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SUPPORT OF UNDERGROUND MINE STRATA WITH ROOF BOLTS

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by

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ABSTRACT

Roof bolting has reached a stage of development where it is now a common method of roof control in mines. This support method is one of the innovative means of strata control useful to increased mechanization of the mining cycle and improved safety.

Research has resulted in improvements in roof bolt design for specific strata, installation equipment, patterns or layouts, and optional uses or aides. The economics, speed, labour and safety in roof bolting applications have all received consideration.

Despite the widespread use of roof bolt support it appears that roof bolting crews often do their work with little understanding of the techniques involved in developing strong safe strata support. Conversely there is also little appreciation of the technical factors that make a bolted roof unsafe. This report outlines details of roof bolt research involved in making exposed mine strata safe for working. Although roof bolts are an effective method of controlling mine strata it is essential to know if the roof is in fact safely supported.

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Key Words: Roof bolt support, mine strata, research.

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INTRODUCTION

The Department of Energy, Mines and Resources through the Canada Centre for Mineral and Energy Technology, Mining Research Laboratories has cooperated in extensive investigations of strata support in Canadian mines.

Roof bolt strata support has developed intermittently and slowly since its inception some forty years ago, to the stage that it is now recognized as a competent means of support when installed properly, for most mine strata. This development has been influenced by and correlated to the increase in mine mechanization. With manual mining methods, mine openings were narrow so that the entry spans were within or close to the strata strength limits, with minimal need for artificial support. When the requirement for extra entry space became important, or the roof rock was weak, supports, generally timber, were made stronger by increasing the size or number. This to some extent was self-defeating as the extra timber occupied more space, increased the friction factor for ventilation airflow and created larger accidents when damaged. The introduction of large powerful mining machines with fast transportation equipment created the need for more entry space and larger entry widths. This tended to approach the failure range of mine roof rocks. The speed of the mining cycle was increased by improved mechanization but offset to a large extent by the extra time and labour required to erect the stronger timber supports. In many cases each variation made to the mechanized mining cycle required a compensating change in the support pattern.

There are many ways of improving mine support. In the design stage improved layouts can help. This includes optimizing dimensions for pillars and openings, orienting the mining to take advantages of strata strength and weakness, concentrating or spreading the working areas, varying the mining method, etc. Within this framework and not discounting any means of strata control improvement, roof bolt techniques will be the main subject of this report.

OBJECTIVE

The Mining Research Laboratories have a commitment to aid in improving mineral extraction and mining methods in Canada. More effective mine strata control has a high priority in this work. The research group has been involved with developing and improving roof bolting techniques since their inception in Canadian mining about 1950, as improved strata control is a major prerequisite to better mining methods.

The prime consideration was to develop and smoothly integrate an economical, safe strata support system into more effective mechanized mining cycles. Consider, for example, a continuous miner driving a coal entry to produce a few hundred tons of coal per shift. This production takes place in less than one third of the shift time, while more than one third of the time is used supporting the newly exposed roof. Roof bolt support systems were experimented with as they appeared to be a reasonable means of strengthening the strata support while increasing the speed of the mechanized mining cycle. All aspects of the roof bolting techniques had to be considered for improvement as the method gradually developed into a standard system of mine support.

Bolting techniques developed slowly due to the difficulty in explaining to the mine personnel the rationale of the way they support strata. There were also problems with designing fast, efficient installing tools. The advantages of roof support using new bolting techniques over established timbering methods in coal mines, or no entry support in hard rock mines, were not understood initially by miners. Acceptance gradually came with experience.

OUTLINE OF ROOF BOLT DEVELOPMENT

The idea for roof bolt support was probably conceived when someone noticed that pegs or dowels wedged into boreholes to support cables or tubes also helped to keep the roof strata in place. This may have been combined with the fact that planks nailed together form a stronger beam. Experiments with the support method were first tried in U.S.A. mines, with organized research in the use of roof bolts promoted and conducted by the United States Bureau of Mines. Within a few years Canadian mines were experimenting with the support system with the Mining Research Laboratories cooperating in this research. The roof bolt support method was probably accepted as a viable strata control method in the late 1940s or early 1950 in some mines. Much of the early development was conducted in the coal mines but the system was quickly adopted and spread in the hard rock mines.

Various factors could receive credit for the push in roof bolt strata support development. Large, mobile, expensive, fast mining machines were being introduced rapidly in the mines to increase production. Each improvement in extraction speed was counteracted by the extra time and labour required to erect the conventional wood or steel sets or posts. In hard rock mines isolated weak segments of the roof could be supported by roof bolts without having to clutter the entry with posts or sets.

The first roof bolts checked were of the split wedge type. This initial design choice was useful, as the bolts could be expanded with a good degree of certainty to form a strong anchor. There was also sufficient manual labour involved that the bolter could tell if the anchorage was good or bad. These bolts gradually were displaced by the expansion shell type of bolt where the threaded rod forces a wedge plug to expand the shell sleeves into the perimeter of the hole to form a strong anchorage. The split wedge type of bolt was strong, simple, reasonably easy to manufacture on the mine site and could be installed with an assured degree of certainty. Its faults were that it was heavy, expensive due to the weight of steel, labour intensive and fairly slow to install. The expansion shell bolts could be mass produced, were easier to install with rotary tools, and were cheaper. Developing useful designs was more difficult and the certainty of strong anchorage was less. A large variety of designs were checked for various mining and strata conditions while trying to establish the most effective design criteria. During this time period other types of bolts were designed and tested with varying degrees of success, such as cement or resin, grouted bolts, expansion cylinders and others. Different sizes, bolt lengths, random and patterned layouts, auxiliary aids and combinations of systems were all experimented with for support of various strata types varying from the soft sediments to the hard quartzites.

The improvements with roof bolt design were matched by developing more effective installation equipment. In the first instance air leg stopers were designed specifically for bolting with more speed, power and precision. Drill bits and steels were manufactured specifically for the mine strata and the hole size required. Tightening adaptors were designed to suit the drill and the bolt. Vacuum systems were experimented with for the compressed air drills to control dust but in most cases proved too cumbersome while they work well with mobile drills. In the softer sedimentary mine strata rotary drills were developed, mounted on vehicles and powered by electric hydraulic systems for faster drilling and bolt installations. Various types of equipment are now on the market with some more suited to more specific strata problems than others.

MINE SUPPORT PARAMETERS

An orebody or mineral deposit is a hetrogeneous mass. The deposit while undisturbed is in an equilibrium condition with stress components resulting from the depths of overburden and residual stresses left by tectonic disturbances and erosion. Both rock strength and overburden pressure increase with depth below surface. The strengths of the rock composing the various formations in the strata may vary considerably and also be affected adversely by tectonic disturbances and depositional irregularities. The introduction of mine openings disturbs the equilibrium state of the rock mass and induces dynamic stress patterns that have to be contained. Efficient mine layout involves transferring the main induced stress concentrations to the abutment pillars, which may be called passive support, while minimizing the load to be held by active artificial supports such as timber, fill, roof bolts or other supports installed in the openings.

When the mine operations are large or concentrated the overburden loads may extend to near the surface and cause surface subsidence. If the strata does not fail easily, stress concentrations can build up to the point that when failure does occur, it happens violently and within the active mine workings. This should be prevented by inducing controlled caving or limiting the amount of movement with pillars or other supports. Roof bolts may cause complications by reinforcing the roof strength too much.

The immediate support problem with most mines is to hold the strata safely in place around entries or development headings. This includes a time factor depending on the length of time the entry is required and its importance, for example whether the entry is an essential haulage way or a regular cross-cut. Most of the overburden load or the extra stress concentration induced by excavation should be transferred to the abutment pillars.

There is a remnant strata load left that, when not sufficiently strong, has to be supported by the entry. The remnant is usually judged to be in the form of a dome or arch with the height above the roof generally limited by the span of the opening. The dome, arch, or beam theories that may be used for support design calculations are based on this assumption. A confirming factor is that most entry caves fail to the shape of a stable arch. Some examples of stress patterns and supports are shown in Figs. 1 and 2.

The overburden or depositional weight compacts the strata, with the stress-strain relationship reasonably in accord with the elastic theory of the strength of materials. The introduction of the mine opening removes some of the constraint allowing the strata bordering the opening to dilate followed by smaller increments of movement with depth into the wall rock. When the strain or deformation is within the elastic limit support problems are minimal. When the strain is more than the elastic limit or leads to fracture of the roof rock or opening of the joint planes, then active or artificial support to control the amount of movement is necessary. Although highly desirable, there is probably no method of installing support fast enough to stop the initial rock dilation. The support effectiveness increases when it is installed quickly. To limit the deformation and retain most of the strength and cohesiveness of the rock walls , the strength of the supports have to be adjusted relative to the inherent strength of the roof rock and the amount of discontinuities in it.

Most former mines were developed by manual labour so that dimensions of the openings were kept small to suit hand mining systems. The beam strength of the roof rock was within reasonable safe limits requiring minimal support. When support was required it could be installed quickly as extraction was slow. As mining became more mechanized the equipment got larger requiring wider entry spans. Higher development production quotas, faster transportation systems and more ventilation were among other factors that promoted larger entries. Such entry spans approached or exceeded the limiting dimensions for the critical beam strengths of the strata. Larger, more expensive mining machines concentrated in smaller areas, faster transportation systems, and critical cave repairs added to the need for effective strata control. The mines tried to satisfy some of these extra support requirements by using heavier timber and closer spacing. This was to some extent self-defeating as the timber used up much of the valuable space required for equipment and air flow. As well this extra timber support took up a larger percentage of time in the mining cycle. Timber supply, transportation, repair and labour problems were all expensive. It was essential to improve the support systems if the mechanized mining cycle was to be speeded up to match the capabilities of the machines. Roof bolt supports were one of the innovative methods tested and improved to provide a safer means of support for a faster mining cycle. Refer to Appendix A for design criteria.

ROOF BOLT SUPPORT DESIGN

Timber supports were created basically to withstand the load of the immediate roof above them. If upward pressure or movement could be exerted against the roof by means of tightening the post, with or without wedges, control was good. When the posts or sets stopped or limited bed separation and prevented further strata movement including side pressure the support job was adequate. It was easy to evaluate the strata support effectiveness of wood as warnings of impending roof failure were both visual and audible due to the wood fracturing.

The characteristics of roof bolt support are more subtle,in that the bolts should reinforce the roof layers to improve the beam strength, stop the bedding joint and fracture planes from opening to retain the roof quality, suspend poor roof from more competent layers to keep the roof in shape. The support performance of roof bolts is more difficult to evaluate by ordinary mine experience except for observation of the length of time it stands in place or the amount of roof failure. It is more difficult to visually evaluate strata reaction with roof bolts than with timber but it possibly is easier to conduct more formalized checks. Mines should use all the means at their disposal to improve their strata support programs.

INSTALLATION TOOLS

A major requirement for effective roof bolt support is use of installation tools designed for the mines physical characteristics. Mines that have hard strata require percussive or rotary percussive compressed air drills or stopers. They should be as light and powerful as needed for the conditions to be encountered. The air leg should be direct-acting and in line for most support purposes, although for installing rib or floor bolts a jack leg may have an advantage. The controls should be precise. If mobility is an important consideration, quick couplers for the lines, drill buggies or other conveyance should be provided. If the unit is not to be moved, vacuum systems may be an asset although these are generally awkward. One of the real advantages of a single stoper is that it can be moved into position quickly to install support into small segments of newly exposed weak roof.

Drill steel should be in the proper length ratios to suit mine heights. The steels should neither be too long, nor too short. One length should not be used to cover an excessive height difference. Drill bits should have the most effective design for the rock they are drilling. Generally this includes the economics based on cost per foot drilled. Usually the bit should be matched to the most suitable type of anchor, with a hole to anchor tolerance of less than 6 mm. Water is generally used as a bit coolant and for dust control. Some thought should be given to substitute systems to eliminate dripping water for more definite and stronger anchorage conditions. Water can soften or weaken rock, lubricates the anchorage horizon and promotes corrosion. These liabilities decrease as the rock hardness increases. Each drill should have an effective tightening adaptor well suited to drill and bolts. For large openings mobile drills designed for bolting could be useful.

There are a variety of rotary roof bolting drills on the market today. Most of these are mobile and powered by electric hydraulic systems. Some of the units have the drill mounted in a set position and the whole machine has to be manoeuvred from hole to hole. Nearly all these machines are on rubber tyres and steered by braking or slewing. These units tend to rip up a soft floor as they manoeuvre into position. They are also difficult to position close to the ribs especially on pitching seams. Some roof bolt machines have the drill units mounted on swinging hydraulic booms that can telescope forward about 3 m and turn about 120° so that the entire mined room can be bolted from 1 or 2 machine settings. The drill is often articulated so that the bolt can be installed off vertical and into the rib corners when required. The hydraulic fittings have to be more substantial on these units and they do receive and have to take more abuse from the operators, than the single acting machines. They are more versatile, faster and more expensive than the other machines. Many of the continuous mining machines also have roof bolters mounted on them. In nearly all cases the mine extraction equipment has to be trammed out of the heading before the bolting machines can be moved in to bolt the newly exposed roof. So each unit of work has to be programed into scheduled cycles. The same details apply to drilling the holes and installing bolts with these types of machines as with the stopers.

There are some electric roof bolting drills mounted on spring type ratchet bars and a few electric hydraulic drills that can be manually operated. These units could work along side a mining machine when required. These drills are not as common nor have they received the attention they should have. The reasons for this are the units are not light or mobile enough to be easily moved by one operator. If one was available the workmen operating the mining machine could do the roof bolting during wait periods. They do not appear to match the rest of the mechanized equipment. On the other hand they are possibly one of the more suitable alternatives for installing bolts promptly and making the support safer in future mining practice.

Most if not all of the mechanized rotary roof bolters have built-in vacuum systems and generally these are efficient. The drill steel, bits and connections should be designed to work well with the vacuum system which should be well maintained. When the mine has steep grades, hard or soft floors or other abnormal characteristics, machines with suitable traction adaptions should be used. At the present time there is an emphasis on designing roof bolting units with more built-in safety features.

ROOF BOLT DESIGN

A very broad selection of roof bolt anchors have been designed and tested, many for specific uses, with the more suitable designs selected for regular use at the present time. Brand names will be omitted from this discussion of working details. For design purposes most components of the roof bolts and installation techniques may be calculated using various formulae although the physical characteristics of the bolt, strata, and the reaction vectors are difficult to accurately define. Usually standard test procedures are used to determine the strata support strengths of the roof bolts.

Rods vary considerably in size and length depending on the application. The split wedge type of bolt or the long bolts used in civil engineering installations are usually large (over 21 mm diameter). The most common size rods in use now are 19 mm diameter mild steel or 16 mm diameter high tension steel for expansion shell roof bolts or No. 6 or 7 rebar rod for grouted bolts for mines. Many of the rods now eliminate the nut and have one forged end (28.6 mm square being fairly standard) for faster installation and ease in handling. The forged end may reduce the high tension quality of the steel. There is some debate as to preference and quality between the 19 mm diameter mild steel and 16 mm diameter high tension steel. The larger steel is probably easier to work with and install while the smaller is lighter and a little cheaper. In either case the steel rod choice should be based on the load it will be expected to bear and the holding strength of the anchor. It is of little value to use a rod that will safely hold 30 ton if the anchor will only hold 10 ton. The threaded end can be rolled or cut with the rolled thread offering more resistance to damage. The length of the rod should be selected in relation to the more competent horizons in the roof rock and the width of the entry. Many mines are trying to increase the safety factor by using longer rods, while ignoring the fact that longer rods are more difficult to install, tighten and more subject to the strain relaxation effects. Forged end bolts are usually cheaper and can be installed faster with less complications. The neck of the forged end is a stress concentration point. The bolt threaded at both ends requires a stud driver for installation, plus another operation for tightening the nut. This is slower and more awkward, but tension or compression can be applied more directly and may be easier to use with auxiliary supports such as mesh or plank collars. It should be remembered, as it occasionally causes complications, that when percussion and rotary systems are in use at the same mine that threads for percussion equipment are left-handed and installed counter clockwise, while threads for rotary equipment are right-handed and installed clockwise.

ROOF BOLT ANCHORS

Roof bolt anchors come in a wide variety of designs, with special features added for specific purposes. The basic reasoning behind all designs is to make an anchor that will expand easily to provide an effective bearing force against the perimeter of the hole at the anchorage horizon for each strata type. The split wedge design of bolt worked well in that it provided a comparatively large bearing area against the hole sides with little relaxation effects when installed properly. The strata at the anchorage horizon had to be hard and strong enough to resist the impact of the top or blunt edge of the wedge. With soft rock the rod and wedge could penetrate the roof of the hole to prevent proper installation.

The expansion shells as shown in Fig. 3 have design points in common as well as specific differences. One group of shells, classed as a bail type, uses a confining bar to hold the shell together, reacts against the rod top so expansion can be provided at any point of the hole length, and appears to have some advantage with wet drilling. The prong type has more need for a definite length of hole and may have some advantage with dry drilling. They are generally of simpler design and cast. The rod screws into the plug or wedge to pull it into the shell to expand the sleeves. The plug should be designed to provide fast direct expansion to the sleeves with a firm consistent bearing area to hold the sleeves extended. The shell or sleeves may be part of one casting, or separate segments but they should be capable of quick firm expansion against the hole sides. The sleeve area generally has serrations forged into it, some vertical to resist the initial horizontal thrust to prevent turning in the hole, some horizontal to provide better anchorage against the rock and resist downward pressure. The serrations are generally designed for the rock type, shallow and blunt for hard rock, deeper for soft. They should not be extreme to either chip the metal or harm the rock surface. There is an ideal expansion volume or area for each shell type and the shells should be designed to reach that easily. The units can come in various sizes with long or short sleeves and plugs to match. The extreme designs are more difficult to manufacture and install for consistent performance. The expansion shell that is well designed for the strata, will expand quickly, with little or no initial rotation, provide a strong bearing surface against the rock with minimum tendency to relax or slip. The shell expansion can be parallel or tapered. The parallel provides more bearing surface but is more difficult to install properly.

The shell sleeves bearing against the wall rock of the hole exert a force, the principal component of which is normal to the shell sides. Minor force components extend out at various angles to the axis of the hole. These react against opposing forces applied by tightening the roof plate to compress the intervening strata or apply tension to the rod. The main reactions are contained within a 45° angle to the bearing forces so that the spacing between bolts can be designed for, plus compressing of the joint or fracture planes of the strata. Conversely some of these minor components may react to weaken the strata, for example at the bottom junction with the shell or between plates, but this should be kept to a minimum. This is partially demonstrated in Figure 2.

PLATE DESIGN

The plate on the bottom of the support system should provide a good contact with the rock. It provides compression to the strata by the tightening of the nut or head. The applied torque may be converted to load by the equation

$p = x \cdot t$ where p = load in kg
t = torque in kN.m
x = conversion factor ≈30 but may vary depending on material

The basic minimum load to be supported can be calculated from the dead weight of strata that one bolt should hold. For example for a 1.2 m bolt on 1.2 m centres

$$\ell = \frac{1.2 \times 1.2 \times 1.2 \times 2.7}{10^3} = 4.7 \text{ tonne}$$

using 1.2 m cube of shale roof strata at 2.7 sp gr. A torque of 23 kN.m to 27 kN.m on the bolt approximates between 3 400 to 4 545 kg applied tension. There is some debate as to the value of applying torque on the bolt to apply pre-tension to the strata to prevent the various fracture planes from opening. No tension or torque on the bolt means the bedding planes have to dilate before load comes on the system to tension the roof bolt. When calculated, the pre-tension force components are small, but they appear to do useful work by preventing the strata from unravelling. The plates have been made in various shapes and sizes with the type, flat square and a circular hole being the most common. Some mines use dome shaped plates with the idea that the dome will crush with increasing load, thus applying a safety factor against sudden failure and an indication of the weight on the roof. This is a questionable indicator of load. Elliptical holes and dished plates can be used for sloping or rough roof. Washers, flat or rounded, also can be used to increase the bearing surface for the forged head or offset eccentricity on the bolt. Many mines, especially coal, like to use wooden cap pieces under the plates. This provides more bearing surface, allows a certain amount of flexture and better contact. Many of the hard rock mines think wood is the weak link in the system. Probably the usefulness of the wood cap-pieces increase as the hardness of the rock decreases.

OTHER ROOF BOLT DESIGNS

Many specially designed bolts have been put on the market for strata control. Some of these are effective when used for the conditions they were designed for but have not established themselves in a regular market. One example is to drive a rod through an offset hole in a plug, so that the rod bending through the plug exerts a strong bearing force against the hole anchorage horizon. One of the main uses for this bolt would be to hold track in place on steep inclines. Split set bolts are another type of special design.

Grouted bolts are being used frequently for more effective anchorage in certain types of strata. These have been in use for a long time in anchoring bridge or dam abutments and stabilizing slopes with cement grout. These were adapted to provide extra strength to mine strata structures by injecting the cement with curing accelerators into the hole around the cable or bolts by pressure. Another application involves placing the cement in perforated cylindrical sleeves, installing the unit in the hole, and then pushing the steel bolt up through it under pressure to force the cement out through the perforations to fill the hole and, when set, provide strong anchorage. Most of the initial systems were too expensive, labour intensive and messy for regular mine strata support. Other problems included uncertainty of curing properly and setting too slow to take up an immediate load. Epoxy (which is strong but expensive) and polyester resin grouts were introduced into this type of service. The grouts and installing techniques have been refined and installation techniques have been improved to minimize problems and increase the advantages of the system. They can now provide strong anchorage support to soft laminated strata where other support methods are inadequate. The grouted bolts provide more bearing surface for anchorage strength, set fairly quickly and can be installed efficiently. Some pre-stress can be applied and they act as a substantial pin against offset strata loads.

ROOF BOLT INSTALLATION TECHNIQUE

The increase in mechanized mining has changed many of the characteristics of mine roof support. In the past with hand mining conditions, the miners had more intimate contact with the geological strengths and weaknesses of the strata and tried to use this knowledge to advantage with their strata support methods. With machine mining at present, the mining crew often attends strictly to mining while a roof bolting crew installs the supports later, and in both cases each crew uses equipment powerful enough to offset any variations in strata strength. This at times masks the usual warning signals of impending strata failure, such as noise, that miners formerly depended on for their own safety. The extra problems caused by modern mining methods should be minimized by improved strata support techniques.

Coal mine roof bolting techniques will be illustrated in the following discussion as the strata problems may be greater due to larger machinery, wider openings, and weaker strata than most other types of mining. Mine management and personnel should attempt to make use of all the available mining support experience gained from similar strata conditions augmented by close observation of the mines own geological anomalies as the development is extended. The most useful support techniques can be selected and then adapted if required to suit the strata encountered. Supervisors and workmen should be trained to recognize geological variations in the strata that will be troublesome. When separate crews are used for mining and support they should be trained in team work, so that each will minimize the others working problems. A prime requisite in this respect is neatness so that each crew does not hide strata problem areas or danger from the other and leaves the work place so that each can do their duties with minimum time lapse and labour.

With very good roof strata the mine management might tell the miners or support crew to install supports at random for weak strata when required. For less competent to weak strata mine management should design the strata support systems to be used with specific instructions on how to install the supports, in this case roof bolts. Usually a rider clause is added that extra support should be installed when considered necessary by the workmen. Mine management should emphasize in the instructions the details it considers important in the roof support installations. These should be periodically reviewed with the workers, utilizing their experience to ensure effectiveness. This would include special supports for more important openings such as junctions, equipment installation rooms, conveyors etc.

Mine management should select the type of roof bolts with lengths of rods that it thinks most suitable for its strata problems. To start, the choice could be made from a small variation of types that could be checked for strength relative to one another. This and succeeding installations would be carried on in conjunction with small scale test programs, part formal to provide strength numbers in relation to quality, part informal to provide experience in relation to roof support, installation ease, economy and suitability. It should be relatively straight-forward to select the best units for general support requirements and alternatives for strata trouble areas. This may at times lose priority to economics and ease of purchase. The selection process should also take into account auxiliary components such as cap pieces, collars, mesh, ropes, etc. or combined support systems: posts, sets, arches or anything that might be useful.

The following factors should be considered for improving roof bolting technique. Drill and bolting equipment should be carefully selected to suit mine conditions. Important points to consider are traction power, mobility, serviceability, drill power, height and span range, installation speed, operating ease and safety.

The hole should be drilled with ease to maintain tolerance and height requirements for the roof bolt.

The roof bolt should be inserted with a snug smooth fit. The expansion shell should be expanded to its optimum limit with no rotation of the shell to cause reaming and not over- or under-expanded to lose strength. This would also hold true with polyester resin grouted bolts. The optimum mixing and curing times should be measured and used. Refer to Figure 4.

The effective tightening torque should be accurately set on the drill to obtain the required anchorage strength of the roof bolts.

The working face should be supported progressively so operators work under a safe roof at all times. An installation pattern should be followed that matches the drill requirements to the mining geometry for installation speed, ease and safety.

It is an established principle that newly exposed mine roof should be supported as soon as possible to limit strata dilation. Mining and support crews should cooperate closely to minimize the time lapse between roof exposure and support and establish useful time limits. This might require the mining crew to erect temporary supports or possibly install the occasional roof bolt.

Useful installation technique adaptions, aides, and combination support methods should be established to suit conditions.

One type of support should not be allowed to offset the strength characteristics of the other. For example a wooden post installed too close to a roof bolt will if the floor heaves push up on the roof thus loosening the bolt.

If roof bolts are installed eccentrically due to sloping or a rough roof, washers can be used to offset stress concentration points found in the bolt usually at the junction of the nut or head.

The bolts should be installed with the correct torque selected to match the bolt characteristics and strata strength. This torque should be set on the installation tool and the operator trained to attain it. Too much torque places too much tension on the anchorage horizon and too much strain on the metal rod, both of which might result in movement to relieve the tension and weaken the anchorage. Too little torque does not place sufficient tension or compression on the strata between anchor and plate to restrain strata dilation or opening of joints. An inspector and the roof bolting crew should check roof bolts occasionally with a torque wrench to check the setting of the bolt, the drill adaptor and the amount of relaxation of the bolts with time.

The working crews should ensure that any loose roof material is scaled down. Then the bolting crew should ensure that the bolts were installed in the most suitable spots to bond slip, fracture or joint planes together to keep the roof from disintegrating. They should also ensure that odd strata sections were safely secured such as wedge sections or odd intrusions. Refer to Fig. 2.

The roof bolter should not leave any bolt improperly installed without rectifying the mistake. These are difficult to notice until a roof cave occurs.

Excessive heat caused by rotation of the tightening nut or head against the plate should be avoided, especially in a gassy coal mine.

The roof bolting and mining crews should try to recognize strata indicators on how the mining conditions would be affected. Roof spans too wide would probably approach failure by tension in the centre causing cracks and sagging. Narrow entries with narrow pillars might tend to fail by shear in the roof along the rib line. Wide pillars might transfer stress concentrations into the entry floor causing heave in the centre if the floor strata is weak or bumps along the rib line if the floor strata and coal are strong. Stress concentrations on strong friable coal might cause outbursts. In any event work crews should recognize the indicators or warning signals of increasing stress concentrations that would be of use to the support installation.

This would include recognizing and remedying dangerous situations along with the ability to repair or reinforce supports.

The mine and crew should ensure that the roof bolts are transported and handled carefully so that there will be minimum loss or damage and the work will not be impeded.

ROOF BOLT TEST PROGRAMS

Test programs should be conducted at intervals to ensure that the bolts are being installed properly, to help improve the procedure, to check and evaluate new roof bolt or support designs.

The first or general check should be a constant visual inspection or observation by the crew, fellow workers, and supervisory staff, who would make comments to the support crew concerned.

The second check should be carried out occasionally by an inspector or official. Random samples of bolts should be checked with a torque wrench to see if bolts have been installed properly and to determine whether they have relaxed their tension or taken on additional roof load. While this is being done it would be expected that the inspector would inspect the roof a little more closely for any visual evidence of strata failure. Tight bolts as well as good roof can at times be checked by sounding, if the checker can distinguish tones reasonably well.

The third program is a more formal test program that should be conducted periodically with engineering staff as well as the roof bolting crew. These tests should be done to provide numbers for comparative purposes and strength evaluation. New roof bolt designs, installation techniques, and equipment could be evaluated as well as support already in use. Time and economic comparisons could also be checked. These tests could be conducted as follows. Refer to Figs. 5 and 6.

Roof bolts with expansion type shells should be checked in the open to determine the optimum expansion, along with the amount of rod rotation needed to achieve it. If resin grouts are to be used, the mixing and curing times required for mine conditions should be measured. This data should be used for reference in relation to installation and test techniques.

The roof bolting equipment should be checked and evaluated as to working order. A test site with typical strata should be selected, preferably away from heavy traffic areas.

The first hole should be drilled to the proper height in the roof using the regular roof bolting procedure. The borehole should be measured up to the anchorage horizon using a borehole gauge to check that the proper diameter had been maintained. An alternate means of checking would be by the use of a slightly expanded roof bolt shell inserted up the hole. The allowable annulus or tolerance between hole and shell diameter should not be more than 6 mm for good bolting performance. If necessary the roof strata may be checked for quality by the drilling or coring.

The roof bolt should be inserted in the hole and installed. This should be done with minimum rotation of the shell, expanded quickly to the optimum and tightened to the designated torque. In doing this any outstanding details should be noted. The torque should be checked with a torque wrench and if necessary corrected.

The pull test equipment should be attached to the unit as shown in Fig. 5. The hydraulic hollow body ram should be attached to the bolt and tension applied in load increments as measured by the hydraulic gauge on the pump. The deformations caused by each load increment are measured by dial gauge on a spring rod mounted between stud and floor. The data is noted and evaluated as shown in Fig. 6. The test is cut off when a steady yield is indicated at a maximum applied load. Usually this is done within 10 to 20 mm of movement. The test is generally repeated to confirm the values and check against rapid failure at yield load. Occasionally the test should be conducted to failure so as to measure the upper limit and yield or stretch of the metal rod against the strength or slippage of the anchor. The limitations of each part of the roof bolt can be defined in this way. Tests to destruction should not be done often as they are hard on the equipment, the nerves of the operators, and actually not essential. The units will generally indicate their strengths before the destructive limit is reached. The data is recorded to be compared with other tests in the program, against units tested in past programs and saved for future comparisons. The results are evaluated for effective performance or where improvements may be made. The load limits can be checked against calculated strata loads to indicate the margin of safety. The tests in the program are conducted as often as necessary to confirm the original intention of the project. That is to show the units offer safe support, are better or not as good as others, to check or improve installation technique in terms of economy and ease of installation, etc. In fact all data deemed useful is noted along with improved techniques.

Simple formulae that may be of use to mine design calculations are given in Appendix A. Table 1 in Appendix B is a comparison of support costs in various mines. It is based on the most economical support method being equal to one. The mines are all in forested areas where the timber costs are relatively cheap. Those are all entry support costs and the comparison is not indicative of the coal recovery index.

Roof bolting is regarded as one of the more hazardous mine operations. Tables reflecting this are shown in Fig. 7 and Table 2. The installation procedure and tests should be conducted with the auxiliary aim of improving roof bolting procedures in relation to safety to lower the accident rating.

CONCLUSION

The support or control of mine strata must be a progressive component of the mining industry. Research should be continuous to ensure that satisfactory or improved safety limitations are maintained despite changes in mining methods or equipment. The support segment is a major priority in any mining cycle and should be improved in relation to safety effectiveness, speed and economy. At the present time roof bolting techniques are stressed whereas future improvements may be derived from more novel support methods.

ACKNOWLEDGEMENTS

Thanks are due to the mines, equipment dealers, the workmen and officials, plus the research staff that have participated in the strata support research program. Special thanks to A. Romaniuk for reviewing this paper.

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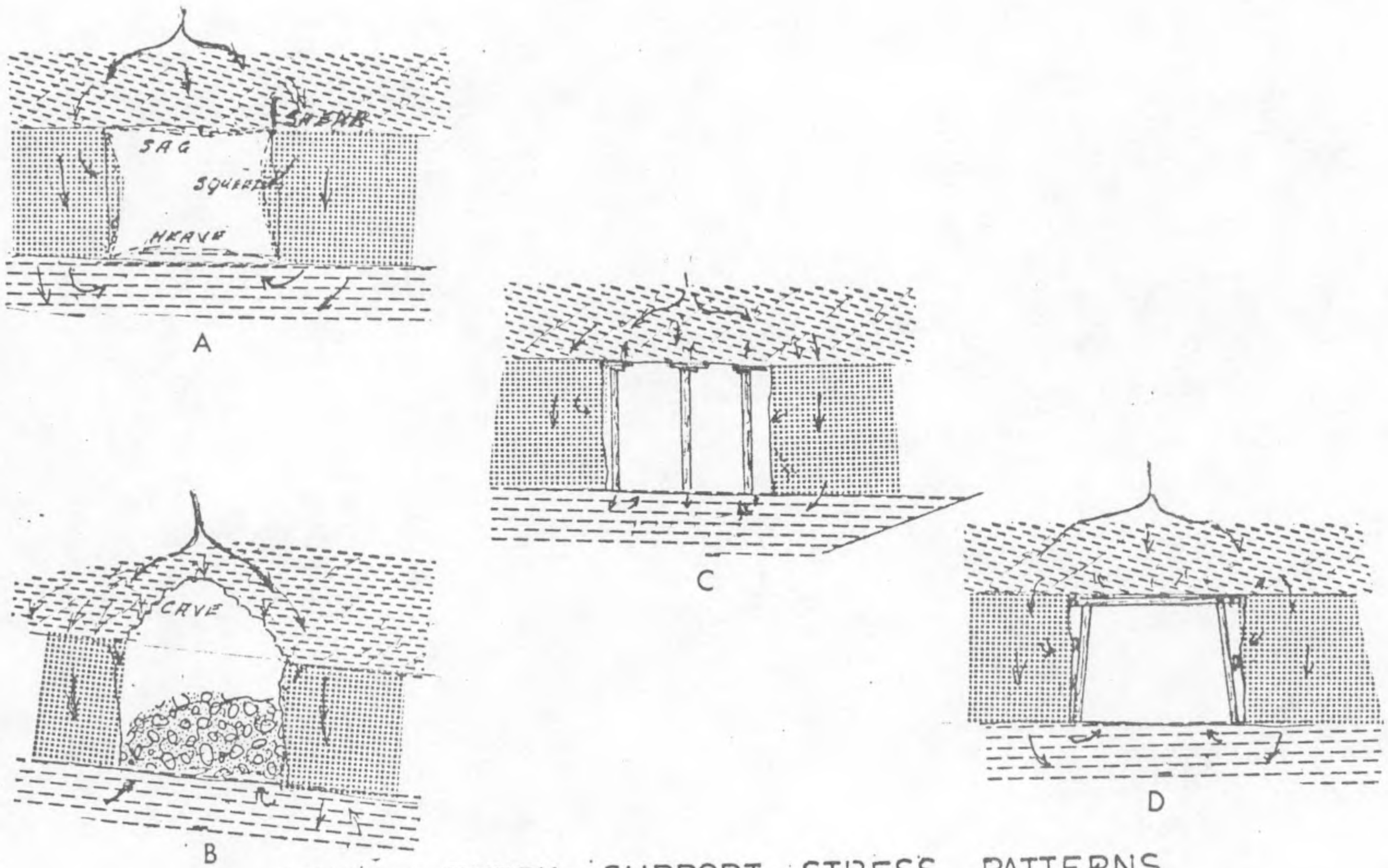
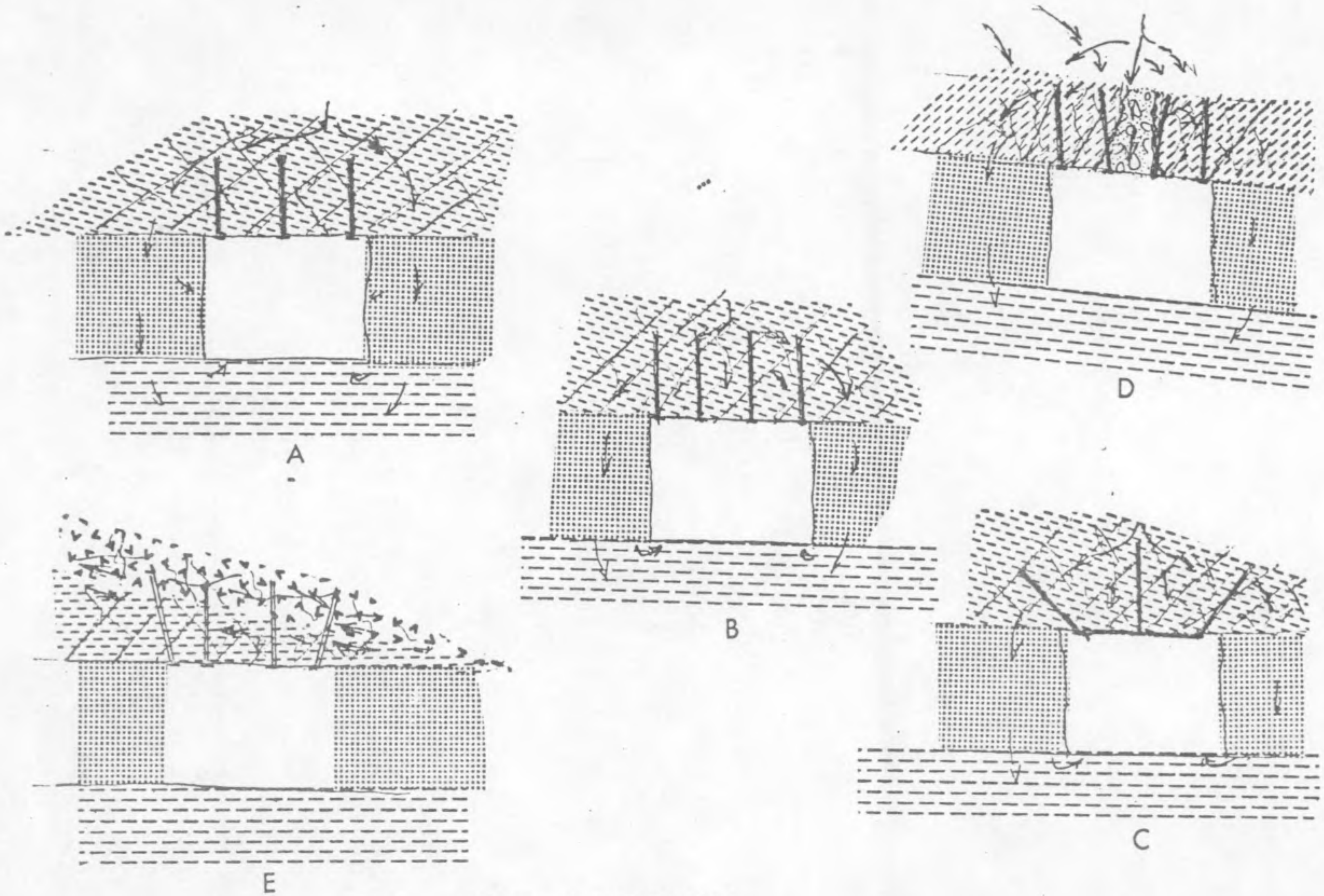


TIMBER ENTRY SUPPORT—STRESS PATTERNS
FIGURE 1



ROOF BOLT SUPPORT
FIGURE 2

EXAMPLES OF ROCK-BOLT EXPANSION SHELLS

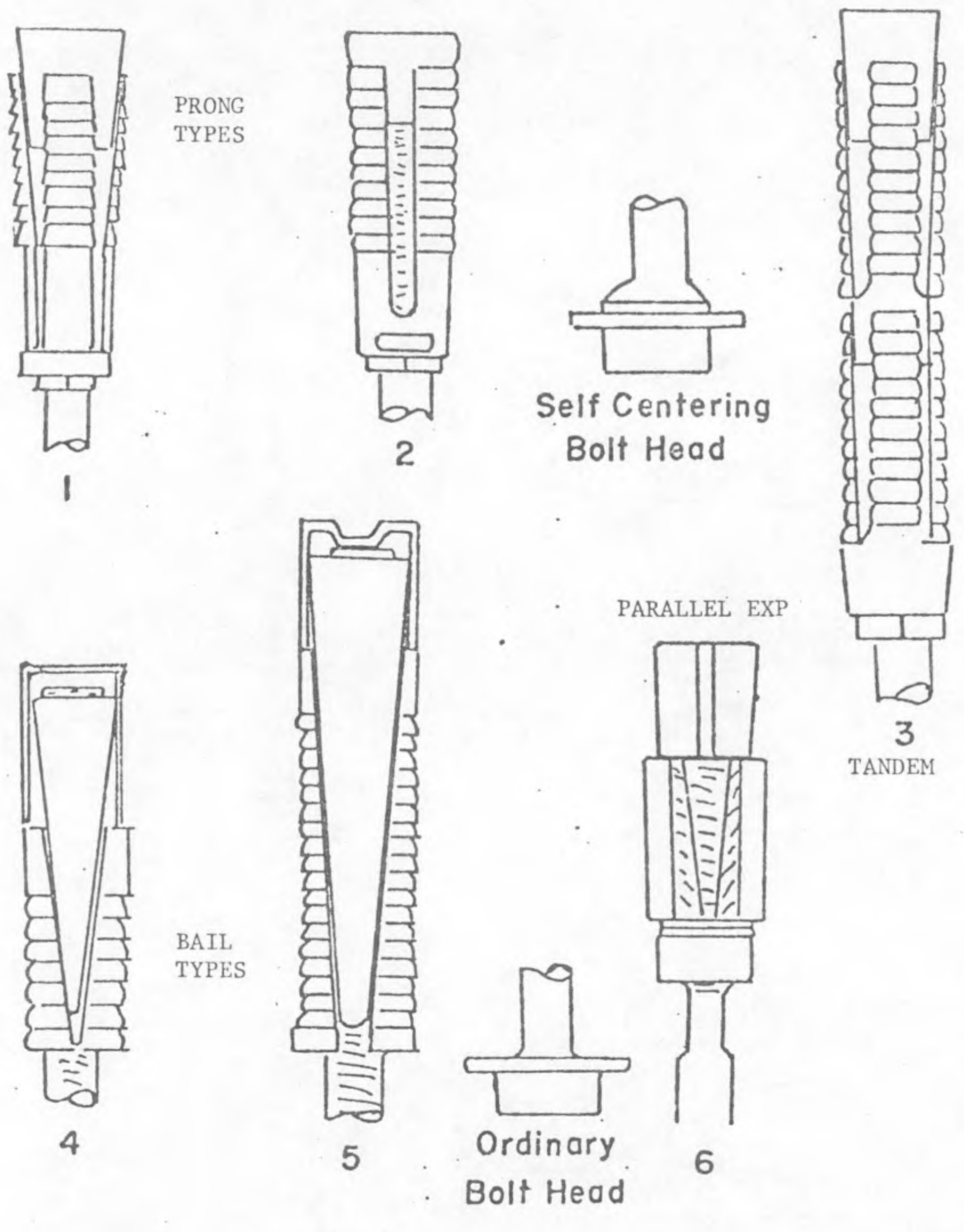


Figure 3

EXAMPLE OF ROOF-BOLT SHELL EXPANSION

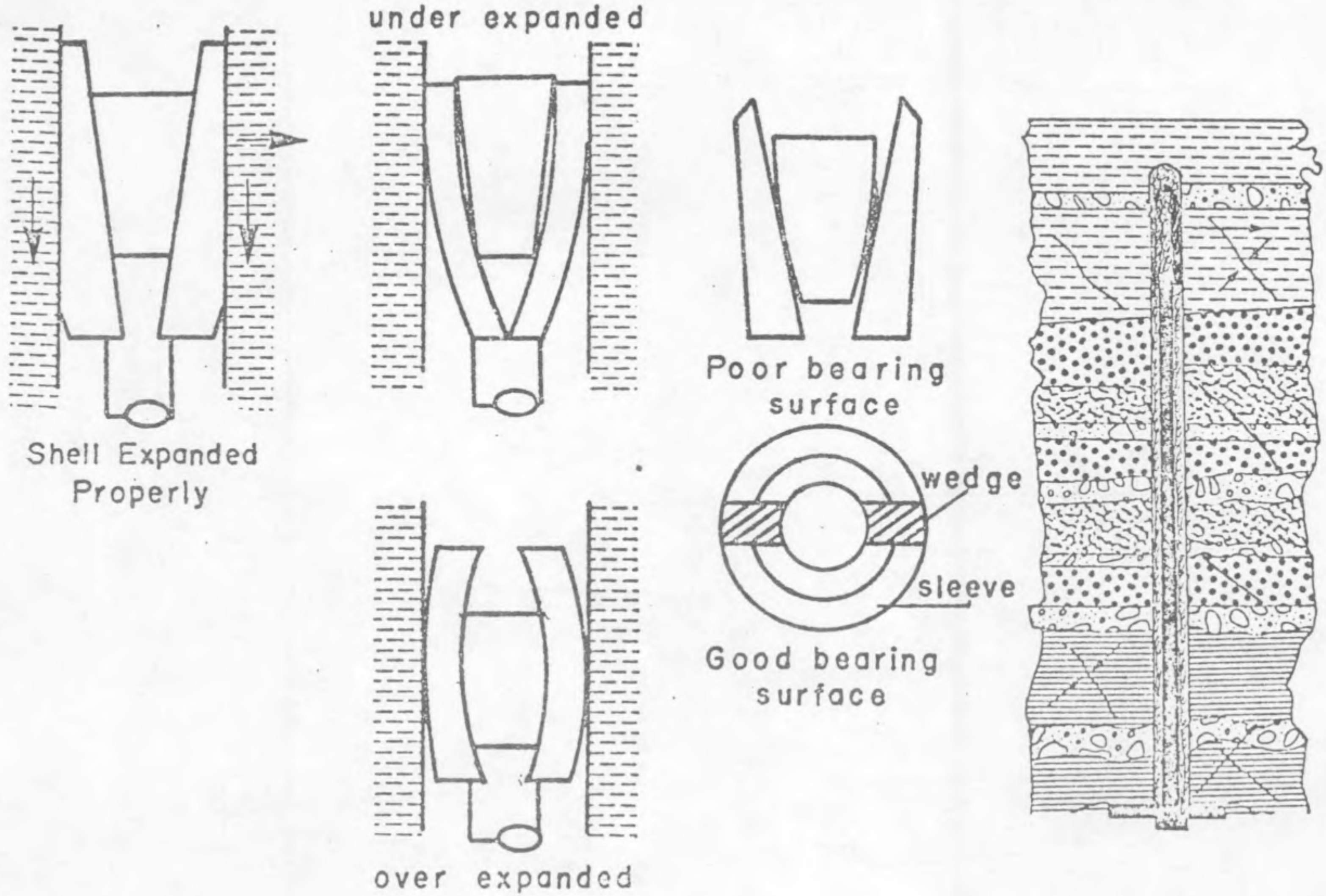
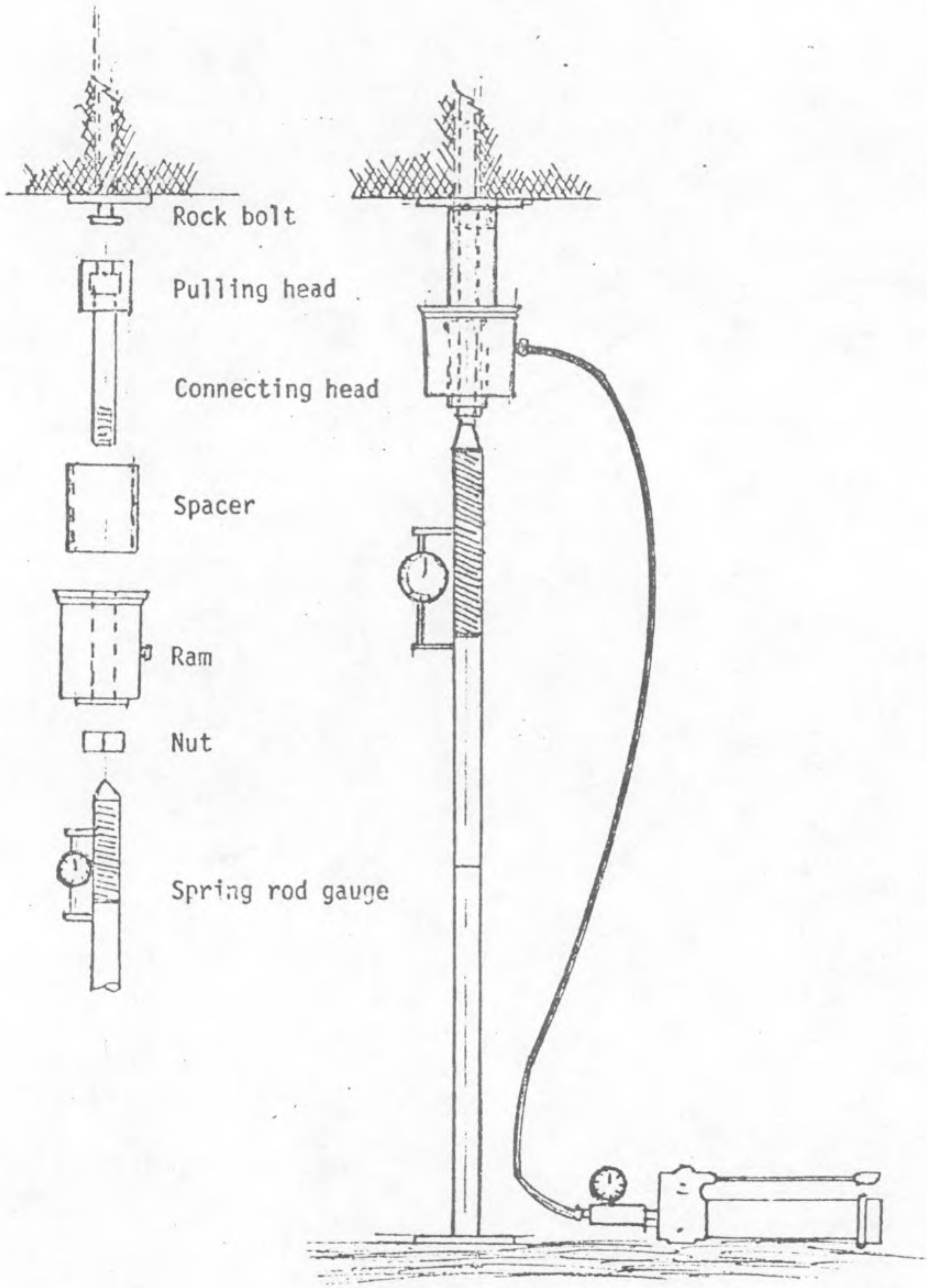


Figure 4



Roof-Bolt Testing Equipment

Figure 5

EXAMPLES OF ROOF BOLT TEST CURVES
SEDIMENTARY STRATA

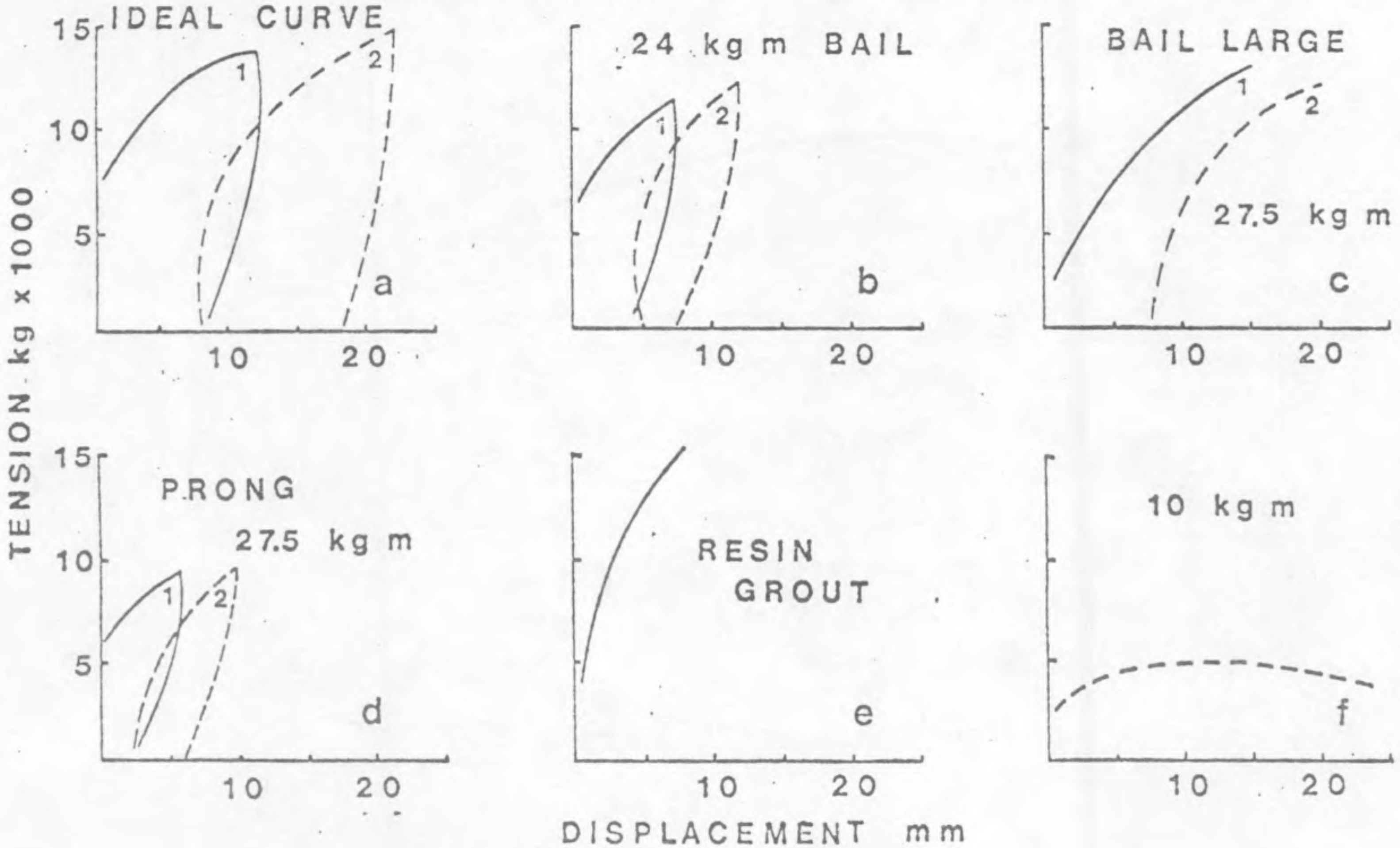


Figure 6

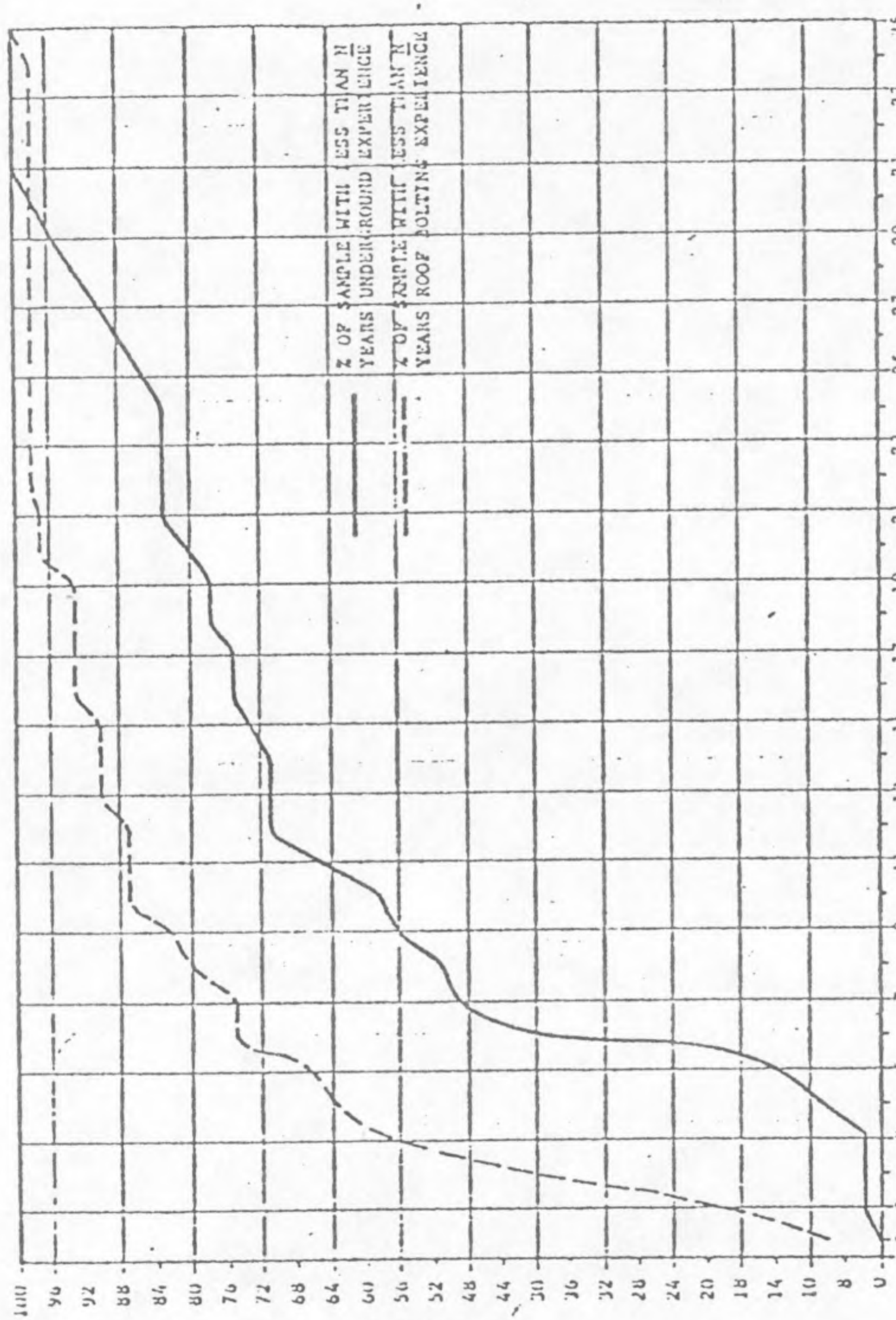


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Fig. 7 - Roof bolters percentage of sample with N years of experience

APPENDIX A - SIMPLE FORMULAE THAT MAY BE USED FOR MINE SUPPORT CALCULATIONS

PILLAR OR SOLID SUPPORT FORMULAE

(1) Unit Overburden Load = Density of Strata × Depth of Overburden

$S = dD$

(1a) $S = Sv \cos^2\alpha + Sh \sin^2\alpha$

(2) $Sp = \frac{dD}{1-R} = \frac{1.1D}{1-R}$

(2a) $Sp = Sv \cos^2\alpha + Sh \sin^2\alpha$

(3) $R = \frac{Ao}{Ao + Ap}$

(4) $Qu = \frac{Kw^a}{h^b}$

(4a) $Qu = \frac{Kw}{h^2}$ Simpler Formula - emphasizes importance of height of pillar to stability

Examples:

Coal: $Qu = 2500 \frac{w}{h^2}$

quartzite: $Qu = \frac{26000\ w^{0.5}}{h^{0.75}}$

(5) Stability Factor = $\frac{\text{Pillar Strength}}{\text{Pillar Stress}}$

(6) $Sf = \frac{Qu}{Sp} = 2500 \frac{w}{h^2} \times \frac{1-R}{1.1D}$

Example equations rate K factors at 10:1, relative to strength of Precambrian quartzite and Cretaceous coal

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S = Unit Stress of Overburden

d = Density of Strata = 1.1 psi

D = Depth of Overburden Feet

Sv = Vertical Stress = S on plains

Sh = Horizontal Stress ≈0 on plains but may be greater than Sv in Mts.

α = Dip of Seam Degrees

Sp = Pillar Stress

R = Extraction Ratio

Ao = Area of Opening

Ap = Area of Pillar

Qu = Pillar Strength

K = Constant Depends on Strength of Strata

w = Width of Pillar

h = Height of Pillar

a = Constant ≈0.5

b = Constant may vary from 0.5 to 2

Sf = Stability Factor should be greater than 1

Ax = Area Supported by Pillar

EMPIRICAL FORMULAE FOR PILLARS

(7) Average Pillar Load $Sp = \frac{dD}{144} \frac{Ax}{Ap}$

(8) Horizontal Mine Critical Width = 1.4D

(9) Maximum Pressure Arch Span $A_R = \frac{D}{20} + 20$

(10) Breadth or Width of Pillar = 1% Depth of Cover for Each 1 ft (0.3 m) of Seam Thickness

30 m pillar for 2 m seam 500 m deep

(11) Barrier Pillar = 20 + 4h + 0.1D

1 psi = 1 MPA/145 1 inch = 0.0254 metre

SPAN OF OPENINGS OR BEAM FORMULAE

The following equations are empirical and derived from beam formulae. The beam is assumed a simple width with the load uniformly distributed from the centre. The height of arch or total weight on the beam is taken as 1/3 the width of the span.

The deflection e is used as the basic component, as this deformation can be equated to the failure deflection of the strata which generally occurs in the centre line and may be measured. For competent shales the failure range is in the order of 5 to 25 mm of separation.

The physical strength characteristics of the strata involved in this type of formulae are difficult to measure accurately but may be approximated and rated roughly to similar strata and openings in other mine areas.

	Simple Beam Uniform Load	Fixed End Beam Uniform Load
(12)	$e = \frac{w\ell^4}{75EI}$	$e = \frac{W\ell^4}{384EI}$
(13)		$W = w\ell$
(14)		$I = \frac{1}{12} bd^3$
(15)	$e_x = 256 \times 10^6 \frac{^4}{d^3}$	

Approximate formulae for Cretaceous mountain shale failure deformation

Most equations taken from Engineering Handbooks

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e = Deflection in inch/inch at centre line of span. May be compared to deflection at failure range

= Length of span over opening, in fact, width of entry or room

E = Deformation modulus of strata $\approx 1 \times 10^6$ psi for average shales

I = Moment of inertia at base of rectangular beam

W = Total weight of arch of unit width with height limited to 1/3 of span

w = Density of rock ≈ 160 lbs/ft^3

d = Thickness of beam in feet. With roof bolt support may be taken as length of roof bolt (14) Approximation formula for average shale strata. The point to note which is valid is the direct exponential effect of increasing the span length on the risk of failure.

Rules of Thumb:

Single opening disturbs the stress field over a distance about twice the span of the opening.

Height of cave above a mined out seam should reach three times the height of seam for recompaction, in fairly brittle strata, e.g. 3 metre seam, 9 metres of cave.

APPENDIX B

Table 1 - Examples of mine roof support costs for various coal mines where roof support research has been conducted

Type Support	Costs			Comparative Rating
	$	Tons	$/Ton	
Ordinary Timber Set	25	22	1.15	1
Special Timber Set	37	22	1.65	1.45
Expansion Shell Roof Bolts	26	20	1.30	1.1
Resin Grouted Roof Bolts	35	22	1.60	1.4
Timber Sets	38.5	28	1.35	1
Roof Bolt Exp. Shells & Steel Plates	46	26	1.80	1.3
Steel Arches	380	31	12.33	9
Resin Grouted Roof Bolts Wood Collars	154	47	3.30	1
Steel Beams Wood Posts	263	47	5.60	1.7
(1) Wood Sets				1.0
(2) Expansion Shell Bolts				2.4
(3) Resin Grouted Roof Bolts				5.5
(4) Steel Beams Wood Posts				7.9
(5) Steel Arches				20
(6) Combination 4 & 3				13.5
(7) Combination 3 & 1				7.4

Rates are based on support costs per unit round of entry coal. Higher rates are usually due to weak roof or special circumstances. Some support types should be rated on extra coal to be extracted later. Rates to some extent depend on mine costs for material. Labour costs are included. Capital and service costs are not.

Comparative rating is based on lowest cost per mine entry equalling one.

Table 2 - Roof bolting injuries by activity as derived from a group of U.S.A. coal mines

ACTIVITY	FREQUENCY	PERCENT TO TOTAL
TRAM	175	9.67
PREP PLACE		
Timber	70	3.87
Temp Jack	35	1.93
Layout Bolt	7	.39
Scale	42	2.32
Makeup Bolt	25	1.38
Prep Place/Undetermined	69	3.81
TOTAL	248	13.70
POSITION BOLTER	52	2.87
SET BOOM, JACK AND SHIELD		
Position Boom	12	.66
Set Floor Jack	15	.83
Raise Roof Shield	12	.66
Undetermined	8	.44
TOTAL	47	2.59
START HOLE		
Drill Start Hole	331	18.29
Lower Drill Steel	12	.66
Remove Drill Steel	1	.06
TOTAL	344	19.01
FINISH DRILLING		
Add Drill Extension	28	1.55
Finish Hole	103	5.69
Lower Drill Head	37	2.04
Remove Steel	42	2.32
Drilling/Undetermined	63	3.48
TOTAL	273	15.08
RESIN BOLT		
Insert Cartridge	2	.11
Insert Bolt	8	.44
Resin Bolting/Undetermined	2	.11
TOTAL	12	.66
STANDARD BOLT		
Insert Bolt	54	2.98
Run Up Bolt	100	5.52
Lower Head	3	.17
Bolting/Undetermined	182	10.06
TOTAL	339	18.73

Table 2 (Cont)

ACTIVITY	FREQUENCY	PERCENT TO TOTAL
TORQUE BOLT		
Insert Wrench	15	.83
Torque Bolt	53	2.93
Lower Boom	10	.55
Lower Shield	2	.11
Torque Bolt/Undetermined	42	2.32
TOTAL	122	6.74
PICKUP/MOVEOUT	7	.39
MATERIAL HANDLING	151	8.34
MAINTENANCE	22	1.22
MISCELLANEOUS OTHER ACTIVITIES	18	1.00
TOTAL ACCIDENTS CODED BY ACTIVITY	1 310	100.00

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