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TUNNELLING AND LIKE SUBTERRANEAN OPERATIONS

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2 Sheets-Sheet 1

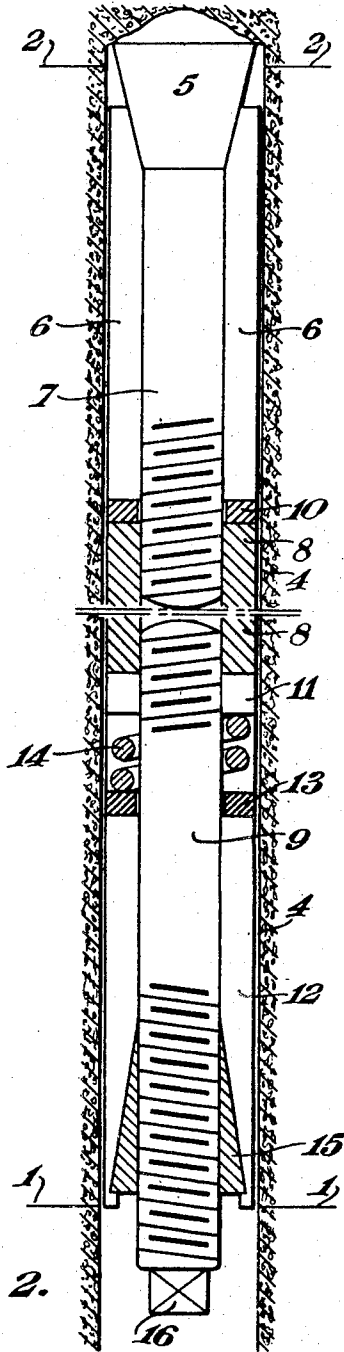


Fig. 2.

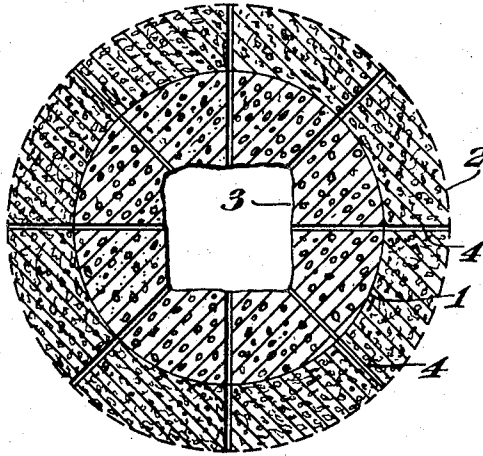


Fig. 1.

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2 Sheets-Sheet 2

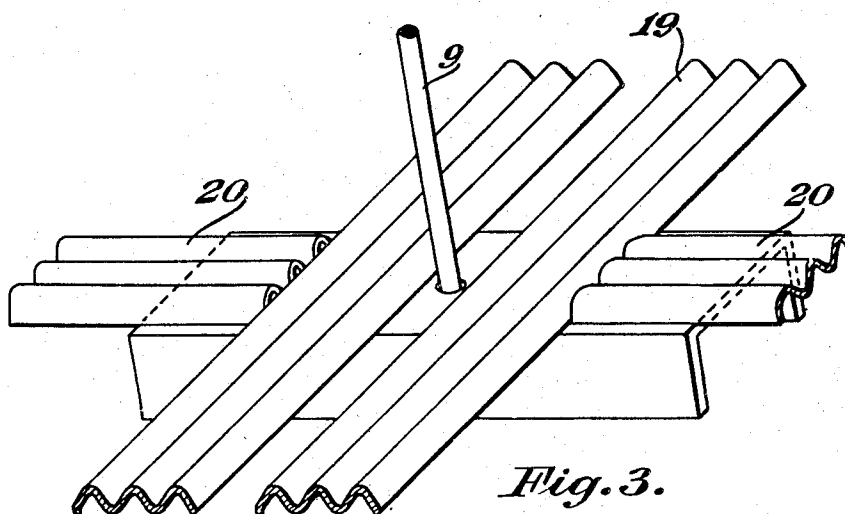


Fig. 3.

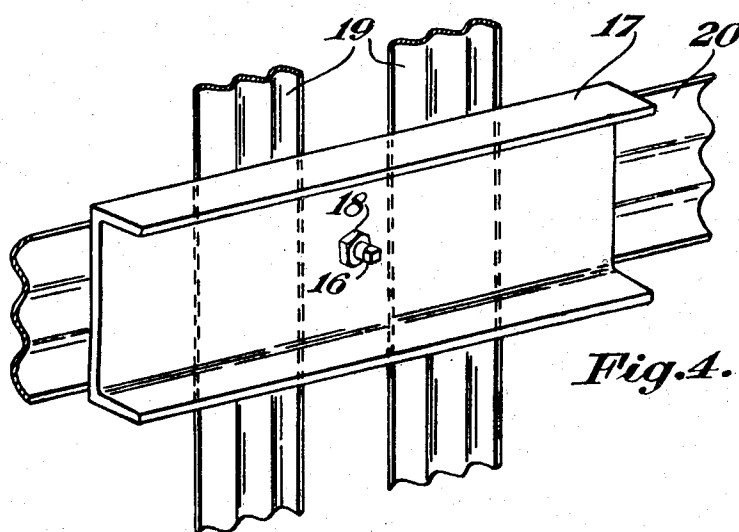


Fig. 4.

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TUNNELLING AND LIKE SUBTERRANEAN
OPERATIONS

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8 Claims. (Cl. 61-42)

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The invention relates to tunnelling and like subterranean operations, such as mining and quarrying. In these operations rock is removed from the earth's crust leaving cavities, and the surrounding rock is always subjected to stresses because the rocks were under strain prior to removal of the excavated portions. The strain was produced by various causes during or after solidification and petrification, but in the course of time some of the rocks may have obtained local strain relief. However, the extent and distribution of such relief is unknown. In any case the rocks are in a state of stable equilibrium, and that state is disturbed by the subterranean operation.

In arriving at a state of equilibrium the crust of the earth has stored an enormous amount of strain energy, also referred to as elastic energy or latent energy of deformation, but the strain is distributed very irregularly on account of various causes, such as hard inclusions or local relief by destructive tectonic forces. Another cause is the existence of planes of weakness, e. g., bedding planes in sedimentary rocks and of joint planes, which occur in parallel sets in the latter and also in igneous rocks. As soon as some rock is removed and a cavity is made, exposing free surfaces, the strain energy receives an opportunity to start work locally and endeavours to expand the rock towards the cavity, and thus to obtain its natural volume, a volume which it has never previously occupied.

Strain relief so started will propagate itself from the free surfaces of the cavity outwards into the virgin rock. There it first produces molecular displacements and then initial disintegration, finally resulting in complete loss of coherence. The virgin rock in its state of stable equilibrium is thus in a pre-stressed condition before the excavation, since the strain was in existence before the formation of the cavity provided the opportunity for the strain energy to start work. If, therefore, it is made possible by some means to stabilise elastic conditions and maintain the original state of stable equilibrium in the rock all around the cavity, the strain energy stored therein would be deprived of the opportunity of doing work and so causing harm. The invention is directed to the provision of such means.

It is known from experiments made by Prof. Adams and others on behalf of the Rockefeller Institution of Washington that the loading capacity of such rock in its pre-stressed condition is much greater than after it has obtained strain relief, that is in the condition in which it is used

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for instance in building construction. The loading capacity in pre-stressed condition may even be seven times that of the same material used as building stone, which of course occupies its natural volume.

Equilibrium in the crust of the earth means that, if an imaginary plane or other surface anywhere in the solid rock is considered, the forces acting on one side of that surface, of whatever kind, magnitude and direction they may be, are exactly balanced by equal and opposite forces acting on the other side of that surface. Thus on the production of some cavity the forces acting on one side of its surface are removed, and accordingly those on the other side are no longer counterbalanced by equal and opposite forces; the unbalanced forces (stresses) produced by the latent strain energy are released and commence work as mentioned above. The intensity of the effect produced is dependent on the quantity of strain energy stored up before the cavity is made and on the resilience or compressibility of the rock material.

The irregularity with which strain relief takes place on the formation of a cavity results in irregular breaking up of the strata. The breaking up starts at the exposed surface of the cavity and works gradually outwards into the rock. This may be expressed otherwise by saying that working in virgin rock disturbs the stable equilibrium existing locally, and the disturbance so commenced spreads outwards and will only stop where a state of unstable equilibrium can be restored.

For maintaining the solidity of the structure and so preventing the destructive effects of the release of the energy, it has been the practice to line any such cavity either permanently or temporarily according to the use to be made of the cavity. Such linings are frequently of concrete or masonry. To make room for the lining more material had to be excavated than was necessary to form the cavity.

Clearly the strain relief all around the cavity is not opposed at all by the lining and may continue outwards to an uncontrolled distance, whereas the main object of the lining is to resist the bulging inwards of the rock and to carry the load of the rock material broken up by strain relief. The lining is in fact always put in too late to act as preventive means, since strain relief commences as soon as the surface is exposed. This explains why so many cases occur of the crushing of linings, leading to continued repairs and expense.

The invention will be described in relation to tunnelling, which is to be taken as typical of other subterranean operations such as sinking shafts, making underground pump rooms, locomotive sheds and other large cavities in mining and quarrying.

According to the invention in making tunnels and like subterranean cavities a pilot tunnel is first driven of smaller cross-section than the final tunnel and at approximately the centre thereof, and at suitable intervals anchoring members or ties are inserted therefrom in a substantially radial direction to clamp a suitable thickness of rock, the ties engaging the rock by a wedging or like grip at both ends of the clamping portion thereof so as to maintain a reinforced envelope in which the elastic condition of the virgin rock is maintained.

The anchoring members or ties should be so arranged that the outer grip can be tightened up first and then the inner grip independently of each other; otherwise it may not be possible to ensure the firm grip at both ends which is necessary for tying the material of the reinforced envelope together.

The grips must be tightened after the insertion of the anchoring member or tie. It may be possible in some cases to insert the ties with the gripping members already in place, but frequently it will only be possible to insert the grip furthest from the working place with the anchoring member. This would then be opened to the gripping position and thereafter the other gripping member would be inserted and expanded ready for tightening the whole anchoring member.

The invention is further explained and illustrated by means of the accompanying drawings, in which

Figure 1 is a cross-section of a tunnel during construction,

Figure 2 shows a reinforcing bolt in place, and

Figures 3 and 4 are perspective views of a reinforcement for the tunnel surface which can be used with the bolts of Figure 2.

Referring first to Figure 1, the circle 1 represents what is ultimately to be the bore of the finished tunnel (in the particular example a circular bore), and the space between that circle and the circle 2 represents the material of the enveloping zone which is maintained by means of the invention in its pre-stressed condition to ensure the permanency of the tunnel.

The first step in making the tunnel is to drive a pilot tunnel, heading or drift 3 spaced away from the ultimate bore 1 on all sides. From the heading 3 holes 4, 4 are drilled in a more or less radial direction as far as the surface represented by the circle 2. Reinforcing bolts are placed in the holes 4, 4 and are tightened up to hold the rock between the circles 1 and 2 in compression. This is effected before deterioration by strain relief commenced at the surface of the heading 3 has had time to reach the surface 1. Thereby the annular zone between the ends 1 and 2 is maintained in its original state of strain. After the bolts have been placed and well tightened the remaining rock inside the circle 1 can be removed without the risk of strain relief in the reinforced shell, which thus forms in effect a lining for the tunnel. The protection so afforded makes it possible to dispense with the temporary wooden supports usually required in tunnel construction. The spacing of the reinforcing bolts around the periphery of the tunnel and along its length will

depend on the nature of rock in which the tunnel is to be made.

Figure 2 shows a form of bolt suitable for carrying out the reinforcement described above. In essence it is a combination of two forms of anchor bolt disclosed in British patent specification No. 444,623. The hole 4 is shown on a larger scale than in Figure 1, but it will be noted that between the portions shown of the circles 1 and 2 a cut has been made in the figure, and that the pilot tunnel outline 3 is off the lower end of the figure.

The outer end of the bolt has a tapered head 5 with an expansible shield 6 of four segments united by a flexible joint at the bottom for gripping the inside of the hole 4. Below the head 5 (as viewed in Figure 2) the bolt is in three parts, a solid part 7 on which the head 5 is formed, a tubular part 8 of the same cross-sectional area as the part 7, and another solid part 9, the parts 7, 8 and 9 being united by right-handed screw threads. A washer 10 is interposed between the top end of the tubular part 8 and the bottom end of the shield 6.

The lower end of the tubular part 8 has a slot 11 cut across it to engage a key resembling a screwdriver, as will be described later. An expansible shield 12 similar to the shield 6 surrounds the part 9 of the bolt, and its upper end is spaced away from the lower end of the bolt part 8 by a washer 13 and spring 14. A conical nut 15 is placed on the lower end of the bolt part 9 by a left-handed thread, having the function of expanding the shield 12. The segments of the shield 12 are of course pivoted at their top end. The part 9 terminates in a square head 16 of such a size as to permit the nut 15 to pass over it.

In putting a bolt into place after the drilling of a hole 4, the part 9 is removed and the parts 7 and 8 are assembled with the washer 10 and the shield 6, the latter being held in place by some temporary means such as a light spring wire ring surrounding them. This assembly is placed in the hole 4 and is pushed to the end of the hole by any suitable means. A key having an end like a screwdriver is inserted to engage the slot 11, and this tool may be the one used to push the assembly into the hole.

The key is turned to screw the part 8 on to the part 7 and through the medium of the washer 10 to press the shield 6 up the slope of the head 5, thereby expanding the shield 6 to grip the walls of the hole 4 as tightly as may be desired. There is sufficient friction between the end of the head 5 and the end of the hole 4 under the pressure of the key to prevent the part 7 from turning with the part 8, and the friction may if necessary be increased by roughnesses or projections on the end of the head 5. Of course, the part 7 is held with increasing force against rotation when the shields 6 commence to grip.

The part 9 has the nut 15 screwed on to it and the shield 12, washer 13 and spring 14 assembled on it and held or located by any suitable temporary means. The assembly is inserted in the hole 4 followed by a key with an end in the form of a box spanner to fit the square end 16. The key is turned to tighten up the whole as will now be explained.

The first effect of turning the key is to commence screwing the part 9 into the part 8. The spring 14 is compressed a little and very soon presses the shield 12 into contact with the walls of the hole 4 due to the conical nut 15. Thereby the nut 15 is held from rotation and is moved in-

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wards by the further rotation of the part 9, since the nut has a left-handed thread. At the same time the part 9 is screwed further into the part 8, and the part 8 may by the same action be screwed further on to the part 7 if it was not previously tightened to the full extent. Thus the operation of screwing the key tightens the grips at both ends, unless, of course, the inner grip has already been fully tightened, and at the same time applies tension between the grips to clamp together the layer of rock between the surfaces 1 and 2.

It may sometimes be necessary to prevent local strain relief in the protective shell of rock due to expansion into the holes 4. For this purpose each hole may be lined between the surfaces 1 and 2 with a thick-walled steel tube, or the reinforcing bolts may be grouted in with cement to fill the voids.

Once the bolts are in place in a sufficient number of holes 4, the rock inside the surface 1 can be removed. The strain relief commencing at the surface 3 will have extended into the surrounding rock, but in all conditions likely to be met with it will not have reached the surface 1 before the reinforcing bolts are in place at the section considered. The reinforced rock may in some cases be strong enough to act by itself as a lining for the tunnel. In other cases some form of lining may be required.

If for any reason a complete covering of the rock is desired or necessary, a lining of masonry, concrete or metal may be applied in the known manner, but the lining in this case is merely a protection and not a support as in the known manner of tunnel construction. It will thus be unnecessary to remove so much rock around the lining as is required in present practice.

Sometimes a partial lining may be suitable, and for this purpose a suggested form is shown in Figures 3 and 4. A piece of channel iron 17 acts as a washer and is held on the end of the bolt 9 by a nut 18, the bolt 9 being suitably extended for this purpose. Corrugated strips of steel 19 are held by the channel 17 against the rock face and extend longitudinally from one hole 4 to the next or to a multiple of that distance, one strip 19 being placed on each side of the bolt 9. Other corrugated strips of steel 20 extend in the peripheral direction of the tunnel from one channel 17, to the next, being supported on the ends of the channel 17 projecting beyond the strips 19.

However the interior of the tunnel or other structure is finished, some consideration must be given to the question of infiltration of water. The protective shell of rock reinforced by clamping may in some cases be of such a nature as to prevent the infiltration of subterranean water. Where the seepage is not entirely prevented but only reduced, the water may be controlled by means of a drainage system extending through the shell.

If the ground around the cavity to be made contains voids, fractures or other sources of weakness, it may be desirable to endow the material of the reinforced zone with greater coherence by means of some binding material such as cement. In the event of salt or acid water being expected around the cavity, some steps should be taken to check the deleterious effect. The tubular part 8 of the reinforcing bolt may be provided with small holes regularly distributed over its length. The cement or other protective substance can then be introduced under pressure into the tubular part 8 before the bolt part 9 with

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its shield 12 is inserted. The cement or other substance will then emerge from the holes and fill up the clearance space around the bolt in the hole 4 as well as any voids or cracks around the hole. It is advantageous to use expanding cement for this purpose, since the pressure produced thereby on setting assists the maintenance of compression in the rock.

The description given above to illustrate the use of the invention showed a circular cross-section for the reinforced rock, and it is evident that such a section is the most appropriate for the purpose envisaged. Within the ring of reinforced rock a cavity of any form can be made, such as a horse-shoe shaped tunnel, an inclined shaft of rectangular cross-section, a subterranean pumping room, or a depot for mine locomotives. Nevertheless the reinforced rock may itself be of other than circular section, depending on the purpose for which the cavity is to be used and the nature of the rock in which it is made.

What I claim is:

1. The method of making subterranean cavities in rock which comprises the steps of making a pilot cavity of smaller cross-section than the final cavity to be formed and located at approximately the centre thereof, drilling holes into the rock in directions radiating outwards from the said pilot cavity, inserting in said holes anchoring members to act in tension and having a wedging grip at both ends, the depth of each hole and the length of the anchoring member inserted therein being such that the anchoring member lies substantially in its entirety outside the surface which is ultimately to be the boundary of the final cavity, tightening the grips at the ends of the anchoring members and tensioning the said members, and finally removing the material between the surface of the pilot cavity and the surface of the final cavity.

2. The method of making tunnels in rock which comprises the steps of making a pilot tunnel of smaller cross-section than the final tunnel to be formed and located at approximately the centre thereof, drilling holes into the rock in directions radiating outwards from the said pilot tunnel, inserting in said holes anchoring members to act in tension and having a wedging grip at both ends, the depth of each hole and the length of the anchoring member inserted therein being such that the anchoring member lies substantially in its entirety outside the surface which is ultimately to be the boundary of the final tunnel, tightening the grips at the ends of the anchoring members and tensioning the said members, and finally removing the material between the surface of the pilot tunnel and the surface of the final tunnel.

3. The method of making subterranean cavities in rock which comprises the steps of making a pilot cavity of smaller cross-section than the final cavity to be formed and located at approximately the centre thereof, drilling holes into the rock in directions radiating outwards from the said pilot cavity, inserting in said holes anchoring members to act in tension and having a wedging grip at both ends, the depth of each hole and the length of the anchoring member inserted therein being such that the anchoring member lies substantially in its entirety outside the surface which is ultimately to be the boundary of the final cavity, tightening the grips at the ends of the anchoring members and tensioning the said members, and finally re-

moving the material between the surface of the pilot cavity and the surface of the final cavity, some at least of the steps recited proceeding concurrently at different parts of the cavity.

4. The method of making tunnels in rock which comprises the steps of making a pilot tunnel of smaller cross-section than the final tunnel to be formed and located at approximately the centre thereof, drilling holes into the rock in directions radiating outwards from the said pilot tunnel, inserting in said holes anchoring members to act in tension and having a wedging grip at both ends, the depth of the holes and the length of the anchoring members being such that the ends of said members towards the centre lie on a surface of circular cross-section touching at least in part the surface which is ultimately to be the boundary of the final tunnel, tightening the grips at the ends of the anchoring members and tensioning the said members, and finally removing the material between the surface of the pilot tunnel and the surface of the final tunnel.

5. The method of making subterranean cavities in rock which comprises the steps of making a pilot cavity of smaller cross-section than the final cavity to be formed and located at approximately the centre thereof, drilling holes into the rock in directions radiating outwards from the said pilot cavity, inserting in said holes anchoring members to act in tension and having a wedging grip at both ends, the depth of each hole and the length of the anchoring member inserted therein being such that the anchoring member lies substantially in its entirety outside the surface which is ultimately to be the boundary of the final cavity, sealing the holes and any voids or cracks adjacent thereto by the injection of a sealing medium while at least a part of each anchoring member is in place in the respective hole, tightening the grips at the ends of the anchoring members and tensioning the said members and finally removing the material between the surface of the pilot cavity and the surface of the final cavity.

6. The method of making subterranean cavities in rock which comprises the steps of making a pilot cavity of smaller cross-section than the final cavity to be formed and located at approximately the centre thereof, drilling holes into the rock in directions radiating outwards from the said pilot cavity, inserting in said holes anchoring members to act in tension and having a wedging grip at both ends, the depth of each hole and the length of the anchoring member inserted

therein being such that the anchoring member lies substantially in its entirety outside the surface which is ultimately to be the boundary of the final cavity, sealing the holes and any voids or cracks adjacent thereto by the injection of expanding cement while at least a part of each anchoring member is in place in the respective hole, tightening the grips at the ends of the anchoring members and tensioning the said members, and finally removing the material between the surface of the pilot cavity and the surface of the final cavity.

7. The method of making subterranean cavities in rock which comprises the steps of making a pilot cavity of smaller cross section than the final cavity to be formed and located within the said final cavity, drilling holes into the rock in directions radiating outwards from the said pilot cavity, inserting in each hole a bolt portion and a tubular portion of an anchoring member united by a screw thread, said bolt portion being surrounded by a wedging element, screwing the tubular portion on to the bolt portion to expand the wedging element into contact with the sides of the hole, screwing into the tubular portion of the anchoring member a second bolt portion thereof surrounded by a wedging element and carrying a conical nut by a screw thread of opposite handing to the threads by which the tubular portion is joined to the two bolt portions, the screwing of the second bolt portion being continued until the conical nut expands said last named wedging element into contact with the walls of the hole and the whole anchoring member is tensioned, and finally removing the material between the surface of the pilot cavity and the surface of the final cavity.

8. The method as defined in claim 1 in which a lining is added and is supported from the anchoring members.

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REFERENCES CITED

The following references are of record in the file of this patent:

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