United States Patent [19]

Askey et al.

[11] **3,797,254**

[45] **Mar. 19, 1974**

[54] **CONSOLIDATION OF ROCK STRATA**

[75] Inventors: **Arthur Askey**, Doncaster; **John Michael Murphy**, Mansfield, both of England

[73] Assignee: **Explosives and Chemical Products Limited**, London, England

[22] Filed: **Feb. 28, 1972**

[21] Appl. No.: **229,844**

[30] **Foreign Application Priority Data**

Mar. 1, 1971 Great Britain 5729/71

[52] **U.S. Cl.** .... **61/45 B**, 85/62, 287/20.3

[51] **Int. Cl.** **E21d 21/00**

[58] **Field of Search** .... 61/45 B, 39, 35; 85/62; 287/20.3; 52/698, 704

[56] **References Cited**

UNITED STATES PATENTS

3,430,449	3/1969	Novotny et al.	61/45 B
2,682,152	6/1954	Bierer	61/45 B
2,492,164	12/1949	Lutts	85/62
2,879,686	3/1959	Lewis et al.	85/62
1,696,861	12/1928	Plimpton	287/20.3 X

FOREIGN PATENTS OR APPLICATIONS

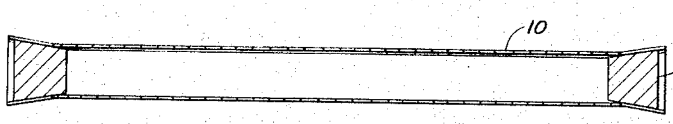
1,178,815	10/1964	Germany	61/45 B

Primary Examiner—Jacob Shapiro
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

The consolidation of friable rock strata found in, for example, underground roadways and tunnels encountered in mining and civil engineering is effected by the use of a hollow tubular reinforcing member having enlarged end portions in a borehole having a diameter which is at least 4 mm. greater than that of the unenlarged portion of the reinforcing member. It is possible to install such reinforcing members using relatively simple hand-held drilling machines, and to provide the reinforcing member with an inner calibrated rod capable of indicating an increase in stress within the tubular member.

10 Claims, 9 Drawing Figures



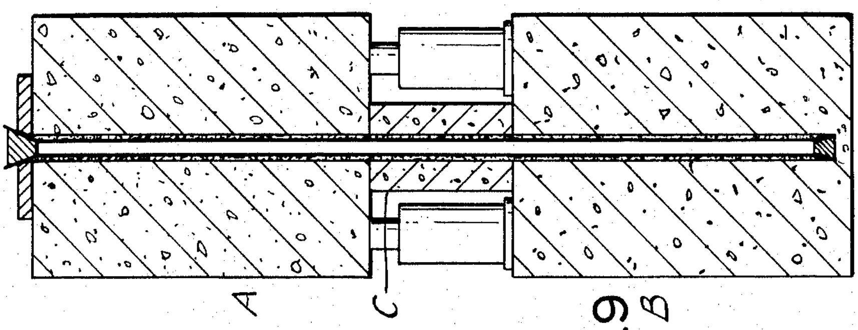


FIG.9

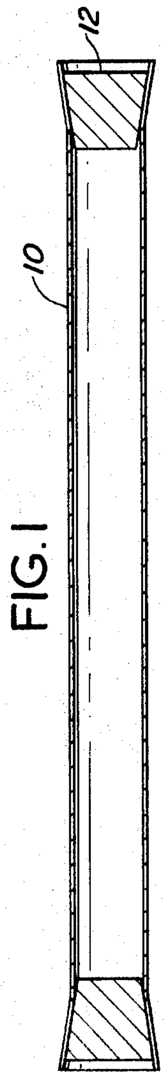


FIG.1

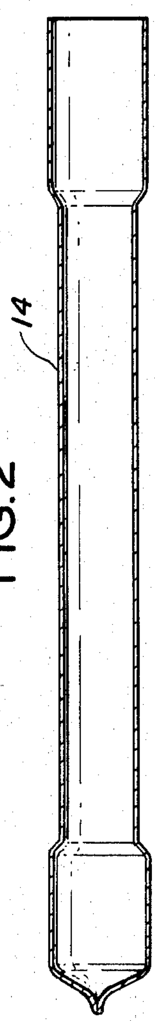


FIG.2

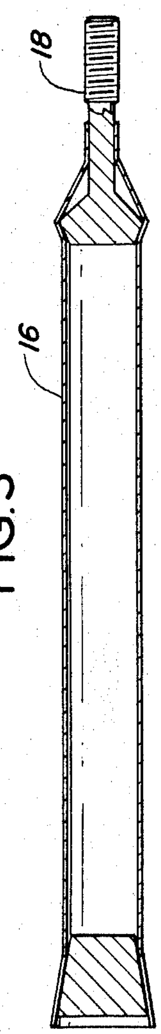


FIG.3

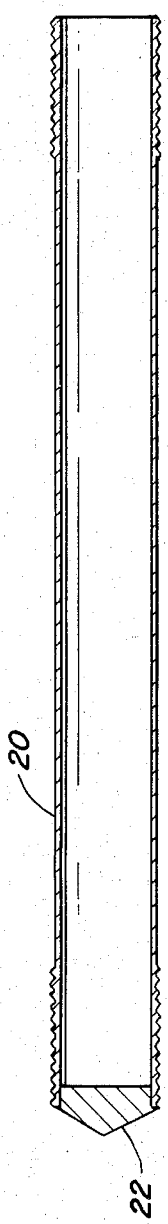


FIG.4

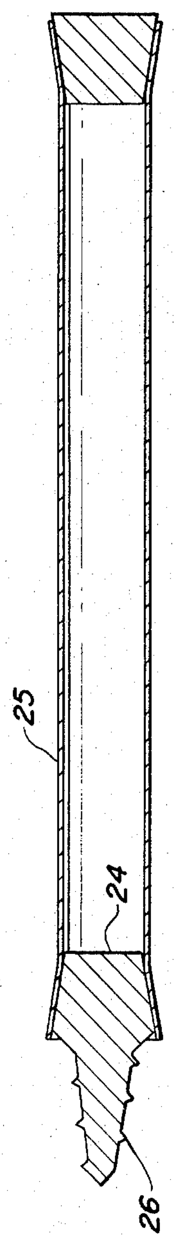


FIG.5

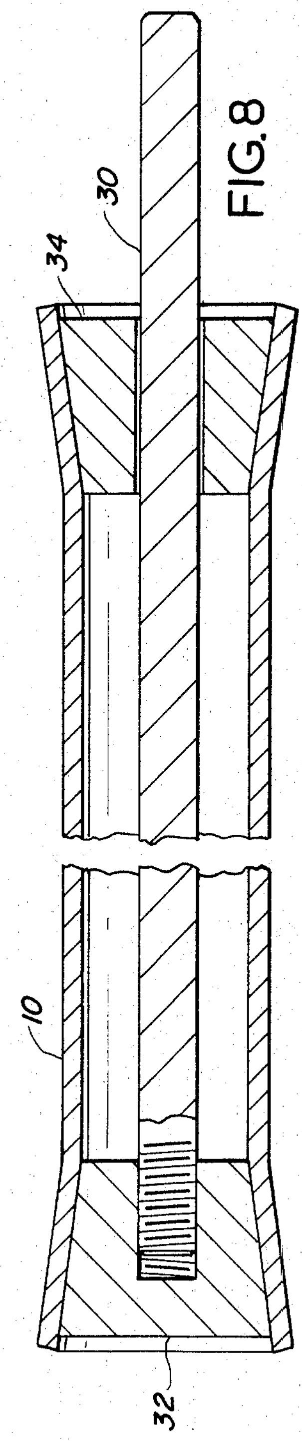


FIG.8

FIG.6

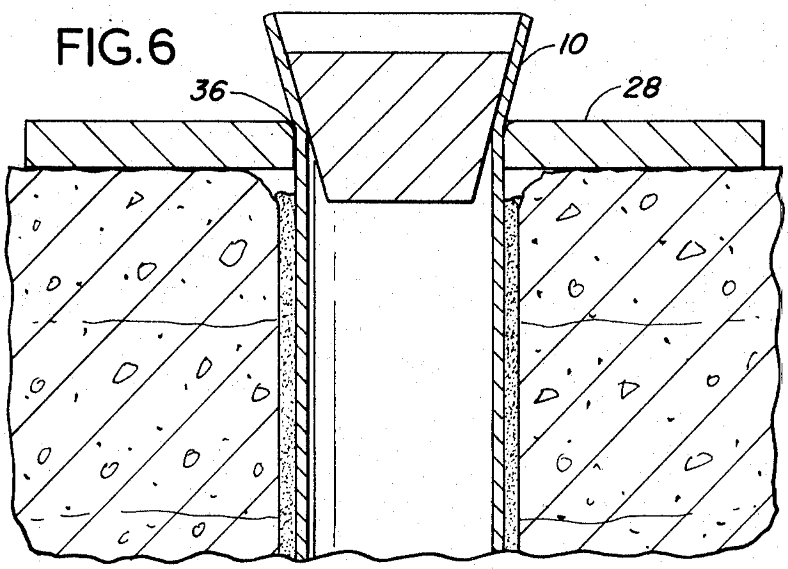
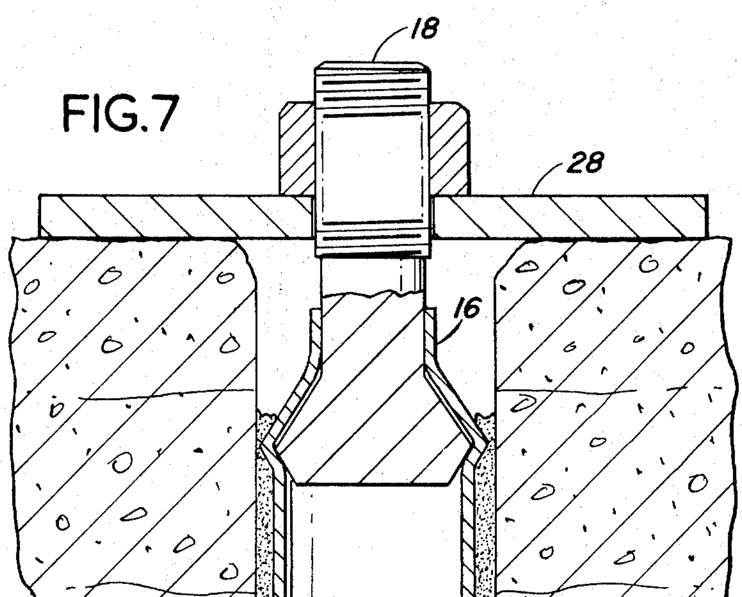


FIG.7



CONSOLIDATION OF ROCK STRATA

This invention relates to the consolidation of rock strata and is concerned with a method of consolidating rock strata, particularly but not exclusively underground rock strata of a friable condition such as those often found in underground roadways and tunnels encountered in mining and civil engineering, and with a reinforcing member suitable for use in said method.

It is known to lock together the roof strata in underground mines by means of tensioned roof bolts anchored in boreholes drilled therein either mechanically or by means of synthetic resin-based compositions, thereby obviating the necessity of using timber shoring to support the roofs of tunnels and roadways in underground mines. However the use of such roof bolts is not always satisfactory in friable rock as the wall of the borehole may not be sufficiently stable to enable the roof bolt to be adequately tensioned. In an effort to overcome this disadvantage, U.K. Specification No. 1,166,816 discloses the use of an untensioned smooth consolidating rod provided with an unsymmetrical tip in a borehole having an annular clearance of 1.5 mm. in conjunction with a cartridge containing in separate compartments respectively a polyester resin together with a filler and accelerator, and a hardener for the resin. The consolidating rod is formed from a tube filled with a stiffening material such as cement and has a conformation at its outward facing end such as to seal the end of the borehole. Such consolidating rods require a mechanically exerted pressure of the order of 900 kg. for insertion and therefore can only be installed with relatively sophisticated machines not conventionally available in most underground mines. Furthermore, such smooth consolidating rods can be withdrawn from the borehole at a load close to the yield point of the material used for the tube.

It is an object of the present invention to provide a method and means for consolidating underground rock strata which will make it possible to install a reinforcing member in a borehole drilled in friable rock using relatively simple hand-held drilling machines and to hinder the ease of withdrawal of the reinforcing member from the borehole.

It has been found that the foregoing object may be achieved by the use of a tubular reinforcing member having enlarged end portions in a borehole having a diameter such that there is an annular clearance between the wall of the borehole and the body portion of the reinforcing member of at least 2 mm., perferably from 3 to 5 mm., the reinforcing member being secured in the borehole, preferably over substantially its full length, by means of a polyester-based resin composition.

Advantageously in the case where one enlarged end portion of the hollow reinforcing member projects from the mouth of the borehole, a bearing plate is secured to said enlarged end portion so as to be in contact with the rock adjacent to the mouth of the borehole. For this purpose said enlarged end portion may be provided with means for securing a bearing plate to the end portion of the reinforcing member.

An unexpected advantage of the use of a tubular reinforcing member in accordance with the invention is that when a tensile stress is imposed on the tubular member, no significant movement occurs up to the yield point of the material from which the tubular member is made, normally a metal or alloy such as

steel, but beyond that point the material draws down uniformly over its whole length between the two enlarged end portions, in contrast to a solid rock bolt which is mechanically or resin anchored at only its inner end portion which on being tensioned beyond the yield point will normally neck down at one point and ultimately fail at this point with relatively small extension of the bolt. This surprising effect is of significant value in the use of the invention in supporting mine roofs, since the additional stretching of the reinforcing member can confer a valuable safety factor which is absent when conventional rock bolts are employed. For example, in a typically bolted roadway where there are employed fully resin bonded ribbed steel rock bolts having a length of 6 feet, a roof movement of only about 2 inches might indicate impending failure of the steel bolts, whereas when using a steel tubular reinforcing member in accordance with the invention, a movement of the order of 10 to 12 inches could be accommodated before the reinforcing members would become critically stressed. Thus in one embodiment of the invention the tubular reinforcing member is provided with a solid indicator rod extending lengthwise thereof and secured, when in use, to the inner end portion of the member, the rod projecting from the other end portion of the member so as to be capable of indicating any extension of the member when in use.

The reinforcing member of the invention, which will generally be formed from a metal or alloy, preferably steel, will advantageously be used in conjunction with a polyester-based resin composition preferably packaged in a multi-component single compartment cartridge such as that described in, for example, our earlier U.K. Specification No. 1,127,913 or the specification of our copending application Ser. No. 49606/70. However, if desired the tubular reinforcing member may be installed with other bonding materials, for example portland cement, gypsum or a resin reinforced hydraulic composition, which may be injected into the borehole in premixed form. When the reinforcing member is used in conjunction with a bonding material packaged in a cartridge, the member must be rotated during insertion in the borehole to ensure destruction of the cartridge casing and adequate mixing of the reactive contents thereof. However in view of the annular clearance employed in accordance with the method of the invention, such rotation may be effected with hand-held drilling machines at a relatively low mechanically exerted pressure of from 20 – 50 kg.

Various embodiments of the tubular reinforcing member of the invention are illustrated in the accompanying drawings.

In FIG. **1**, the reinforcing member **10** consists of a length of steel tube which is slotted at each end and then expanded by driving in a steel conical wedge **12.** This is advantageous in that in use the expansion of the outer end of the tube in this manner may be carried out at the same time as the fixing of a bearing plate.

In FIG. **2**, the reinforcing member consists of a steel tube **14** the ends of which have been expanded by hot working the metal on a suitable forming die.

In FIG. **3**, one end of a steel tube **16** has been expanded by hot working in a manner such as to provide a means of securing a captive threaded stud **18** to which in use a bearing plate can be secured. The other end of the tube may be expanded in the manner shown in FIG. **1.**

In FIG. 4, adequate expansion of the end portions of the tube **20** has been achieved by roll threading the tube for a short length at each end. In this manner it is possible to increase the diameter of the ends of the tube **20** by up to 2 mm. and this has proved to be quite adequate to achieve secure anchorage at the ends of the reinforcing member. One end of the tube **20** may be closed by a simple plug **22** of metal, wood or plastics material, sufficient merely to resist the pressure of inserting the tube through a resin cartridge.

FIG. **5** illustrates a further embodiment of the reinforcing member of the invention in which a conical wedge **24** at one end of the tube **25** is extended and fitted with a coarse thread **26.** In using this reinforcing member, a short length of thick walled plastic tubing is inserted in the borehole ahead of the resin cartridge(s) and the member is then inserted with rotation in the normal way. After mixing the contents of the cartridge(s), the threaded end of the bolt engages with the plastic sleeve thereby expanding it against the wall of the borehole and providing immediate support for the member before gelation of the resin has commenced. Such a supporting sleeve serves to retain the reinforcing member in the borehole and permits immediate removal of the drilling machine. A bearing plate may subsequently be attached by any of the means outlined below.

FIG. **6** illustrates how a bearing plate **28** can be used in conjunction with a tubular reinforcing member **10** such as the embodiment of FIG. **1**, whilst FIG. **7** illustrates the use of a bearing plate **28** in conjunction with a tubular reinforcing member **16** such as the embodiment of FIG. **3.**

In FIG. **8** there is illustrated a reinforcing member similar to that shown in FIG. **1** but having an axially extending rod **30** secured by a screwthread to a threaded socket in the conical wedge **32** at one end and projecting from the other end through an axial bore in the conical wedge **34** at that end, so as to provide an indication of an extension of the tubular member **10** when in use.

FIG. **9** illustrates an arrangement for testing the effectiveness of tubular reinforcing members in accordance with the invention.

The simplest method of fixing a bearing plate to the reinforcing member involves the use of the embodiment of FIG. **1**, which is expanded at its inner end before insertion in the borehole. A close fitting bearing plate **28** having a central aperture **36** is then placed over the protruding end of the tube **10** and a tapered conical wedge **12** is hammered or pushed with a hydraulic ram (not shown) into the open end of the tube to expand the end adjacent the aperture in the plate. FIG. **6** illustrates this method of fixing the bearing plate **28.**

An alternative method of attaching a bearing plate **28** consists in the use of a tubular reinforcing member **16** having a captive steel threaded stud **18** at its outer end as shown in FIG. **3.** In practice this reinforcing member **16** is inserted in the usual fashion and a standard roof-bolt bearing plate **28** subsequently applied to the protruding captive stud **18** and tensioned by conventional means, as illustrated in FIG. **7.**

In order to minimise the annular volume between a rock bolt or dowel and the borehole drilled to receive it, and hence to minimise the quantity of resin composition used, the tendency throughout the mining industry has been towards drilling boreholes of diameter only marginally oversized with respect to that of the reinforcing element. With relatively large diameter dowels this approach is quite satisfactory and it is now customary to use 30 mm. and 36 mm. diameter wood dowels in boreholes of 36 mm. and 43 mm. diameter, respectively. However, with relatively small diameter steel dowels, i.e. between 16 and 25 mm. diameter, which have quite adequate intrinsic strength for strata reinforcement, it has proved to be difficult to drill boreholes of small enough diameter. In certain hard rock conditions where sophisticated drilling machines of adequate power are available, 16 mm. rods have been successfully inserted in 22 mm. holes and in softer, dry shale conditions some success has been achieved with 20 mm. rods inserted in 28 mm. boreholes. Frequently, however, the ground which is required to be bolted contains water bearing layers and the drilling dust is thus wetted and readily clogs in small diameter boreholes. In practice, therefore, the difficulties of drilling boreholes of 28 mm. diameter and less in the conditions customarily encountered in the British coal mining industry have largely retarded the use of full resin bonded reinforcing dowels for permanent support work.

The benefits of being able to drill relatively large boreholes, i.e. of 36 to 43 mm. diameter, may be utilised in accordance with the present invention in conjunction with large steel reinforcing dowels of a tubular nature. Besides the ease of hole drilling another advantage of the invention lies in the fact that it enables a relatively large area for load distribution around each reinforcing member. With the fully resin bonded ribbed type of rock bolt, using a 28 mm. hole, there is a real danger that in lock of low compressive strength subjected to high pressures across the direction of bolting, the rock may be squeezed past the bolt. Using a larger diameter tubular reinforcing member in a borehole of 43 mm. diameter provides considerably more support in these conditions, since for a given ground pressure the compressive load against the rock in contact with the bonded member is only approximately 60 percent of that experienced with the 28 mm. rock bolt.

While it is of course possible to install a relatively small diameter reinforcing bolt in a large hole, the cost of such a system is high because of the large quantity of bonding cement required. The installed cost of the tubular reinforcing member systems of this invention may be comparable with that of solid bolts in small diameter boreholes.

Primarily, the tubular reinforcing members of the invention are of use for full or supplementary support in mine roadways. In this use, tubular members of adequate length, up to 4 metres, can be inserted into the strata surrounding the rock opening and spalling of the immediate surface rock minimised by attachment of suitable bearing plates to the exposed ends of the reinforcing members. In such use, it is important to monitor the movement of the supported strata beds so that adequate warning of impending failure of the supported structure can be given. For this purpose various devices have hitherto been used to measure bed separation in the roof of a mine roadway. Such devices measure only the movement of the ground and do not indicate the stress developing within the individual reinforcing members. The tubular reinforcing member of the invention offers the advantage of a means of measuring actual bolt stress by means of an inner calibrated rod located within the tube bolt **10** itself, as previously described with reference to FIG. **8.** In the case where severe stress is developing within the body of the member **10** causing extension of the reinforcing member, the exposed free end of the rod **30** will be observed to withdraw within the open end of the tubular member. Such a situation indicates that the tubular member **10** is already bearing stress in excess of its yield load and provides a valuable warning of serious movement within the supported roof structure.

The embodiment illustrated in FIG. **7**, in which a bearing plate **28** is attached to the tubular member **16** by means of a captive stud **18**, is of particular value in that it allows a high degree of flexibility in the use of the system, for example, it may not always be desirable or necessary to fully bond the tubular member over its whole length, so that in a 6 ft. borehole adequate performance may be achieved by bonding only the upper 4 ft. of the tubular member into the borehole. Making use of this method of plate fixing it is possible to vary the lengths of the tubular member **16** and solid captive stud **18** so that in the instance above, a 4 ft. tubular member could be fitted with a 2 ft. captive stud. Similarly, reinforcing systems designed for use in rippings or to counteract floor movement in mines, can be devised where the tubular member **16** is inserted deep into the rock and a removable extension piece attached to the captive stud **18.** Immediate support is therefore available when the tubular member **16** is installed and subsequent removal of the extension piece permits ripping or dinting of the floor and re-use of the reinforcing member by using an extension piece of a shorter length.

The use of the tubular reinforcing member is also of value when buried relatively deep into the strata. Thus in a situation where heavy load is encountered on a coal face, significant improvement may be achieved by installing tubular members deep into the strata ahead and above the coal seam. For example, a 12 ft. borehole may be bored at an angle through the coal and into the overlying rock and a 6 ft. tubular member then installed in the inner end of the borehole. The total length of the tubular member is kept well clear of the track of the coal cutting equipment but nevertheless provides valuable support to the ground before removal of the underlying support coal. In poor conditions it is possible to provide immediate reinforcement of the coal face itself by using the outer 6 ft. of the same borehole for the insertion of a wooden reinforcing dowel.

The invention is illustrated by the following examples.

EXAMPLE 1

Three concrete blocks were arranged as illustrated in FIG. **9** of the accompanying drawings. The blocks A and B were each 24 inches in length and 18 inches in diameter and the block C was 10 inches in length and 6 inches in diameter. Blocks A and B were heavily reinforced with steel mesh and cast from concrete of 5,000 lbs p.s.i. compressive strength. A centre hole 43 mm. in diameter was bored in the blocks as illustrated. Cartridges 40 mm. in diameter and having a total weight of 110 g., containing a reactive filled polyester resin grouting composition, were inserted into the hole, followed by a tubular member as illustrated in FIG. **1.** The bolt was rotated at a speed of 500 r.p.m. and thrust through the resin cartridges to release and mix the reactive contents. When the bolt was fully inserted into the hole the resin completely filled the annulus between the hole and the tubular member. A steel plate ⅝ inches thick was placed over the free end of the bolt and secured by insertion of a conically tapered steel wedge as shown in FIG. **6.** The resinous mass gelled within 5 minutes from insertion of the bolt and after 1 hour a load was applied with two hydraulic jacks in such a fashion as to force apart blocks A and B. A load applied in this way closely simulates the type of condition which could arise in underground rock formation due to separation of laminated strata beds. The load was increased to 10 tons without detectable movement of the fixing. On increasing the load a steady extension of the bar occurred as the two blocks were forced apart. The overall extension of the tube was recorded as 9.2 inches and necking and ultimate tensile failure finally occurred at a load of 16 tons.

Example 2

A tubular reinforcing member as illustrated in FIG. **4** was manufactured from mild steel welded tube, having an external diameter of 37 mm, and an internal diameter of 31.5 mm. A rolled thread was formed over a length of 150 mm. at either end of the tube so as to increase the diameter of 38.6 mm. The tube was closed with a pressed steel cap which was tack welded in place. The tube, of 1.8 m. overall length, was installed in a 43 mm. diameter borehole in the laminated shale roof of a mine roadway. Sufficient resin cartridges were inserted into the borehole before installation of the tube to ensure that the annular space between the tube and the hole would subsequently be filled with resinous composition. The borehole was drilled approximately 40 mm. shorter than the length of the tube so that a length of the tube remained protruding from the mouth of the hole after installation thereof. A steel plate, approximately 200 mm. square and 10 mm. thick, was centrally bored with a 39 mm. diameter hole so that it fitted smoothly over the protruding rolled thread end of the tube. The plate was secured in firm contact with the roof of the roadway by means of a tapered steel wedge, approximately 30 mm. in length having a minimum diameter of 30 mm. and maximum diameter of 37 mm. After sliding the plate over the protruding end of the tube the wedge was inserted within the end of the tube and forced home with a hydraulic ram providing a thrust of 1 ton, thereby expanding the tube end within the plate.

A pattern of reinforcing tubes was installed in this manner along a length of roadway to give a tubing density of one tube per square metre of exposed roof surface. The pattern was installed progressively along the roadway as soon as possible after exposure of fresh roof. A total length of roadway of 50 m. was reinforced in this way using a total of 250 tubular reinforcing members. The convergence of this supported roadway was measured in comparison with a similar length of the same roadway before and after the reinforced section. From the results it was evident that the support provided by the bonded tubular members had effectively limited convergence to only about one-tenth of that observed in the unreinforced portions of the roadway.

Example 3

Tubular reinforcing members of the type illustrated in FIG. 4 and described in Example 2 were installed into the overlying strata above a coal face to provide support prior to extraction of the coal. In the prevailing conditions of this particular coal face, the use of wood dowels alone had proved to be insufficient to restrain movement of the overlying strata and the wood dowels were observed to fail in shear. Angled holes 43 mm. in diameter were, therefore, drilled through the coal face up into the overlying shale to a total depth of 3.5 m. The tubular members were then installed with resin cartridges positioned in the inner end of these holes, adequate resin being used to fill the annular space between the tubular member and the hole. The tubular members were 1.7 m. in length and after installation the lower open end of the tube was closed by inserting a tapered hardwood plug. The remaining outer end of the borehole was then utilised for reinforcement by means of a 36 mm. diameter solid wood dowel, also resin bonded into position. In this way support was provided within the shale above the coal and also within the coal itself. A pattern of tubular members and dowels of this type was installed across the faulted area of the coal face at a spacing of approximately 0.5 m. between boreholes. The coal cutting machine was able to remove a strip of coal 600 mm. in depth in a single pass, cutting through the wooden dowels where these lay in its path. After one pass of the machine the process was repeated and a second pattern of angled holes were reinforced as described above. The process was repeated in this way after each pass of the machine until the ground conditions improved and the operation of the coal face equipment was thereby facilitated.

I claim:

1. A method of consolidating friable rock strata, characterized in that a tubular reinforcing member having preformed enlarged end portions is secured with a bonding material in an oversized borehole drilled in the friable rock strata with one enlarged end portion of said tubular member being positioned adjacent the inner end of said borehole and the other enlarged end portion being retained in a position adjacent the mouth of said borehole by means of a bearing plate, the diameter of the borehole being such that there is an annular clearance between the wall of the borehole and the body portion of the reinforcing member of at least 2 mm.

2. A method according to claim **1,** wherein the annular clearance is from 3 to 5 mm.

3. A method according to claim **1,** wherein said other enlarged end portion of the tubular reinforcing member projects from the mouth of the borehole when the tubular member has been positioned therein and said bearing plate is secured to said projecting end portion so as to be in contact with the rock adjacent to the mouth of the borehole.

4. A method according to claim **3,** wherein said projecting end portion is provided with means for securing the bearing plate in position.

5. A method according to claim **1,** wherein the tubular reinforcing member is formed from a metal or alloy.

6. A method according to claim **5,** wherein the tubular reinforcing member is formed from steel.

7. A method according to claim **1,** wherein the tubular reinforcing member is provided with a solid indicator rod extending lengthwise thereof, the rod being secured to the inner enlarged end portion of said tubular member and projecting from the other end portion of said member so as to be capable of indicating any longitudinal extension of the tubular member when in use.

8. A method according to claim **1,** wherein the tubular reinforcing member is secured in the borehole by means of a bonding material consisting of a polyester-based resin composition.

9. A method according to claim **8,** wherein said resin composition is contained in at least one multi-component single compartment cartridge which is inserted into the borehole prior to the insertion therein of the tubular reinforcing member, the latter being rotated during insertion so as to cause the contents of the cartridge to be released and mixed in situ.

10. A method according to claim **9,** wherein a sufficient number of cartridges is used to ensure that the annular space between the wall of the borehole and the tubular reinforcing member is substantially completely filled with the resin composition.

* * * * *