April 16, 1940.

A. BULL

2,197,374

TUNNEL CONSTRUCTION

Filed Feb. 6, 1939

2 Sheets-Sheet 1

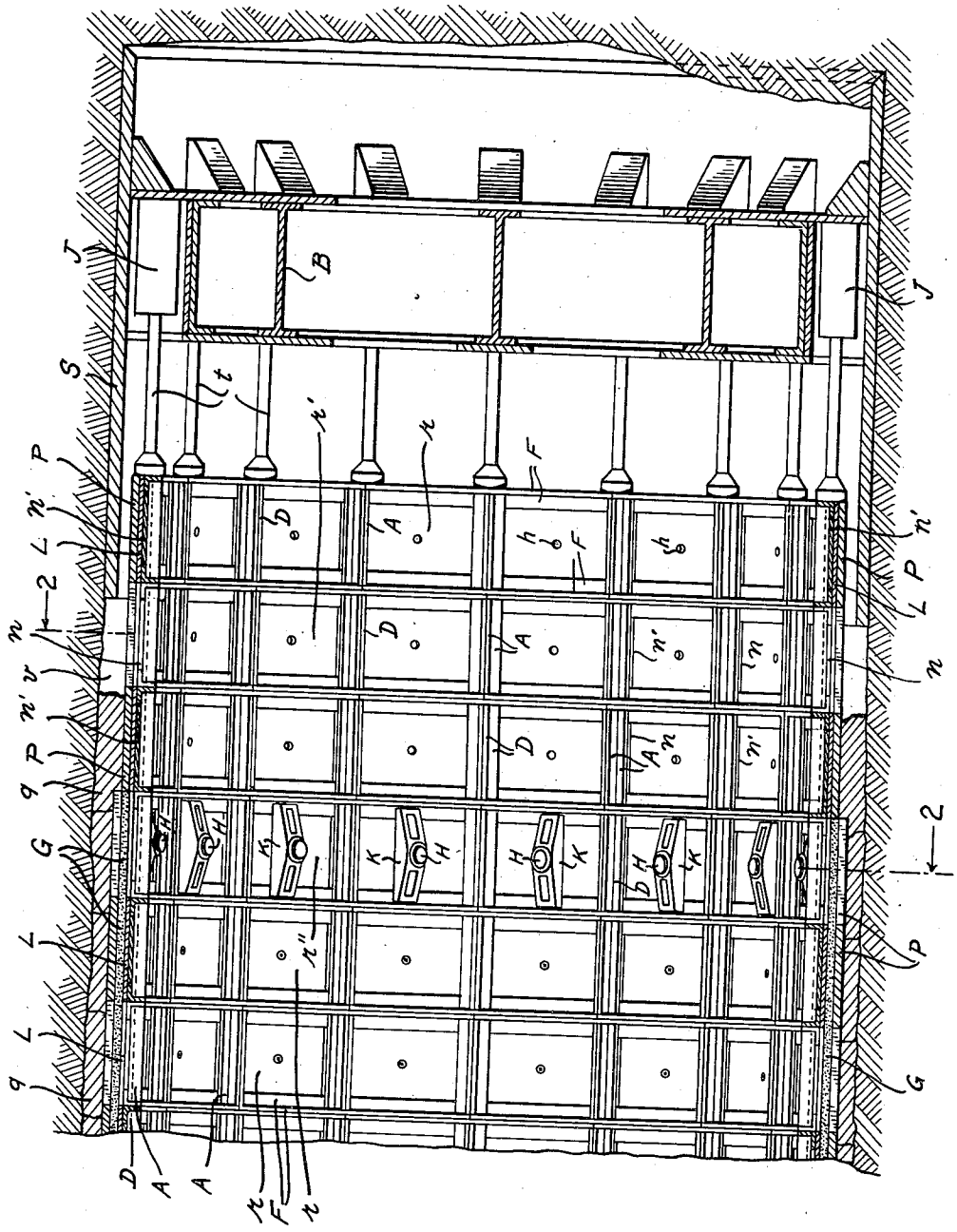


Fig. 1.

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Fig. 2.

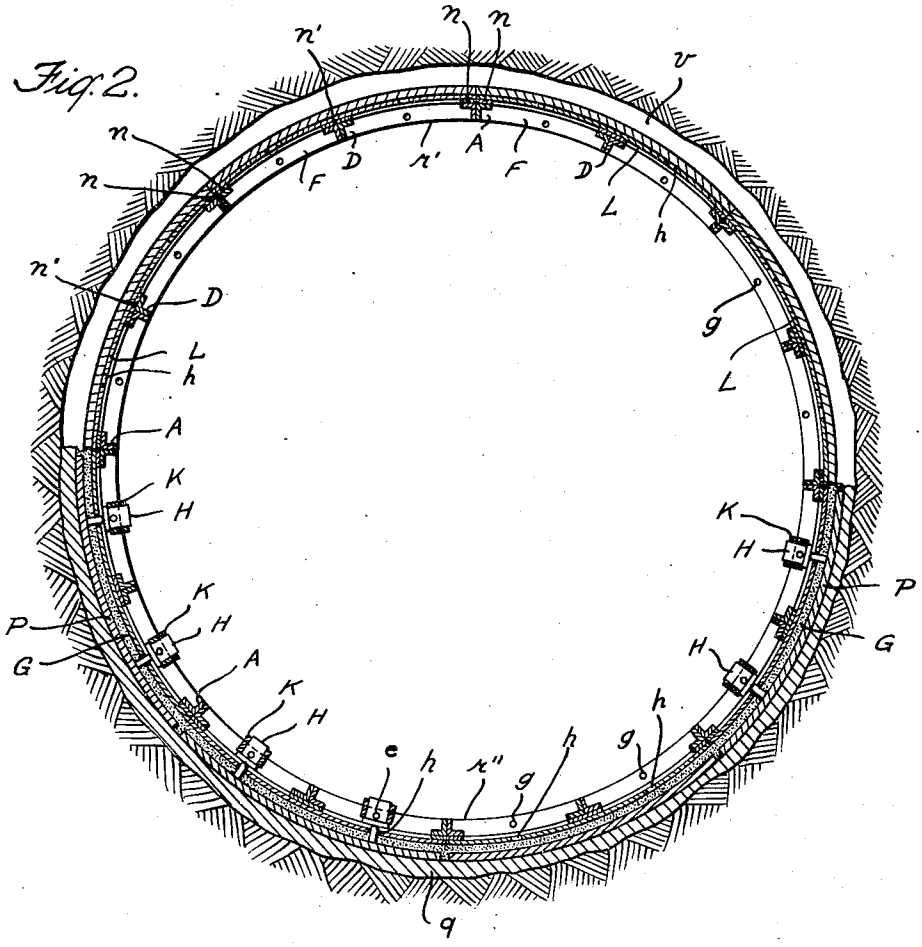


Fig. 3.

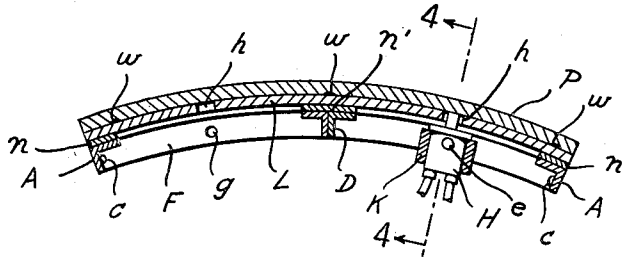
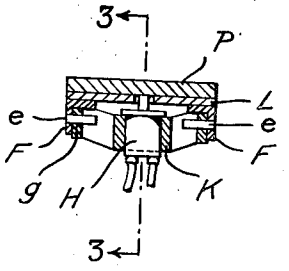


Fig. 4.



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TUNNEL CONSTRUCTION

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Application February 6, 1939, Serial No. 254,838

11 Claims. (Cl. 61—42)

In the shield method of tunnel construction a protective encasing is advanced step by step in front of the completed portion of the tunnel and serves as a shield protecting the workers against caving in of the ground and the inrush of water. Some distance back of the shield the tunnel is closed off by an air-tight bulkhead, and in the chamber thus formed at the working end of the tunnel the air pressure is raised to a point equaling the pressure head of the ground water.

The tunnel lining which is usually circular in cross-section is progressively constructed of ring sections which are added one by one within the protection of the shield between steps, each ring as it is added being connected to the last adjacent ring by bolts or rivets. In this way a rigid structure is obtained capable of withstanding the pressure of the soil.

The shield consists of a shell made of heavy steel plates and has an inside diameter somewhat larger than the outside diameter of the tunnel lining, the clearance being necessary for conveniently placing the segments of a ring and for giving the shield a certain freedom of motion in turning curves as well as for taking up unavoidable deviations from its straight course. To supply the power needed to advance the shield hydraulic jacks are commonly employed which are carried by the internal bracing structure of the shield and are so arranged that their plungers bear against the axial face of the ring last completed. Before another forward shove can be taken it is necessary to excavate in front of the shield for a distance equal to the length of a shove. The excavated soil is taken through openings in the bracing structure and the bulkhead and through the completed portion of the tunnel to the surface.

Since the shell must be of considerable thickness to make it sufficiently rigid, its outside diameter is several inches larger than that of the tunnel lining. The progress of the shield therefore serves to leave a void comprising the annular space just occupied by the rear end of the shield.

It is important that this void be promptly filled up and it is the usual practice to do this in tunnel construction, for if the soil be allowed to fill this void by closing in upon the lining considerable damage might result. For example, due to the fact that the initial pressure acting upon the lining from above would be much larger than that acting from below, the lining would be carried down gradually as the soil adjusted itself, and such settlement would seriously interfere with the alinement of the tunnel and cause excessive buckling stresses in the lining. Furthermore as the void is of a volume between 3% and 5% of the tunnel, the loss of ground in the soil prism above would be a serious feature, involving the safety and appearance of buildings and other structures under which the tunnel is driven.

It is, therefore, of great importance that this void be filled in as soon as practicable, while the shield is still sufficiently proximate to serve as a substantial support for the soil, and this is usually accomplished by blowing gravel into the void through holes left in the lining for that purpose, after which grout is forced in, consolidating the gravel.

By thus promptly filling the void the effects consequent upon the soil conditions from the very fact of creating a subterranean opening are materially counteracted. However certain factors which have a direct bearing upon the engineering considerations are not satisfied by this mode of filling the void, be it ever so promptly accomplished.

The soil is of course initially under compression and as the annular void is formed expansion of the soil tends to take place to relieve the compression. As the shield is shoved further and further ahead, the soil surrounding the filled-in pockets is gradually again subjected to the full weight of the soil above and is again compressed. The difference in the volume of the soil in its compressed and expanded state is therefore to all intents and purposes itself a void, resulting in soil adjustments.

This invention aims to eliminate these soil adjustments which tend to occur following the progress of the shield with resultant development of buckling stresses and settlement of the soil.

As a matter of fact investigation of the pressure distribution around a tunnel lining made in connection with this invention has revealed that the assumptions respecting the bending stresses to which a tunnel lining is subjected are too severe, and that tunnel linings may safely be made much lighter than has heretofore been supposed. If the tunnel lining is made flexible enough the bending stresses will be reduced to a negligible factor. If the lining is flexible enough the pressures acting on a lining will be of approximately the same intensity at all points of the periphery and they will all be directed radially.

Accordingly this invention contemplates the provision of expansion means about the tunnel

lining which will immediately restore the soil to its compressed state, with means to transfer the pressure of the surrounding soil to the lining. Preferably the lining is made sufficiently flexible to absorb the bending stresses and equalize the radial pressure about its periphery. In this way earth movement with tendency of the tunnel lining to settle is eliminated.

The specific means illustrated in the accompanying drawings for carrying out the invention will now be described, after which the invention will be pointed out in claims.

Fig. 1 is a longitudinal section of a completed section of tunnel constructed according to the invention;

Fig. 2 is a transverse section of the same on line 2—2 of Fig. 1;

Fig. 3 is a transverse section of a single ring segment of tunnel lining on enlarged scale, taken on line 3—3 of Fig. 4, and showing the parts employed at an intermediate stage of the method; and

Fig. 4 is a partial longitudinal section of a single ring and other parts shown in Fig. 3, being taken on line 4—4 of Fig. 3.

The completed portion of the tunnel lining, as shown in Fig. 1, is made up of a series of connected ring sections *r*. Each ring is built up of segments. The mode of uniting the segments and of attaching each successive ring to its predecessor will be presently described.

The building up of the rings is performed inside of the tail end of the shield S. This shield is composed of heavy steel plates and is braced by a strong steel structure B to which are fastened a large number of hydraulic jacks J. The plungers *t* of the jacks are made to bear against the axial face of the last completed ring *r*. By admitting pressure water to the jacks the shield is shoved forward through the ground one step, the length of the shove being equal to the width of the ring *r*. In Fig. 1 the shield is shown in the position assumed at the end of a shove. The water is now let out of the jacks and their plungers are withdrawn into the cylinders, affording unobstructed space for the forming of another ring *r*.

In shoving the shield ahead by the width of a ring a void *v* is created between the lining immediately back of the shield and the surrounding soil. As above mentioned, this void is filled in with a gravel and grout mixture forced in through holes left in the lining for that purpose. In Fig. 1 the filled-in pockets are indicated by the letter *q*, and the void *v* about the ring marked *r'* is next to be filled.

The method of attaching the ring segments to each other and of attaching the successive rings together will best be understood by reference to Figs. 3 and 4. The lining is assumed to be made of structural steel, although other materials would also be suitable, and is somewhat thinner and more flexible than has heretofore been the case. Each ring is composed of several arcuate segments L, and a segment is provided on its inner face at each end with an angle strip A extending axially. The abutting angles of the adjacent segments are secured together in any suitable way, as by rivet *c*. Each segment may also be braced at its center with a pair of oppositely disposed contiguous angle strips D.

Likewise the ring segments are provided on each side of their inner faces with circumferential angle strips F which serve not only as reinforcements but also as a means for attaching the contiguous ring sections either by riveting, welding, or otherwise securing the adjacent angle strips F together. It will be noted that the segments in consecutive rings are staggered, as shown in Fig. 1.

As shown, filler strips *n* extend between the opposing flanges of the angles F to accommodate the angles A, and a single wide filler strip *n'* extends across each segment midway of its ends and between the opposing flanges of the angles F to accommodate the pair of angles D.

Outside of the tunnel lining around its entire periphery are arranged a number of liner plates P having a curvature corresponding to that of the lining. These plates are initially attached to the lining by means of tack welds *w* (Fig. 3) or small bolts of just sufficient strength to prevent the plates from becoming displaced in handling the segments. Holes *h* are provided in the lining in addition to those required for graveling and grouting.

By means of plungers inserted through the holes *h* the liner plates P may be forced out from the lining by pressure exerted by small size jacks H. Each of these jacks is mounted in an individual frame K which fits into the space between the connection angles F and is held in position by means of pins *e* inserted through holes *g* in the angles. As shown there are two holes *h* to each segment, and therefore if, as in the construction shown, each ring is composed of eight segments, there will be sixteen equally spaced jacks H.

After the gravel and grout injected through the grout holes (not shown) has had time to consolidate, the shield being, say, in the position shown in Fig. 1, the plungers of the jacks H are inserted through the holes in the ring *r''* located two or three shove lengths back of the one which the shield has just left exposed. While the void around the latter ring is being filled, pressure is applied to the jacks H so that the liner plates P are torn loose and forced outward against the soil, thereby compressing it. The pressure is regulated until the force with which the liner plates bear against the soil somewhat exceeds the force with which the soil would bear against the ring if given time to settle in the natural way. Its magnitude may be roughly calculated from the depth of cover above the tunnel. The voids created between the liner plates and the lining are next filled in with fast setting grout, as indicated in Figs. 1 and 2 by the latter G, and after the time allowed for setting, the jack pressure is released, the plungers withdrawn and all the holes plugged. In one segment of Fig. 2 the holes *h* are shown thus plugged, and the plugs are shown in all of the holes in the two rings *r* back of the ring *r''* in Fig. 1.

As the jack pressure is released the elastic pressure exerted by the compressed soil against the liner plates is transferred through the hardened grout to the lining, while at the same time the angles F are relieved of their load. This will cause some adjustment and yielding of the lining, which is the reason for the excess of force above referred to. Since the pressure is the same at any point of the periphery the ring is subjected to practically no bending, the only stresses to be considered being those due to rib shortening; and since the forces are of the same amount as those the ring will finally be subjected to, no settlement can take place.

The working platform extending backward from the shield may make the bottom segments

near the end of the finished portion of the tunnel inaccessible for some time. This creates no difficulty, however, since the jacks H and the frames K may be placed in the bottom segments immediately after the erection of a ring.

The liner plates will add to the clearance requirements for the shield, but as the lining can be made shallow because of the absence of high-bending movements, its overall depth can always be made less than that of a lining designed in accordance with the theories of tunnel design heretofore prevailing.

The invention is not necessarily limited to the precise method and construction above described, but only by the scope of the appended claims.

I claim:

1. The method of tunnel construction in which a shield is employed and advanced step by step comprising adding a ring section of tunnel lining within the shield between steps, filling the void left by the shield around the section of lining after the shield is advanced, and then creating a radially expansive pressure externally about the lining section compressing the soil surrounding the section.

2. The method of tunnel construction in which a shield is employed and advanced step by step comprising adding a ring section of tunnel lining within the shield between steps, filling the void left by the shield around the section of lining after the shield is advanced, and then creating a radially expansive pressure externally about the lining section compressing the soil surrounding the section and sustaining the soil in the compressed state.

3. The method of tunnel construction in which a shield is employed and advanced step by step comprising adding a ring section of tunnel lining within the shield between steps, filling the void left by the shield around the section of lining after the shield is advanced, creating a radially expansive pressure upon the soil surrounding the section, and then relieving the expansive force and allowing the reacting pressure of the soil to be applied to the outside face of the section.

4. The method of tunnel construction in which a shield is employed and advanced step by step comprising adding a ring section of tunnel lining within the shield between steps, filling the void left by the shield around the section of lining after the shield is advanced, forcing out liner plates disposed externally of the ring section, thereby compressing the soil surrounding the section, and coupling the plates to the ring in their outwardly displaced position.

5. The method of tunnel construction in which a shield is employed and advanced step by step comprising adding a ring section of tunnel lining within the shield between steps, filling the void left by the shield around the section of lining after the shield is advanced, forcing out liner plates disposed externally of the ring section, thereby compressing the soil surrounding the section, and filling in the circumferential void thus created between the liner plates and the external surface of the ring.

6. The method of tunnel construction in which a shield is employed and advanced step by step comprising adding a ring section of tunnel lining within the shield between steps, filling the void left by the shield around the section of lining after the shield is advanced, forcing out liner plates disposed externally of the ring section by means of outward radial forces, thereby compressing the soil surrounding the section, and coupling the plates to the ring in their outwardly displaced position.

7. The method of tunnel construction in which a shield is advanced step by step comprising adding within the protection of the shield between steps a ring section of tunnel lining, advancing the shield, and then creating a radially expansive pressure externally of the added section compressing the soil surrounding the section.

8. The method of tunnel construction in which a shield is advanced step by step comprising adding within the protection of the shield between steps a ring section of tunnel lining having arcuate liner plates loosely secured upon its external periphery, advancing the shield, and applying outward radial pressure upon the liner plates sufficient to separate the plates from the ring and move them outwardly and compress the surrounding soil.

9. The method of tunnel construction in which a shield is advanced step by step comprising adding within the protection of the shield between steps a ring section of tunnel lining having arcuate liner plates loosely secured upon its external surface, advancing the shield, applying outward radial pressure upon the liner plates sufficient to separate the plates from the ring and move them outwardly and compress the surrounding soil, and coupling the plates to the ring in their outwardly displaced position.

10. For a tunnel structure, a ring section of tunnel lining having a circumferential series of holes for the accommodation of radial power implements, and a series of supplemental liner plates attached to the external face of the ring over the holes and adapted to be torn loose by said implements.

11. A tunnel structure comprising a succession of ring sections of lining material each sufficiently flexible to allow it to yield to such an extent as to practically equalize surrounding pressures thereby minimizing bending stresses in the ring sections, a circumferential reinforcing rib secured to the inner face of each ring at each edge thereof, separate liner plates outwardly spaced from and substantially surrounding the tunnel lining, and spacing means between the liner plates and the tunnel lining operative to transfer external pressure upon the plates to the lining.

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