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# USE OF RESINS IN MINE ROOF SUPPORT

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This report summarizes the work that has been done during the past several years in adapting resins for use as auxiliaries in mine roof support. The resins were applied in two ways: 1) by injection into the strata, and 2) as a bonding agent for roof bolts and reinforcing bar. The Explosives and Mining Chemicals Department of the American Cyanamid Co. has worked during this period in cooperation with the Roof Control Research Group of the U.S. Bureau of Mines, the Pattin Manufacturing Co., the J. H. Fletcher Co., the Homestake Mining Co., the U.S. Steel Corp., the National Mines Corp. and the Pocahontas Land Corp. in an effort to create resin formulations and methods for applying them as a practical and safe type of roof support for mining areas particularly where conventional support is inadequate, yet expensive.

This work has involved much pioneering in a field where theory, speculation, and pure mythology predominates, and little basic engineering data is available. It is strange but true that, despite the importance of roof control both from an operational and safety standpoint, there is scarcely a mining company in this country that has an engineer, or anyone, assigned to the study of roof support problems, except temporarily—*after* a bad roof fall.

The responsibility for improving roof control methods seems to have been placed entirely upon the shoulders of the USBM, various State departments of mines, and individual roof bolt manufacturing companies. It was in cooperation with the USBM that Cyanamid first developed resins for mining use.

## APPLICATION FOR RESINS IN MINING

A survey of a large number of metal and coal mines had indicated that conventional roof bolts are entirely adequate for controlling ground 90 to 95% of the time. However, there are difficult ground conditions that occur in almost every operation that cannot be controlled by rock bolts alone. It is here that resins, used in conjunction with roof bolts, have shown promise through making possible a different and more permanent type of bolt anchorage than can be obtained in any other way. The resin-roof bolt combination provides a new ground control device, the proper use of which can prevent much costly maintenance and repair work.

The following applications are typical of those occurring in metal mines in which resined bolts should prove most effective:

1) Ore passes, dump chutes, slusher drift intersections with feed raises (boxhole brows) where conventional bolt life is short.

2) Conventional drifts at depth (6600 ft) where unusually high rock wall stresses are encountered.

3) Air shafts as a possible alternate technique to gunniting.

4) Stopes where square setting is replaced with a cut-and-fill method.

5) Soft sandstones such as occur in the Grants area in New Mexico where good bolt anchorage is often a problem.

6) Setting equipment foundation bolts and anchor bolts and pins of several types.

It is also expected that resins can be utilized in coal mining. The principle applications here would be:

1) Mining areas where roof is composed of soft shales or mudstones.

2) Roof in which fault planes, slips, and stress cracks occur frequently.

3) Intersections where roof falls most often occur.

4) Main haulage ways and air ways where permanent bolt installations can be justified.

5) High walls and floors which undergo buckling and heaving.

Where excessive breaking and sloughing can be expected (e.g. in air shafts, deep drifts, stopes, fractured ground), it is recommended that expanded metal mesh or 9-gauge wire mesh be used in conjunction with the resined bolts. Fig. 1 illustrates standard types of bonded reinforcing bar installations that have been used successfully in several Canadian metal mines.

## RESIN INJECTION CONCEPT

In 1956, Maize and Wallace[1] of the Roof Control Group, USBM, Bruceton, Pa., discussed the idea of injecting chemicals into stratified roof in coal mines in an effort to produce a consolidated, laminated rock beam that would have sufficient strength to be self-supporting.

Laboratory tests indicated that slate or tile "sandwiches" glued together with certain resins form beams with 3 to 4 times the strength of the original unbonded material. Small scale underground tests in old roof were also encouraging.[2] It was hoped ultimately that the additional safety feature of being able to inject resin ahead of the working face to produce a consolidated roof *before exposure* could be realized. Cyanamid agreed to cooperate with the Bureau in investigating this concept, and during the years of 1957 to 1959, concentrated on the development of a special resin and equipment for its injection. Two major tests were carried out; one at the Renton mine at Renton, Pa., and one at U.S. Steel No. 14 mine at Gary, W. Va.

The results obtained from this work can be summarized briefly as follows. It was comparatively difficult to control the flow of resin in the roof. Resin alone gave less support than was desired in

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newly exposed roof where only a few, relatively fine cracks had developed. Cure time, especially in a wet cold roof, was slower than desirable. In these particular tests, no openings in the roof appeared to exist ahead of the working face into which resin could be injected, hence the safety feature of prestabilizing the roof could not be realized. At these two mines preliminary bolting was found to be necessary, requiring special sealed bolts to prevent resin leakage through the bolt holes. The special pumping equipment was too complicated for production operation, and the handling of bulk chemicals was time consuming and objectionable. Resin consumption was high, 5 to 40 gal per hole, thus making costs unattractive.

In the positive side, it was definitely established that resin could be injected properly through proportioning pumps into rock strata at pressures up to 3000 psig without inducing catastrophic hydrostatic rupture of the roof. Resin flow was observed at distances as great as 40 ft from the point of injection. Hair line cracks were completely filled in several instances. After 48 hours, the resin cured properly and gave good bonding. Subsequent failure in injected roof was never observed to occur along a bonded crack. Positive indications were obtained that resin, injected into roof which had undergone extensive stress relief and had developed many cracks, could consolidate and effectively strengthen a badly fractured roof. This has been confirmed in subsequent tests at two other locations, one a military installation.

## LIMITED INJECTION TECHNIQUE

It was apparent from these tests that to apply the resin injection technique at low cost, the quantity of resin used would have to be held to a minimum.

Tests of this nature were made at Homestake mine where pillar failures in stoping areas occur due to fracturing in metamorphosed wall rock when the adjacent ore is removed. In tests designed by R. Oitto of the USBM, Cyanamid resins in small quantities were injected into holes drilled perpendicular to the plane of the rock fractures. Before the resin was pumped, ⅞-in. reinforcing bars were placed in the holes. Installation was relatively simple and rapid. Resin cure was complete within 1 hour at the ambient temperature of 80°F, and total resin consumption was about 50 gal per pillar at a cost of approximately $200. After 3 years, the injected portions of pillar and drift walls are intact in contrast to the adjacent walls, supported by standard nonbonded roof bolts, where deterioration has continued.

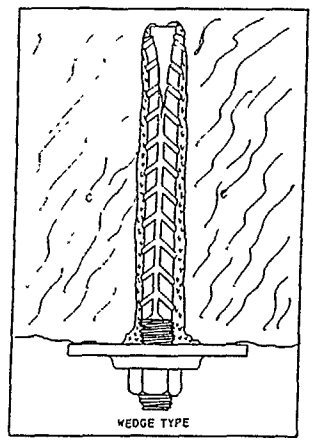
These tests have been most encouraging and have demonstrated that resin injection can be effective in special metal mining conditions where conventional bolting provides support for only relatively short periods of time. These tests will be described in detail in a future publication by the USBM.

## PATTIN RESIN PACKAGE

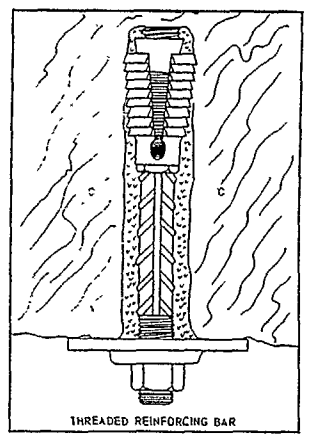
While working on resin injection methods, Cyanamid also undertook another cooperative investigation with the Pattin Manufacturing Co., the objective of which was to produce a resin package which could be used to cement expansion shells into place in roof bolt holes. The basic principle is to provide shell anchorage which is permanent (especially in soft ground) and not subject to deterioration due to shell slippage, corrosion or rock

*Fig. 1—Typical resin bonded re-bar applications.*

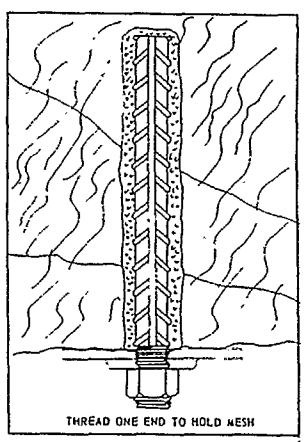
A—Wedge type, bonded full length permanently stressed is best suited for permanent anchorage of foundation bolts, especially for holes with diameters larger or smaller than those of commonly available expansion shells.




B—Re-bar threaded at both ends with expansion shell, bonded full length, permanently stressed is used where immediate roof support is required for safe working conditions, or where a prestressed bolt is needed. Typical applications are broken roof or pillars, or intersections in coal mines.

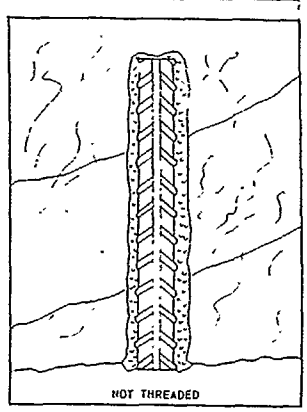



C—Re-bar threaded at one end with collar plate, bonded full length is useful in raises and shafts where protection of workmen is required during subsequent operations. Wire mesh can be hung on end of bolt, and nut tightened to full torque when resin has cured. Re-bar shown is straight, but a slight bend put into it during insertion will hold it in place while resin is setting.




D—Dowel pin, bonded full length is most useful in ore passes and chutes where continuously falling rock loosens a regular bolt almost immediately. The re-bar can be replaced with wire rope in some cases. Re-bar can be wedged into hole by bending slightly.

This technique is also excellent for anchoring crushers, slushers to concrete foundations.



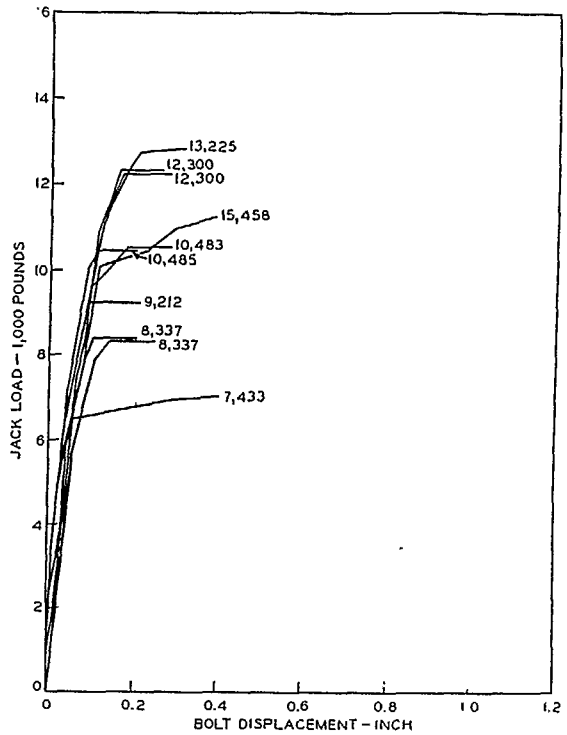



*Fig. 2—Pull test performance of ⅝-in bolt anchorage supplemented with ROC-LOC product. Compare with Figs. 3 and 4, all replicate tests.*

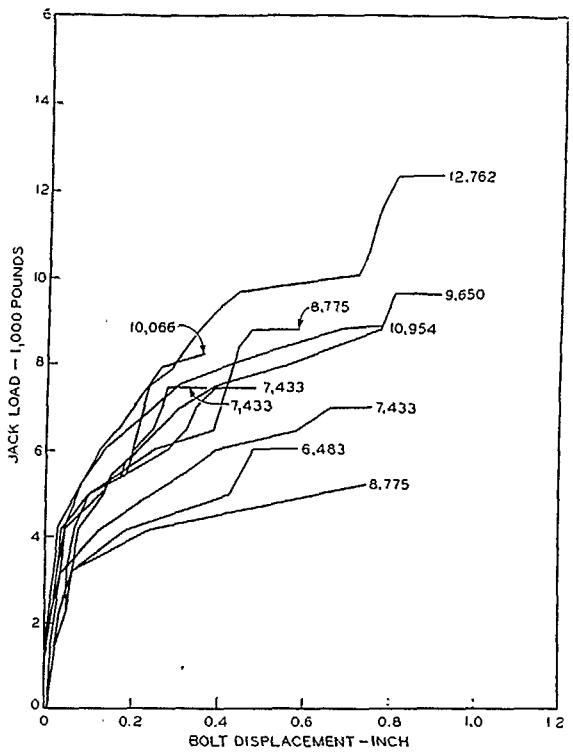



*Fig. 3—This pull-test data is also for a ⅝-in. bolt which is anchored with ⅜-in. expansion shell only.*

weathering effects. Details are given in U.S. Pat. Nos. 2,829,502 and 2,952,129 and in several foreign patents issued to J. B. Dempsey, president of Pattin Mfg. Co.

The Pattin package was a small dual compartment film pack containing about 3 oz of a new bonding material which is available under the trademark ROC-LOC. When installed, the separator between compartments is slipped off, and the two components are kneaded together for about 1 minute. The mixed package is then pushed into the top of the bolt hole. A standard roof bolt and shell assembly is next pushed vigorously up into the hole, smashing the package against the top of the hole and forcing the mixed paste to flow around the shell, thus completely encasing it. The shell is then tightened immediately in the usual manner. Depending upon rock temperature, the paste cures in 1 to 8 hr and is not adversely effected by moisture.

The anchorage performance characteristics of this type of bonded shell installation are shown in Fig. 2. Comparative data for standard unbonded shells and shells bonded in the same manner with a typical epoxy resin are shown in Fig. 3 and Fig. 4. These data are another contribution of the Roof Control Group of the USBM[3]. The roof tested is composed of a soft, wet, badly weathered shale at 57°F. All bolts were installed initially at a load value of approximately 5000 pounds. This load was selected to insure that anchorage capacity would not be exceeded, since preliminary testing in this particular roof area had disclosed that at higher loadings, a high percentage of "spinners" occurred (expansion shell rotated in hole, losing anchorage completely). Ten replicate ⅝-in. bolt installations were made for each type tested. Pull tests were made after one week.

In the writer's opinion, the curves indicate that both bonding materials are capable of greatly improving anchorage of an expansion shell, increasing the holding power in several instances by a factor greater than 100%. What is more important is that the anchorage capability has been increased from an unsatisfactory maximum of about 5000 lb to values greater than 8000 lb. Although the tests described here involve the use of only 3 oz of resin, the Pattin package is available in a range of sizes so that bolts can be grouted any desired distance, including full length.

## THE ROCK GRIP RESIN PACK

Recently, Cyanamid in cooperation with the Rockiron Co. of Sudbury, Ont., developed a unique and effective resin kit for completely cementing roof bolts.

The mechanical devices used in this kit for transferring resin into a bolt hole are simple and inexpensive, yet permit rapid installation of fluid resin with which roof bolts of any type can be used. This kit is sold exclusively by American Cyanamid Co. and is described below.

Favorable results with these kits containing both polyester and epoxy resins have been reported from several operations in Canada.

## THE GERMAN RESIN CARTRIDGE

During the past few years, the Germans have also been quite active in developing a polyester resin package for use with a special bolt for supporting soft ground in coal mines. These developments have been described by F. Schuermann.[4]

This is a glass capsule about 1 in. diam by 12 in. long containing a mixture of polyester and quartz sand and a thin glass catalyst container. The capsule

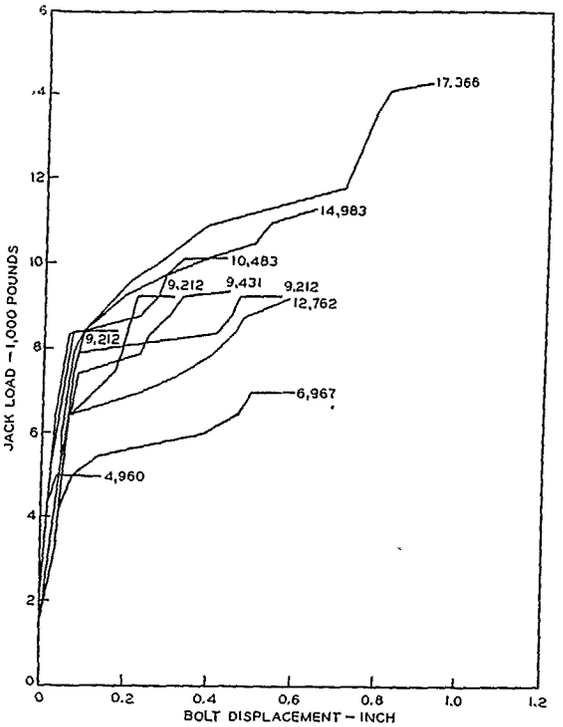



*Fig. 4—This test series is of ⅝-in. bolts using a typical epoxy resin to supplement anchorage. Tests made by U.S. Bureau of Mines.*

is placed in the top of the hole and completely smashed and mixed by rapidly rotating the bolt as it is inserted. The bolt can be tensioned after some 20 to 30 minutes. The degree of (purchase) amounts to 1.2 to 1.7 tons per cm of insertion length, this figure falling by amounts up to 50% in damp boreholes.

The special "bolt" required for use with this resin pack is a 1-in. rod threaded on both ends. The resined end has about 14 in. of thread and has no shell. The bottom end has about 4 in. of thread and a specially forged square end to permit attachment to a rapidly rotating driving machine. This bolt can be tightened only after the resin has set.

German coal mines are reportedly using about 5000 of these resin bolts per month, and major improvements in ground control have been reported as a result of their use. This is highly significant since ground support problems in German coal mines are usually more severe than those in most American mines.

## INORGANIC CEMENT-TYPE BOLTS

Perfo, Injekto, and Williams bolts are closely akin to resin-bolts in that they use inorganic cements to completely grout bolts, whereas the resins are synthetic organic chemicals. The cement-type bolts have proven effective in ground control on many locations all over the world. However, their effectiveness is limited to a large degree by the physical and chemical properties of the cement used, and the transfer of cement up a hole is inherently cumbersome and time consuming. While cement grouted bolts will probably always have a well-earned place in controlling difficult ground, it is expected that forthcoming work will demonstrate that resins are more universally applicable, especially as a production method in bad ground.

## ROC-LOC MINING KITS

Experience has indicated that no single type of resin kit would meet all needs, and that a variety of styles of resin kits should be made available. It was also Cyanamid's conclusion that a fully grouted bolt provided the best type of ground support. As a result, three types of ROC-LOC Mining Kits have been developed, a brief description of which follows:

**Plastic Bag or "Sausage Kit"** (ROC-LOC 20 Mining Kit). This is a two-compartment unit containing 20 cu. in. of bonding agent. A reinforcing rod rapidly rotated by an impact wrench is driven through the plastic bag. This completely shreds the package, thoroughly mixes the two components in the hole, and distributes the resin uniformly around the bolt.

**Single Hole Canned Kit** (Rock Grip type called ROC-LOC 60 Mining Kit). The two chemical ingredients, constituting a total volume of 60 cu. in., are mixed thoroughly in the larger container and then forced by hand pressure into a transfer tube. The transfer tube permits the simple placing of the thick ROC-LOC paste into the top of the bolt hole, thus eliminating the possibility of air entrapment. Any type of bolt, including those with expansion shells, can then be pushed up through the paste easily, causing it to extrude along whatever length of bolt is desired. The degree of coverage of the bolt will be determined by the amount of resin put into the hole. It is designed to provide sufficient material to completely bond a 6-ft. ⅞-in. diam reinforcing rod into a 1¼-in. drill hole. Total installation time required is 8 to 10 minutes.

**Multiple Hole Canned Kit** (ROC-LOC 540 Mining Kit). This kit contains 540 cu. in. of ROC-LOC ingredients in a 3-gal pail and is the most practical kit for filling a large number of bolt holes which can be drilled in advance of actual bolt placing. The mixed paste is sucked into the transfer tube by a simple plunger arrangement on the end of a small flexible plastic hose. The plunger can then be used to push the resin out of the transfer tube into the top of the bolt hole. This arrangement also permits the placing of any quantity of resin that is considered necessary. With a little experience, a two-man crew can completely install nine 6-ft bolts in about 20 minutes. This, of course, does not include drilling time.

## PHYSICAL AND CHEMICAL PROPERTIES

The mixed Cyanamid product is a nontoxic, thick paste which flows readily when stirred or pumped, but becomes essentially immobile when placed into an overhead hole. The mixture hardens in two stages: (1) the gel stage, in which it becomes a jelly-like plastic mass which is then no longer transferable or workable; and (2) the cure stage during which it gradually forms a hard resilient mass with the evolution of some heat. The times at which the gel stage and full cure occur are a function of the formulation used and the rock temperature, and both stages can be controlled over wide ranges. As normally supplied for metal mine usage, the gel time or pot life is about 30 minutes, and sufficient cure to attain the bonding strengths indicated occurs in 8 to 24 hours over the temperature range 40 to 70°F. The higher the rock temperature, the faster the cure. It is a simple matter to speed up cure times at low mine temperatures

Table I. Pull Tests Data for Bonded Re-bar Bolts in Hard Igneous Rock

| Temp. | 55°F | | 55°F | | 90°F | | 90°F | | 90°F | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cure Time | 2 Weeks | | 3 Weeks | | 1 Week | | 2 Weeks | | 2 Weeks | |
| Hole Condition | Wet | | Wet | | Wet | | Wet | | Wet | |
| ⅞" Re-bar Bolt Lengths | | | | | | | | | Re-bars hammered 5 min. prior to pulling | |
| 4" | 10.5T | Bond Slipped in hole | 10.5T | Bond Slipped in hole | | | | | | |
| 6" | 17.0T | Bolt Broke | 14.0T | Bond Slipped in hole | 11.0T | Bond Slipped in hole | 14.5T | Bolt Broke | 7.0T | Bond Slipped in hole |
| 8" | 15.0T | Bolt Broke | 15.0T | Bolt Broke | 9.0T | Bond Slipped in hole | 14.0T | Bolt Broke | 8.0T | Bond Slipped in hole |
| 10" | 12.0T | Bolt Broke | 16.0T | Bolt Broke | | | | | | |
| 12" | 15.0T | Bolt Broke | 16.0T | Bolt Broke | 12.0T | Bond Slipped in hole | 15.0T | Bolt Broke | 15.0T | Bolt Broke |
| 14" | 14.0T | Stripped Threads | 15.5T | Bolt Broke | | | | | | |
| 16" | 17.0T | Bolt Broke | 16.0T | Bolt Broke | | | | | | |
| 18" | 16.0T | Bolt Broke | 15.5T | Bolt Broke | 18.0T | Bolt Broke | 15.0T | Bolt Broke | 17.0T | Bolt Broke |
| 20" | 16.0T | Bolt Broke | 14.5T | Stripped Threads | | | | | | |
| 22" | 16.0T | Stripped Threads | 17.0T | Bolt Broke | | | | | | |
| 24" | 16.5T | Bolt Broke | 14.5T | Bolt Broke | 15.0T | Bolt Broke | 16.0T | Bolt Broke | 15.0T | Bolt Broke |

T = Short Tons.
NOTE: In tests where bonding agent slipped in hole, bolts were still able to support loads of 1 ton less than the loads producing slippage.

by adding an accelerating agent during the mixing operation.

This material has been especially developed for use under wet or dry conditions. The outstanding useful properties for mining application are the high tensile strength (2000 to 8000 psi) compressive strength (10,000 to 20,000 psi) and the excellent corrosion resistance.

## REINFORCING BAR ANCHORAGE CHARACTERISTICS

In granite, fully cured material provides load bearing strength of 15 tons per linear foot of bonded bolt length with a ⅞-in. re-bar in a 1.25 in. drill hole. In concrete, anchorage strength for the same bolt hole size combination is greater than 11 tons per linear foot. See Table I for typical pull test data.

An interesting observation made in collecting the data in Table I was that once the re-bar had slipped, the load could be reapplied, several times, and each time the original slippage loading would be reached before further movement occurred. Thus, with bonded re-bars, it may be possible to build a "shock absorber" effect into the roof so that instantaneous shock loads will not cause catastrophic failure as might occur with a standard bolt when the head is suddenly sheared off.

## THE CASE FOR RESINED BOLTS

These are the advantages to be gained from bolts completely grouted in place with resins or cements.

1) Within a relatively short time, good bolt anchorage is achieved regardless of how faulty the initial installation might have been.

2) There is no dependency upon sustained single point anchorage, which may be quite risky. The bolt is anchored along its entire length, giving adequate anchorage for bonding distances as short as 12 in. of bolt length.

3) There is no subsequent support failure due to accidental loss of anchorage at either the shell or the collar plate.

4) The use of grouts in conjunction with bolts provides the only method for preventing loss of bolt tension due to rock deterioration at the collar plates. This appears to be one of the major sources of difficulty.

5) The strata remain sealed off from the attack of air and atmospheric moisture to which many types of roof failure are attributed.

In addition to the above, special bolts totally cemented with resins can offer these additional features:

1) A wide variety of types of support are possible with the same equipment. (See Fig. 1).

2) The fast setting resins give quicker support than cement.

3) The resins are less cumbersome and less costly to install than cement.

4) Bolts can be installed tensioned or untensioned.

5) Resins are chemically inert, hence afford excellent corrosion protection from acid environments, especially sulfate waters which rapidly deteriorate concrete.

## COSTS OF RESINS

Obviously, the cost of a resin installation will be a function of the quantity of resin used, which in turn is established by the depth and diameter of the bolt hole, the size of bolt used, and the type of anchorage required. As an approximation, however, resin costs for a six foot hole using ⅞-in. re-bar would be $2.50 to $4.50 at the present time. When ease of installation, time of effectiveness, and the numerous advantages to be gained are taken into account, this cost is competitive with the cement grouted bolt. In fact, in many instances it is a relatively inexpensive permanent installation for which there is no good substitute at any price.

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