to transfer the load of the jack to the bearing plate. The jack is then repumped to the desired anchor load, thus drawing the anchor block off the bearing plate. A shim can then be inserted into the gap between the anchor block and bearing plate, and the jack released without loss of anchor load. The jacking arrangement for this operation is shown in Figure 19.

The final grouting of the down-hole anchor can and should be done as soon as tensioning is completed. Grout is pumped into the hole until it emerges from the air-bleed, showing the hole is full. If grouting must be delayed, safety anchors with spring-loaded grips placed on each strand of a cable will ensure that the cable tension is retained. Grouting should not be done if there is ice in the hole.

After final grouting, or after tensioning for the up-hole anchor, the surplus anchor length may be cut away (at least 2 inches of the anchor should be left projecting from the plate). A high-speed disc cutter should be used. Flame-cutting may be used, although in this case at least 12 inches of anchor must be left projecting to protect the anchor head from excessive heat conducted from the cut.

Grouting adjacent to holes containing cables awaiting grouting may cause leakage of grout into these holes, jeopardising the effectiveness of the subsequent tensioning and grouting. Cables should not be placed within such a damaging range, which depends on the rock conditions and which might be as much as forty feet.

Precautions

The rock anchor must be protected from corrosion due to chemical attack or rusting. Severe rusting, especially on the small diameter strands that make up the cable, can result in a large loss of net area and consequent reduction of strength. The surface pitting associated with rusting may act as a point of stress concentration, causing anchor damage at the very high stresses used in tensioning. Steel must be clean and free from grease, except where this is especially applied to prevent bond. However, a light film of rust - sufficient to cause discolouration but not pitting - is permissible since this will help develop the necessary grip for anchorage.

Steel in both strand and bar is adversely affected by heat, so cutting during anchor fabrication must be by high-speed carborundum - disc cutter ; no flame cutting or welding should be allowed. The use of strands of an anchor or bar as a return for arc welding should not be permitted. Any strand or bar that is suspected of having been heated should be discarded.

The projecting ends of cables should be shielded to prevent danger to personnel and to prevent damage to the cable. The energy stored in a typical 100-foot strand, tensioned to 40,000 pounds, is about the same as the energy of a small car moving at 20 mph. If an anchorage slips or a strand breaks, some of this energy will be converted into motion of the strand or grips.

Never stand in line with the strand while jacking is in progress, and also make sure no one else is in the end region of the anchor. Warning notices should be considered. Personnel involved in the tensioning operations must keep to one side of the anchor line at all times. If it is not possible to keep the area in line with the anchor clear, then arrange for a timber or sandbag barricade to be erected for personnel protection. Alternatively, postpone tensioning until the area is clear. If the anchor is exposed at both ends, e.g., as in pillar strengthening, both ends require these safety precautions. Only after the anchor is completely tensioned and the jack has been removed can the anchor be regarded as safe.

Anchors that are exposed after installation can be protected by embedding in mass concrete. Where an anchor failure, accompanied by the possibility of flying grips, would be dangerous, embedding is also recommended. A foot of concrete will be adequate cover and will also protect the anchor from corrosion.

The jack, hoses, and fittings should be checked before each day's use. To determine if the equipment is satisfactory, the jack should develop the maximum pressure of the system, i.e., up to the relief valve setting, and maintain this pressure for at least 2 minutes. Even with this precaution, danger to personnel from the failing of a hose or fitting should be anticipated and minimized.

WHAT TO DO WHEN THINGS GO WRONG

Incomplete Anchor Insertion

If no amount of force will complete penetration of the anchor into the borehole, check the amount of hole left unfilled (the hole length should have been marked on the cable before insertion). The most likely reason for lack of penetration is debris in the hole. A loss of about 1 foot per 25 feet of hole can usually be accepted; a sensible design policy is to allow this much anyway. If the lack of penetration is larger than this, one solution is to withdraw the cable and attempt to re-drill the end of the borehole; another solution is to accept the reduced length and compensate with design changes in the system, e.g., changing the spacing and/or length of adjacent anchors. It may be worth-while partly withdrawing and then attempting insertion again.

Unexpected Extensions on Jacking

If the anchor extensions are not within 10% of the expected figure, check the jack calibration. This is usually done by using a test gauge to replace the jack gauge. If the jack cannot be checked, use the spare jack and check the load at which the grips start to free. This should correspond to the load indicated by the previous jack. The design calculations should also be checked.

If the jack is working and the calculations are correct, then unexpected extensions indicate that the anchor is not functioning correctly. Too much extension means the grouted anchorage has slipped. Little can be done about this. It is worth-while leaving the anchor for, say, a week, and then checking the load by jacking the anchor. If the load has been retained, then the anchor is satisfactory and can be left indefinitely. If the load has dropped, an attempt can be made to re-tension the anchor. However, success is unlikely at this stage.

Sudden changes in the rate of increase, or a decrease, in jack pressure may indicate failure of the anchorage or of a wire in a strand. It may prove impossible to reach the required jack load without excessive extensions. This means that the bottom anchorage is slipping. It is best to lock the anchor by releasing the jack pressure very slowly and again attempt to re-tension after a few days. Conclusive evidence that slippage is chronic means that a pre-stressed anchor cannot be obtained in this hole. Grouting the hole full at least obtains the benefit of the dowel effect. Reappraisal of the system is then required.

If the extensions are less than expected, assuming the jack is working properly and the design calculations are correct, the cause will probably be friction on the anchor. This means that part of the anchor load is being transferred to the rock by friction above the bottom anchorage and, as a result, less of the anchor is being stretched. The solution is to release the entire load and re-tension, which may cure the fault. Alternatively, or if the anchor cannot be released, the anchor can be left for some days and then re-tensioned. The friction may dissipate in the meantime and full extensions can then be realized on re-jacking. The third possibility is to increase the initial jacking loads to overcome the friction losses; care must be taken in this case that the loads are within the strength of the anchor. Fourthly, a high-frequency vibrator, used with great caution on the collar end of the cable, might dissipate the friction.

Releasing the Anchor Load

Releasing the load on an anchor can be difficult and hazardous. It is possible only if the jack design allows the removal of the anchor cones while the anchor is under tension. This usually requires a chair to be placed overthe anchor head and the jack pumped up to take the load in the anchor. If the grips are properly locked, they will be difficult or even impossible to free. The jack can be pumped up to a load higher than the initial installation load, but again, care must be taken not to exceed the anchor strength. Often when the grips do release, they do so suddenly, and the resulting dynamic impulse in the anchor may cause damage to the anchorage. If pumping up to, say, 90% of ultimate load and releasing several times does not free the grips, the operation should be abandoned.

Before attempting the anchor release, make sure the jack is fully pumped out to give enough travel to release the tension of the anchor. If re-tensioning an anchor, always use new grips, and be particularly careful to control the load, because the capacity of the strand may have been reduced by the damage caused by the original grips.

Strand or Grip Failure

If one strand of a cable anchor fails, it is not possible to replace it. When the strands are tensioned separately, the remaining strands, to compensate after a strand failure, may be overtensioned to about 90% of ultimate load before anchoring. If the broken strand is one of the last strands tensioned, however, the reduced anchor capacity must be accepted and the effect of this on the over-all support scheme considered. If the strands are tensioned together and one strand fails, again the jacking load on the remaining strands may be increased to compensate. However, the new jacking pressure must be recalculated to account for the reduced number of strands.

Grip failure may occur either on or after anchoring. The strand or bar can slip through the grips refusing to anchor. If the grips completely refuse to hold the anchor, fresh grips should be fitted and tensioning attempted again. Failure after anchoring will usually be sudden and, in the case of a cable anchor, the strands involved may disappear into the borehole and so be lost. The worst problem will arise when the strand or anchor is partly gripped at some reduced load. If possible, the anchor should be released and re-tensioned using fresh grips. If this is impossible, the anchor must be left. In the case of a single strand with a reduced load, tensioning of the anchor should continue with the sound strands, taking special care to avoid the line of the suspect strand. In this case, it is advisable, after completion, to concrete the anchor head to provide extra security for the anchor.

Where an anchor is faulty or cannot maintain the required load, it may be necessary to install another anchor nearby.

MONITORING

Monitoring or measuring the performance of the anchor through part or all of its working life can give valuable indications of the rock behaviour around the anchor. Such monitoring may indicate the necessity, or otherwise, of further support measures.

The most direct procedure is the measurement of the load in the anchor. This may be done in two ways; either by re-jacking the cable and measuring the load at which the anchor block lifts off the bearing plate; or by installing a load cell between the anchor block and bearing plate. The first method is not recommended because of the disturbance to the anchor.

A load cell is relatively expensive to install. However, it provides a continuous measure of the anchor load and requires no disturbance to the anchor and very little time to read.

Variations in anchor load will give an indication of movements, if any, in the rock mass. An increase in anchor load, for example, shows that the rock is expanding because the increased anchor load can be caused only by an extension of the anchor. A loss of load, however, is not such a clear indication of rock contraction because creep in the anchor steel or anchorage slip will also cause a decrease in load.

Borehole extensometers may be installed in the rock near the anchor to measure rock movement as the anchor load is applied initially and during the working life of the anchor. With such instruments it is possible to use the initial tensioning of the rock anchor to conduct a load test on the rock mass itself.

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GLOSSARY

Anchor head	- the assemblage that secures the anchor at the collar of the borehole. Usually an anchor block and cones, for wedging the bar or cable, and a bearing plate to transmit load to the rock.
Anchor block	- a block with holes through which the anchor is passed at the collar of the anchor hole. The tensioned anchor is usually secured by conical wedges (cones) which fit into the hole around the anchor, and tighten against the cable or bar as they are pulled into the anchor block. For a bar anchor, a nut and washer may be used instead of cones.
Anchorage	- the assemblage that secures the anchor at the far end of the borehole, away from the collar. Usually a grouted length of cable, a grouted nut and washer on a bar, a "deadman", or a combination of these.
Deadman	- a device attached to the end of the cable to help form a secure anchorage. Usually a length of pipe attached by resin or a metal block attached by deforming the ends of the cable wires or strands.
Rock anchor	- a tensioned steel cable or bar, of strength usually 50 tons or more, fixed at each end inside a borehole.

TABLE 1

TYPICAL SIZES AND CAPACITIES OF CABLE ROCK ANCHORS

No. of Strands	Strand Size (inches)	Ultimate Strength of Cable (kips)	Maximum allowable Load while jacking (kips)	Design Load (kips)	Overall diam. of Cable (inches)
1	0.5	41.3	33.0	24.8	0.5
	0.6	54.0	43.2	32.4	0.6
2	0.5	82.6	66.1	49.6	1.0
	0.6	108.0	86.4	64.8	1.25
3	0.5	124.0	99.2	74.4	1.5
	0.6	162.0	130.0	97.2	1.75
4	0.5	165.0	132.0	99.0	1.75
	0.6	216.0	173.0	130.0	2.25
5	0.5	248.0	198.0	149.0	2.25
	0.6	324.0	259.0	194.0	2.5

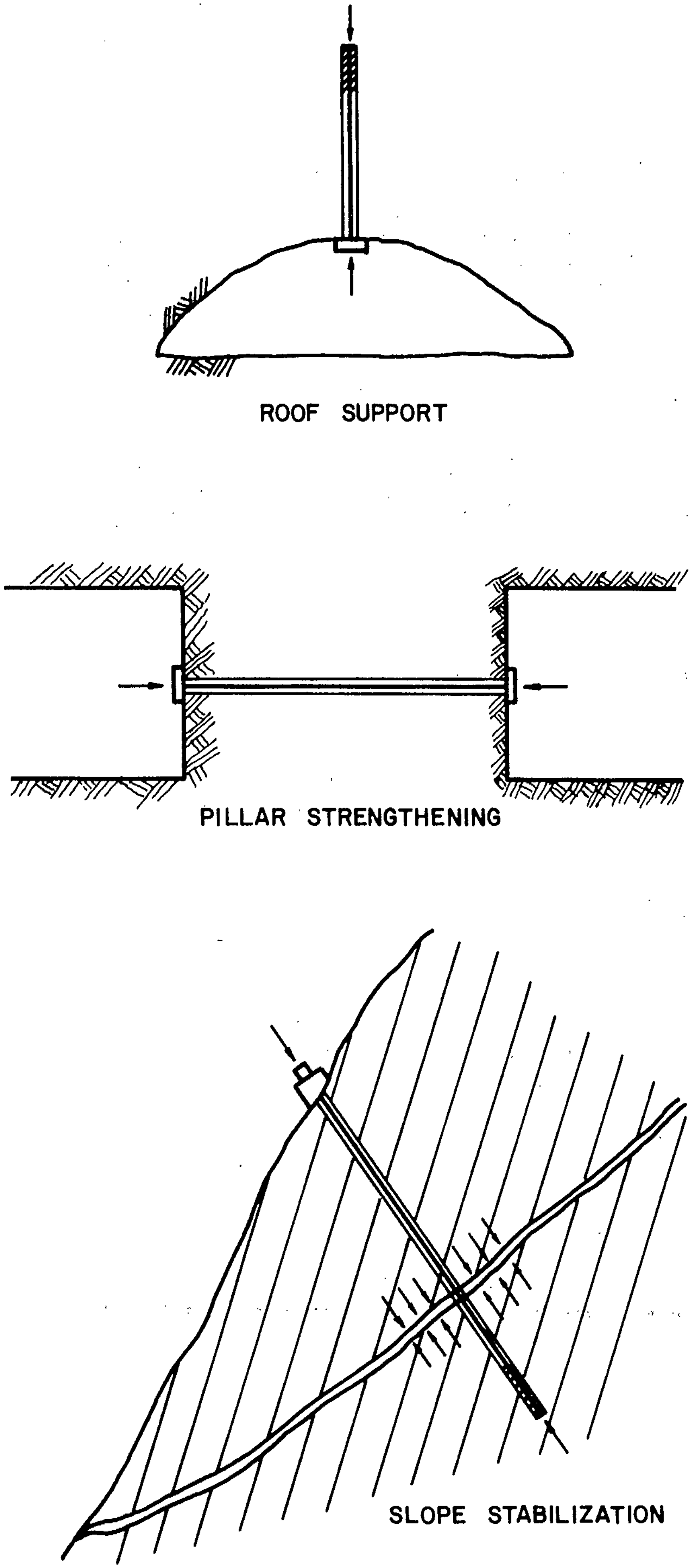


Figure 1: Some uses of Rock Anchors

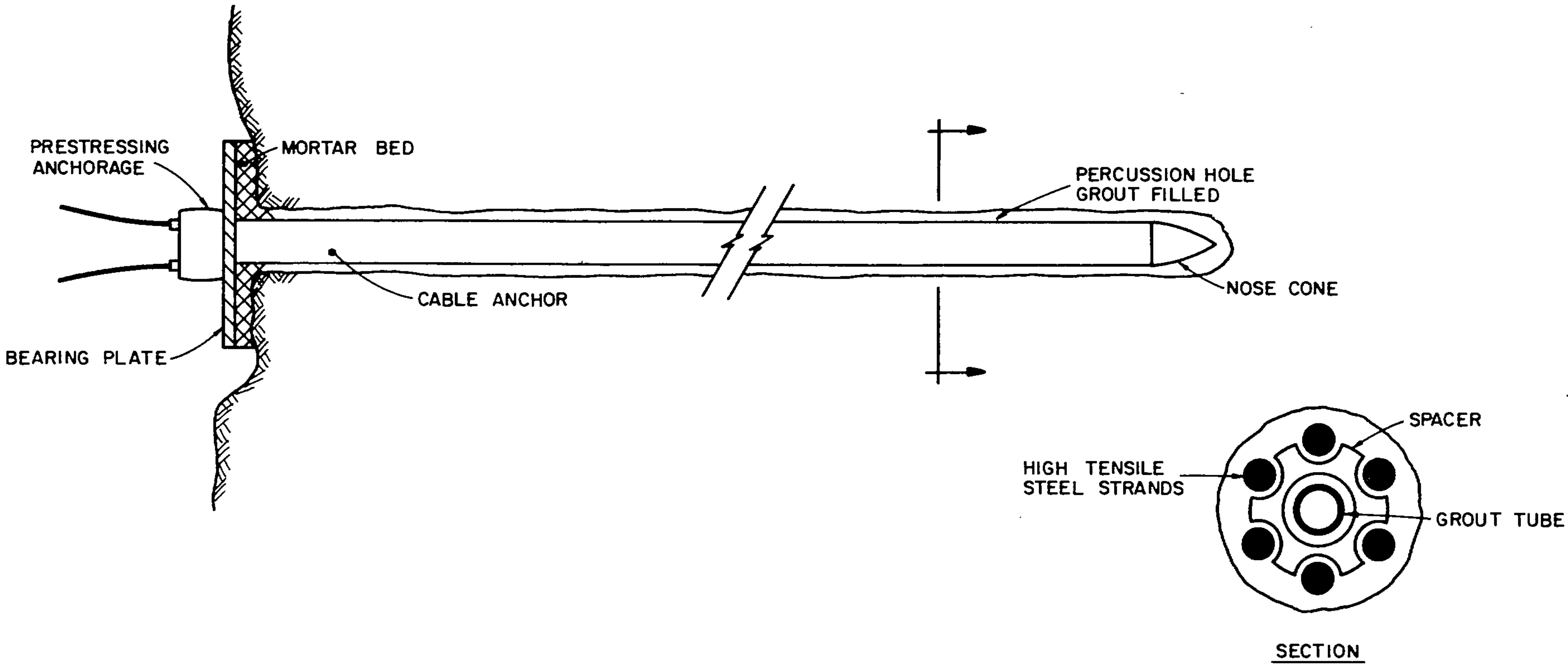


Figure 2: A typical Cable Rock Anchor.

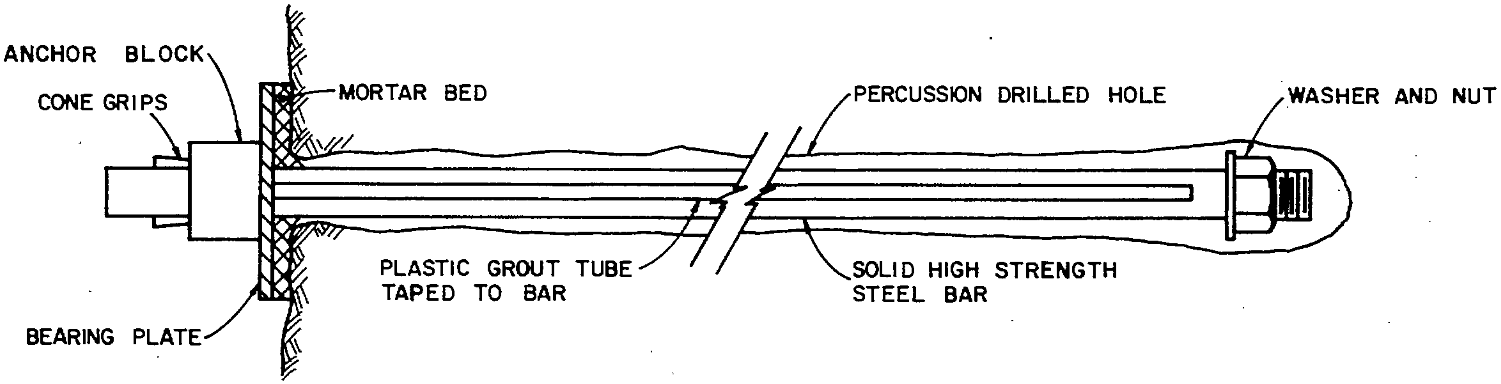


Figure 3: A typical Bar Rock Anchor.

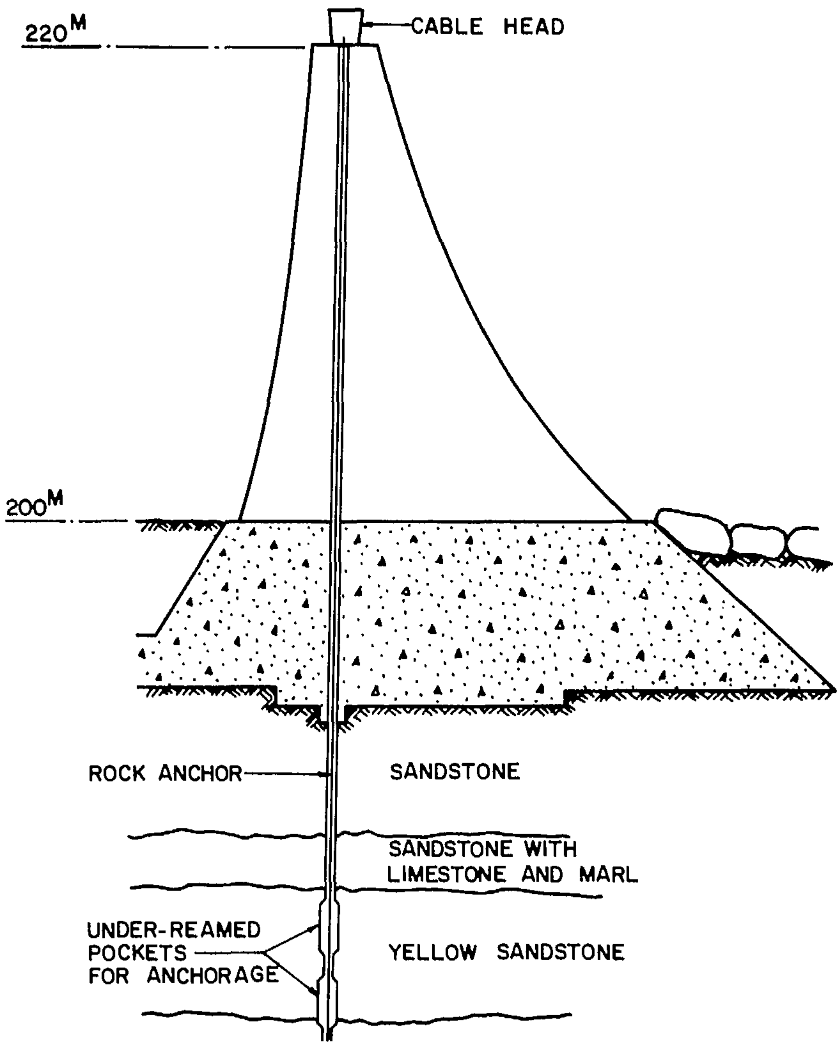


Figure 4: Strengthening of the Cheurfas Dam, Algeria (1).

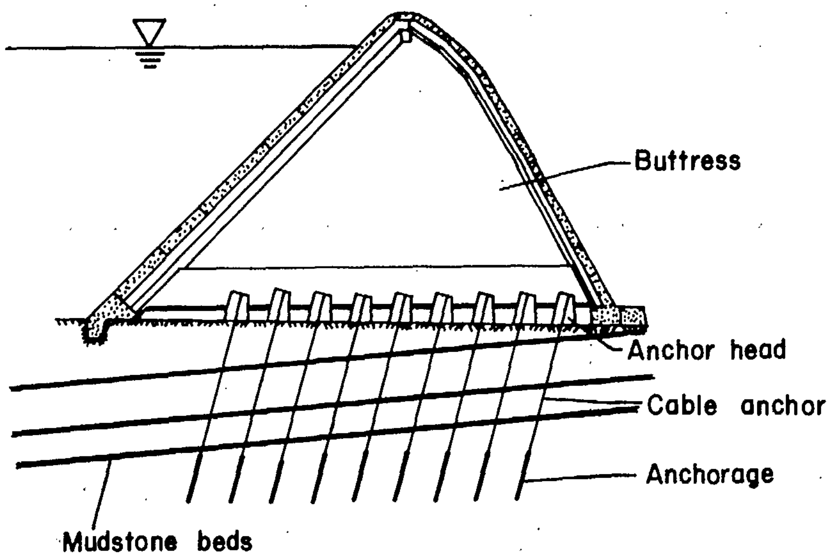


Figure 5: Section through Muda Dam, Malaysia, Showing Rock Anchors (2).

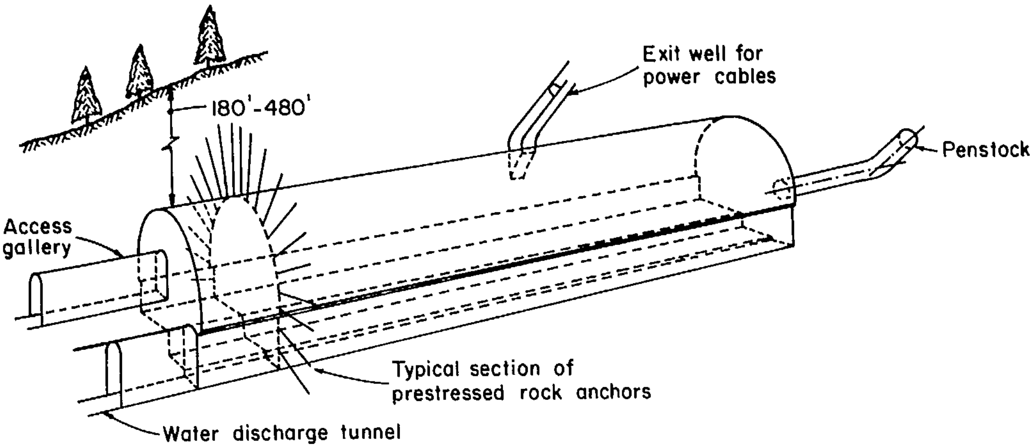


Figure 6: Layout of Rock Anchors at Hongrin Powerhouse, Switzerland (5).

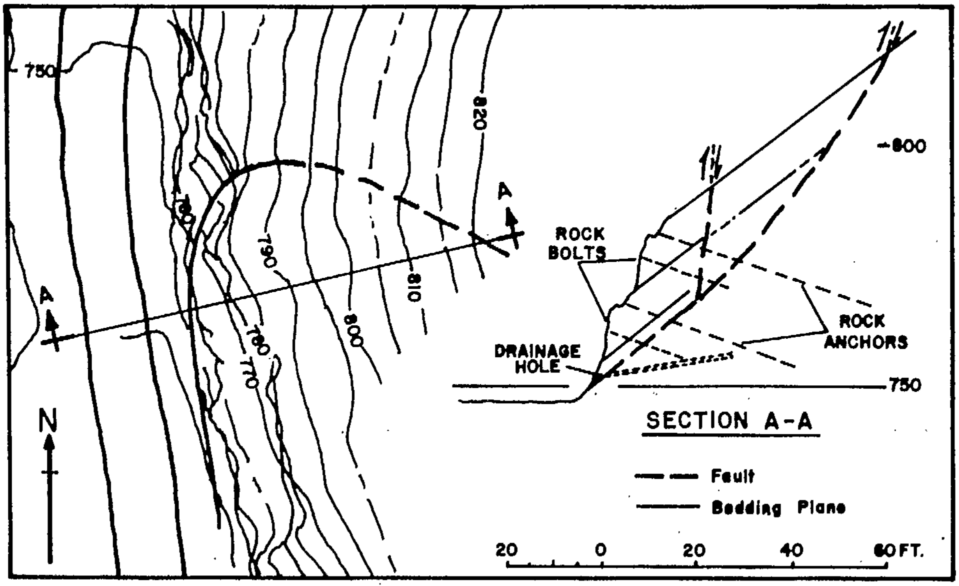


Figure 7: Cethana Dam Access Road, Tasmania (6).

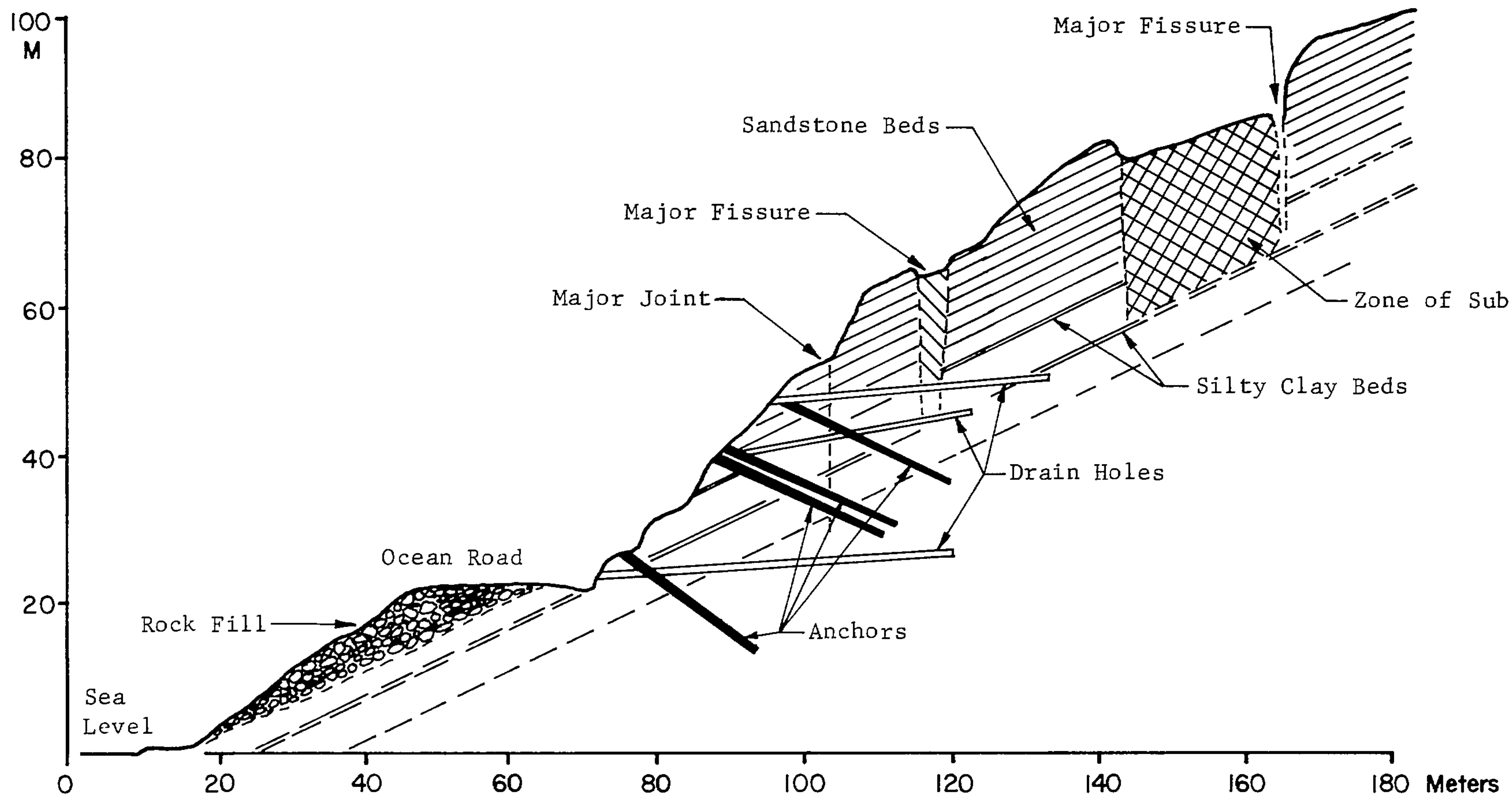


Figure 8: Section through Windy Point Slide, Australia (7).

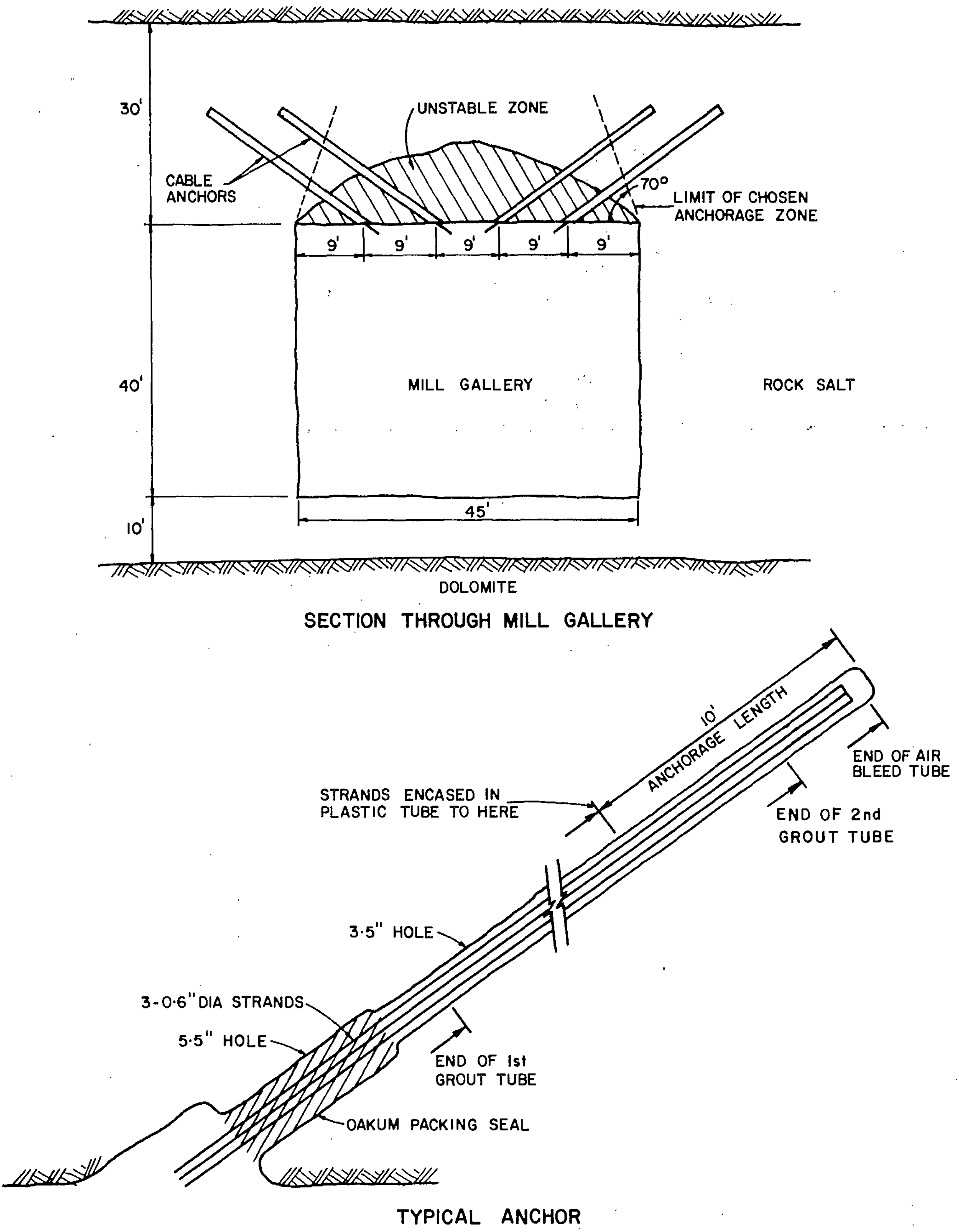


Figure 9: Rock Anchor Installation at a Salt Mine.

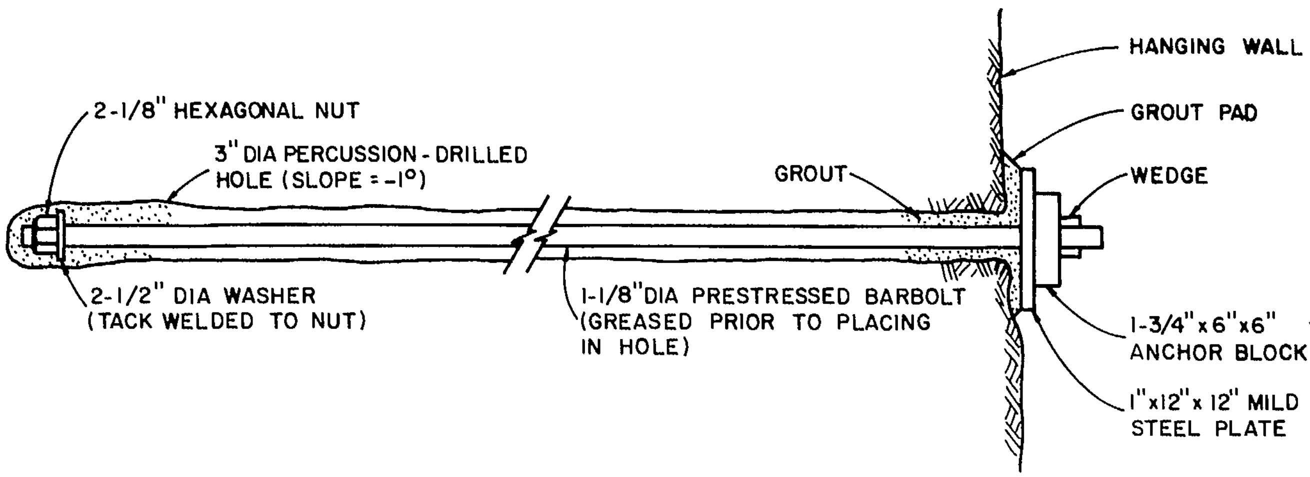


Figure 10: Solid Bar Rock Anchor Used in a Canadian Underground Copper Mine (9).

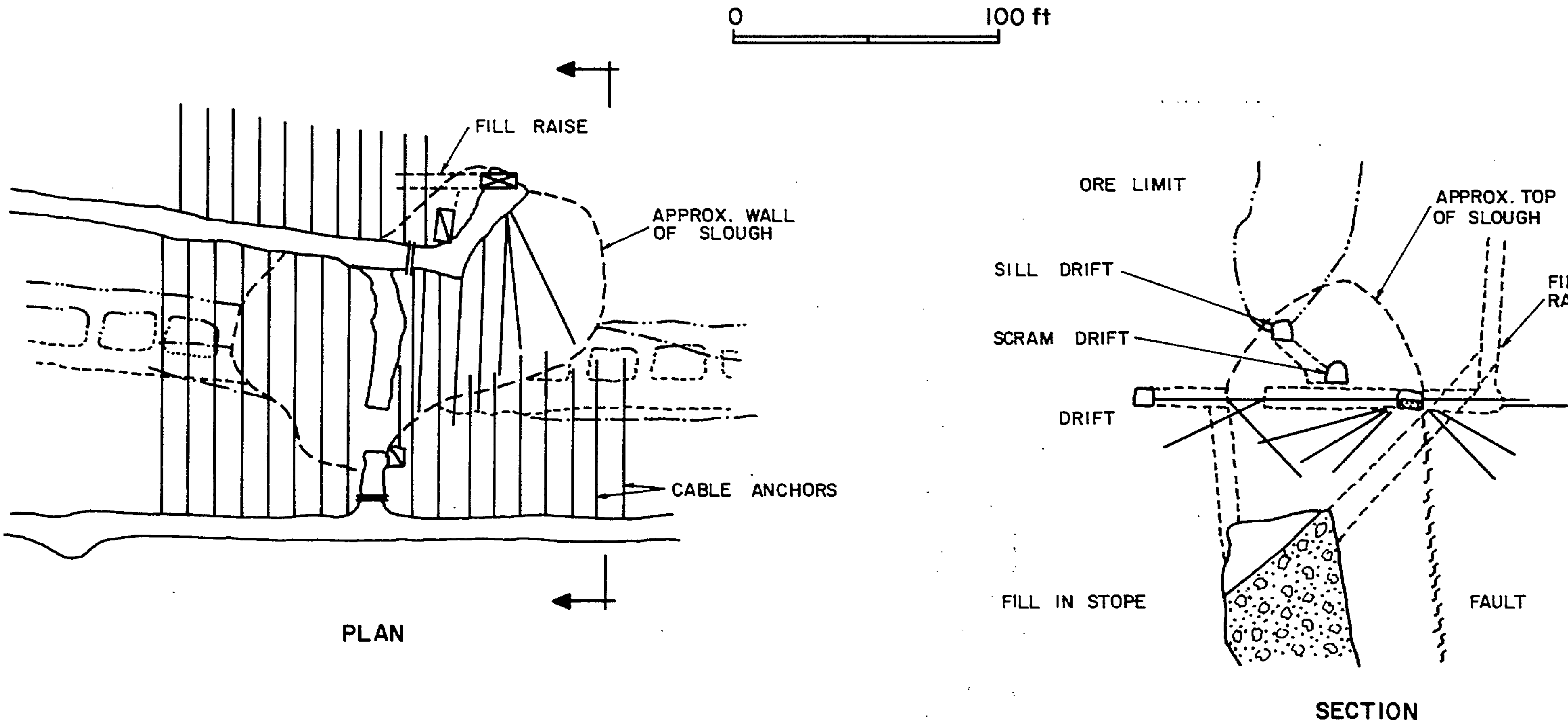


Figure 11: Layout of Rock Anchors in a Canadian Underground Copper Mine (10, 11).

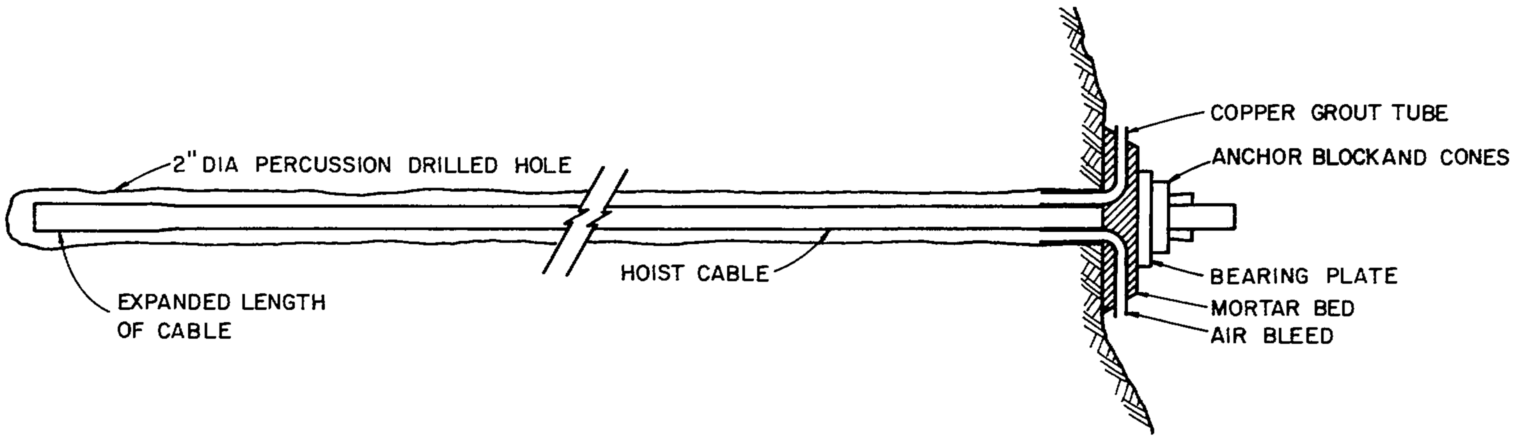


Figure 12: Detail of Cable Rock Anchor used in a Canadian Underground Copper Mine (10,11).

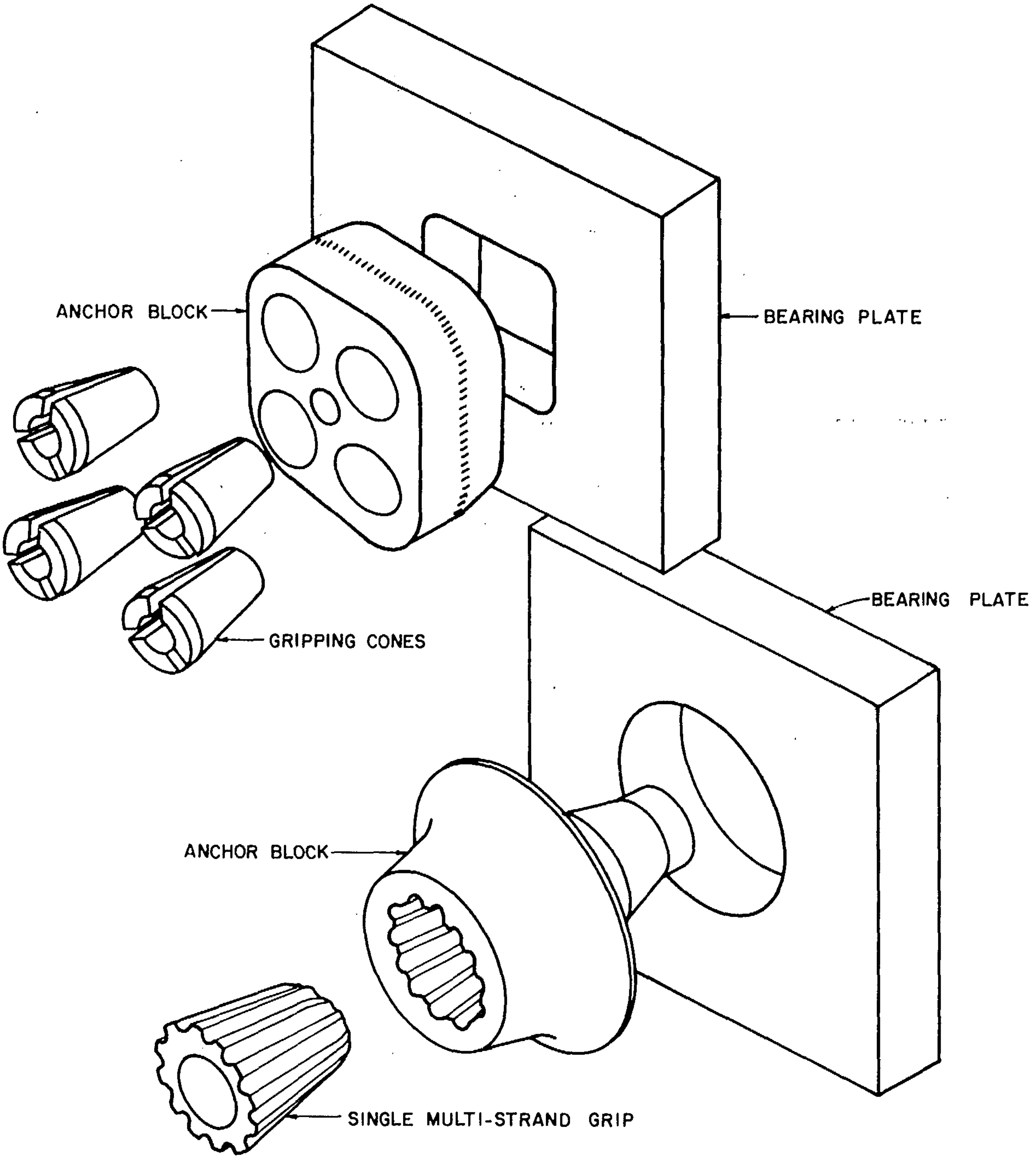
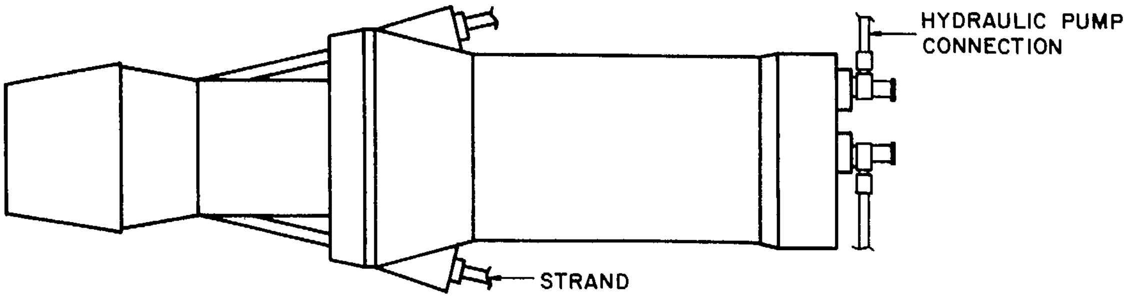
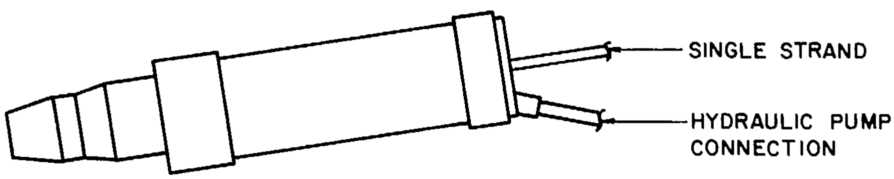


Figure 13: Typical Anchor Heads for a Cable Rock Anchor.



MULTI-STRAND JACK



SINGLE STRAND JACK

Figure 14: Typical Jacks for Tensioning Cable Rock Anchors.

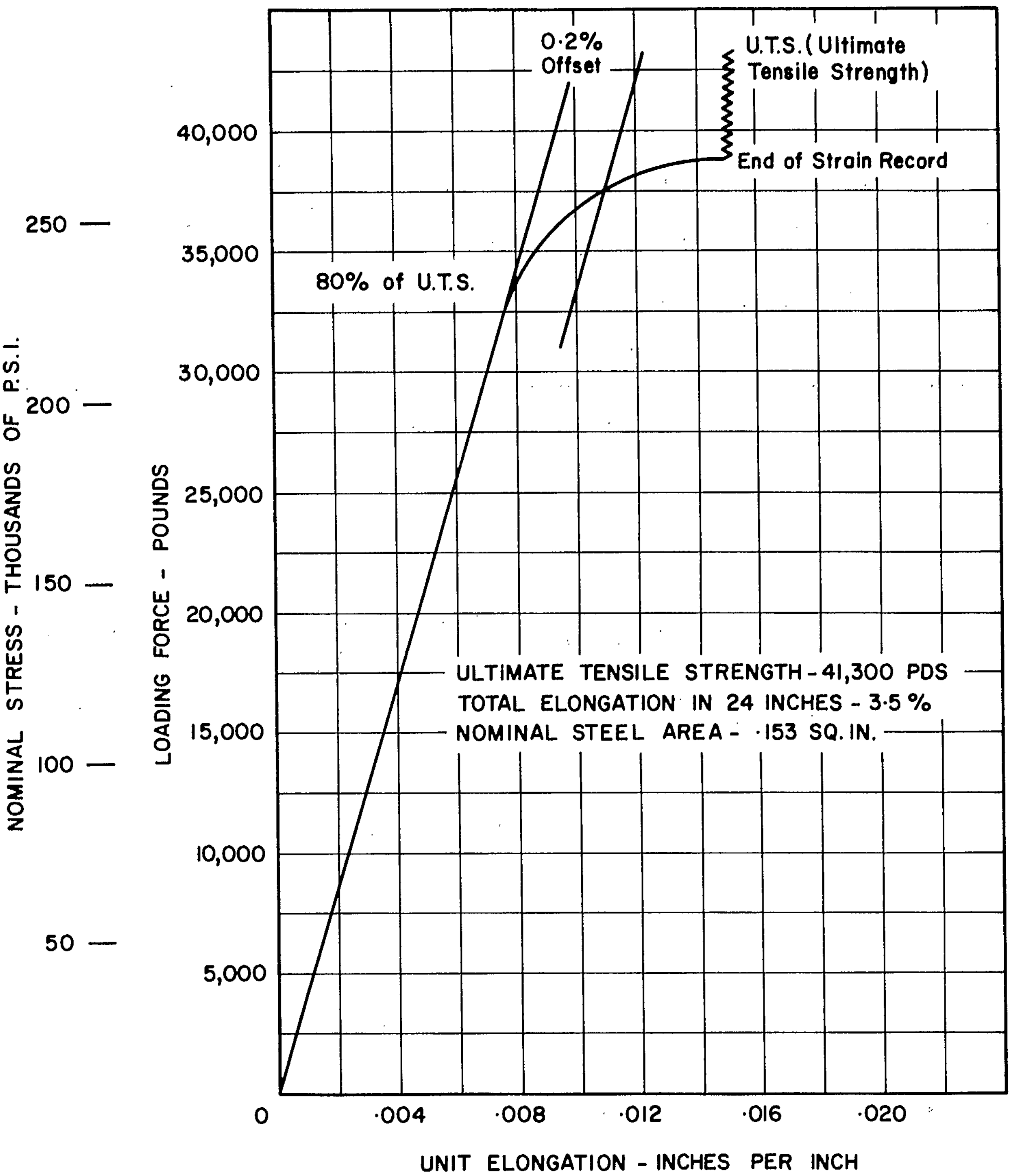


Figure 15: A Typical Load-Extension Chart for High Strength Steel Strand.

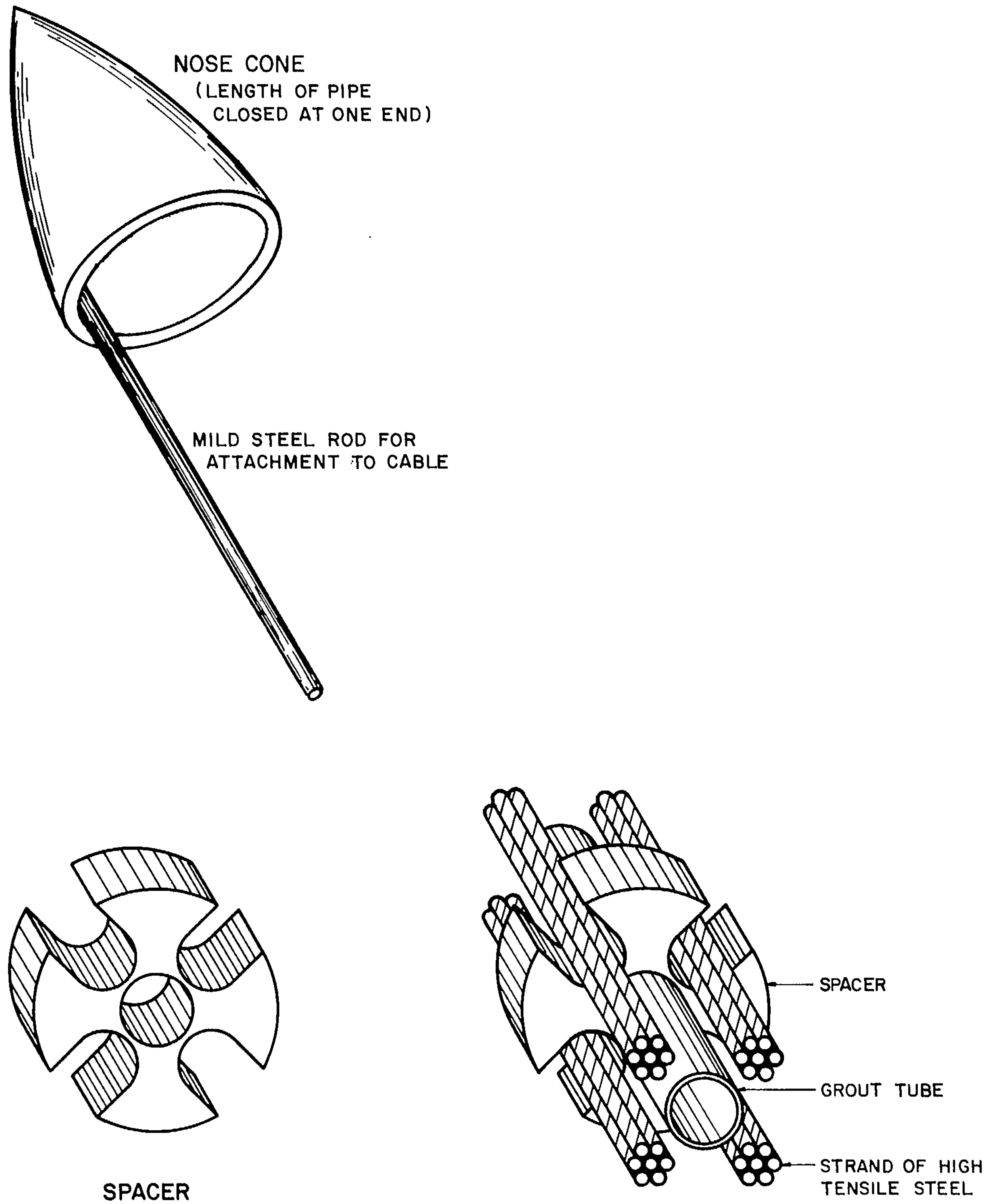


Figure 16: A Typical Nose Cone and Strand Spacer.

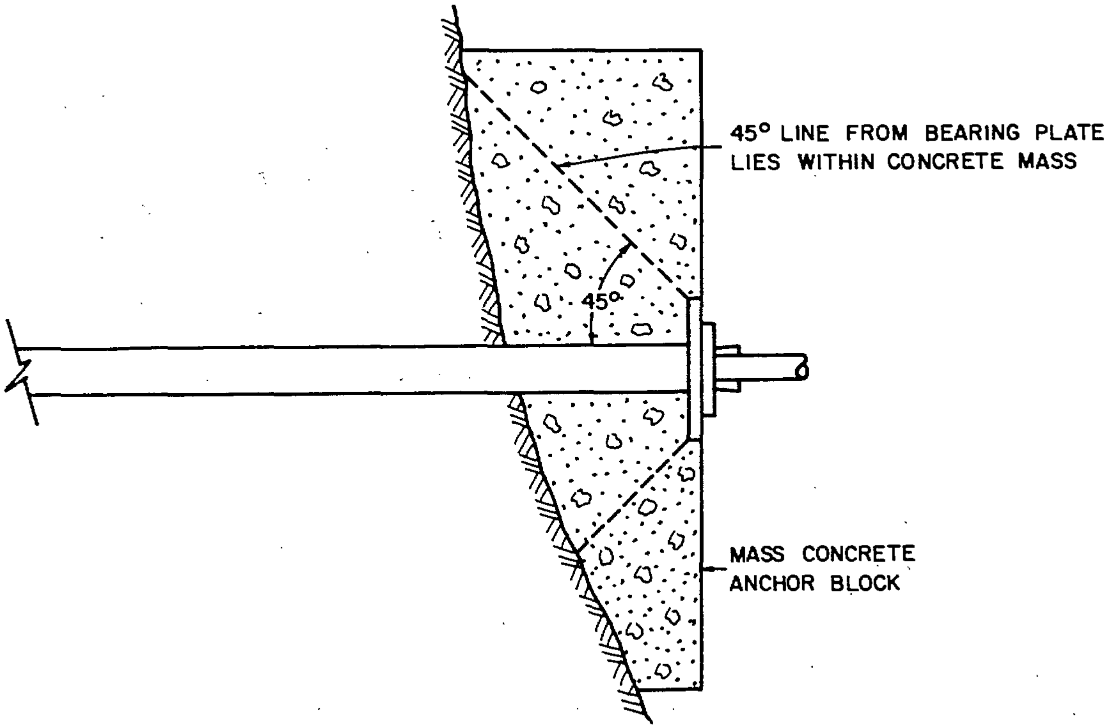


Figure 17: Mass Concrete Block to Support Anchor Head on Weak Rock.

Data Sheet For Anchor Tensioning

Anchor No. ________ Jack No. ________

Date Anchor Grouted ________ Date Anchor Tensioned ________

Length of Anchor Above Grouted Bottom Length ________ Ft.

Required Maximum Anchor Load on Jacking ________ Kips

Expected Anchor Extension at Maximum Load ________ Inches

Expected Anchor Draw-in on Jack Release ________ Inches

Expected Net Anchor Extension ________ Inches

Allowable Range of Maximum Anchor Load on Jacking ________ Kips to ________ Kips

Allowable Range of Anchor Extension at Maximum Load ________ Inches to ________ Inches

Initial Jack Pressure When Extensometer Zeroed ________ psi

Jack Pressure psi	Anchor Load Kips	Anchor Extension Inches	Remarks

Maximum Jack Pressure at end of Jacking ________ psi Anchor Load at end of Jacking ________ Kips

Anchor Extension at end of Jacking ________ Inches

If Anchors load or extension at end of jacking is outside allowable range of anchor load consult engineer before proceeding

Anchor Draw-in on Release of Jack ________ Inches Net Anchor Extension ________ Inches

Remarks

WARNING: Do Not Work in Line With Anchor While Jacking is in Process

Figure 18: Data Sheet for Recording Rock Anchor Tensioning Loads and Extensions.

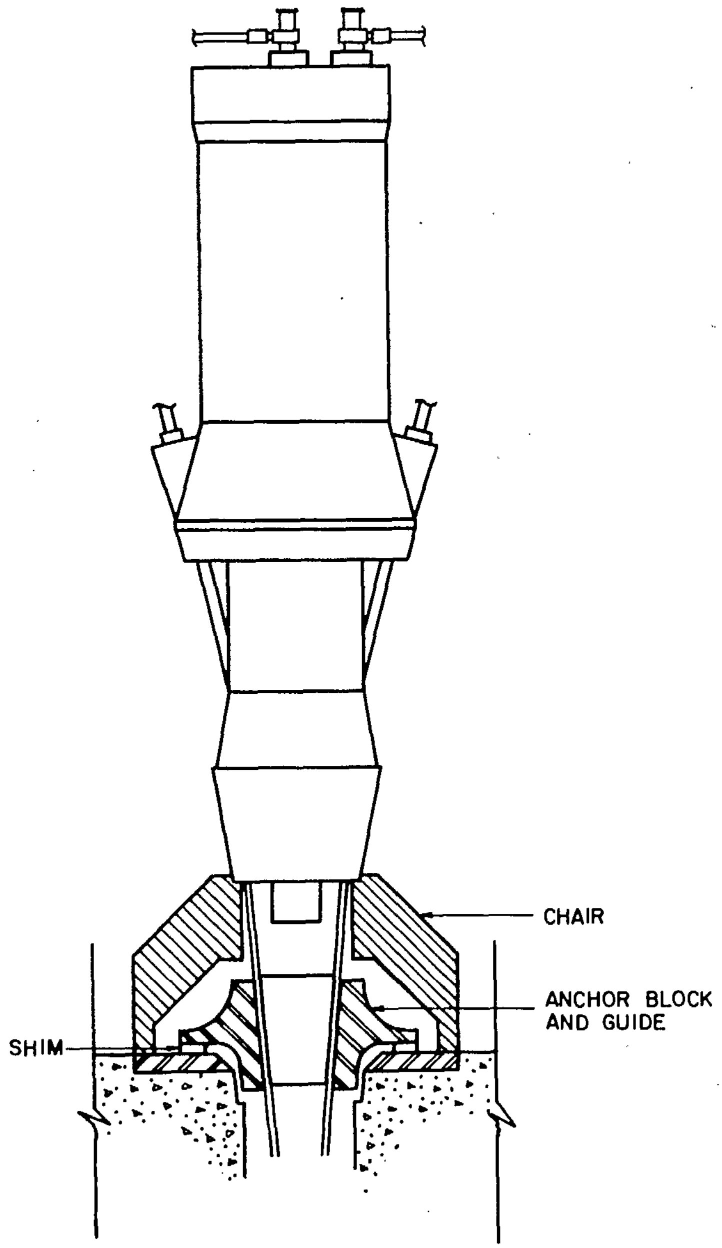


Figure 19: Jack Arrangement for Shimming a Cable Rock Anchor.

APPENDIX

EQUIPMENT AND MATERIALS REQUIRED FOR ROCK ANCHOR INSTALLATION

Materials

Cable Anchors: Strand (7-wire, high tensile, stress-relieved pre-stressing strand)
Strand spacers
Nose cones
Tie wire

Solid Anchors: Bar (high-strength, stress-relieved pre-stressing bar)
Couplers
Nut and washers for end anchorage

0.5 - inch-I.D. plastic tubing for grout tubes
0.5 - inch-I.D. plastic tubing for air bleeds
0.5 - inch copper tubing for grouting tubes and air bleeds

Grease

Sand, cement and gravel for grout, mortar and concrete

Expanding additive for grout

Mild-steel bearing plate

Surface assemblage (anchor blocks, cones or grips)

Oakum

Equipment

Tensioning equipment (jacks, pumps, pressure gauges and extension gauges)

High-speed carborundum disc cutter

Percussion-drilling equipment

Grout pump

Concrete mixer

Concrete vibrator (for mass-concrete anchor blocks)

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Publications Distribution Office, Mines Branch,
Department of Energy, Mines & Resources,
555 Booth Street,
Ottawa, Ontario. K1A OG1.

All requests should be accompanied by a cheque or money order made payable to: Receiver General of Canada.

R = Research Report
IC = Information Circular
TB = Technical Bulletin
RS = Reprint Series

Bielenstein, H. U. and Eisbacher, G. H., "Tectonic Interpretation of Elastic Strain-Recovery Measurements at Elliot Lake, Ontario", R 210, 1970. $1.00.

Coates, D. F. and Cochrane, T. S., "Development of Design Specifications for Rock Bolting from Research in Mines", R 224, 1970. $0.75.

Coates, D. F., "Rock Mechanics Principles" (Revised), Monograph 874, 1970. $8.75.

Barron, K., Coates, D. F., and Gyenge, M., "Artificial Support of Rock Slopes", R 228, 1971. $1.25.

Coates, D. F. and Muir, W. G., "Some Observed Deformations Underground in Various Canadian Mines", R 226, 1971. $0.75.

Coates, D. F. and Yu, Y. S., "Rock Anchor Design Mechanics", R 233, 1971. $0.50.

Canadian Advisory Committee on Rock Mechanics, "Report for 1969 of the Subcommittee on Research Requirements for Rock Foundations", Le comité consultatif canadien sur la mécanique des roches, "Rapport pour l'année 1969 du sous-comité relativement aux besoins de la recherche pour l'étude des fondations rocheuses", IC 251, 1971. $1.00.

Verity, T. W., "Ground Support with Sprayed Concrete in Canadian Underground Mines", IC 258, 1971. $0.75.

Proceedings of the 6th Canadian Rock Mechanics Symposium, Ecole Polytechnique, Special Publication. Délibérations du 6iemme symposium canadien sur la mécanique des roches. Publication spéciale, 1971. $6.50.

Coates, D.F., "L'exploitation minière", IC 285F, 1972. $0.50.

"Tentative Design Guide for Mine Waste Embankments in Canada", TB 145, 1972. $5.00.

Proceedings of the 7th Canadian Rock Mechanics Symposium, Edmonton, March 1971, Cat. No. M37-1572. $5.00.

Coates, D.F., "Principes de la méchanique des roches" (revisé), Monographie 874, 1972. $8.75.

Cochrane, T.S., Knight, G., Richards, L.C. and Stefanich, W., "Comparison of Dust Sampling Instruments", R 250, 1971. $1.25.

Gray, W.M. and Toews, N.A., "Analysis of Accuracy in the Determination of the Ground-Stress Tensor by Means of Borehole Devices", RS 109, 1972. $0.25.

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Gyenge, M. and Coates, D.F., "Mine Fill System Design based on Optimization", RS 113, 1972, $0.25.

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Dubnie, A., "Surface Mining Practice in Canada", Mines Branch Information Circular 292, 1972. $3.00.

Yu, Y.S. and Coates, D.F., "Analysis of Rock Slopes Using the Finite Element Method", R 229, October 1970. $1.25.

Dubnie, A., "Problems miniers dans le nord avec reference particuliere aux chantiers d'exploitation dans le pergelisol", TB 148F, September 1972. $0.75.

Murray, D.R., "Vegetation of Mine Waste Embankments in Canada", IC 301, January 1973. $1.00.

Sage, R. and Coates, D.F., "Survey of Physical-Mineralogical Characteristics of Underground Mines in Canada", IC 306, May 1973. $0.75.

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Larocque, G.E., Kapeller, F., and Coates, D.F., "Seismic Measurements and Borehole Photographic Observation", RS 123, 1973. $0.25.

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Everell, M.D., "Foncage Mécanique de Tunnels et de Montées", Circulaire d'information IC 304F, mars 1973.