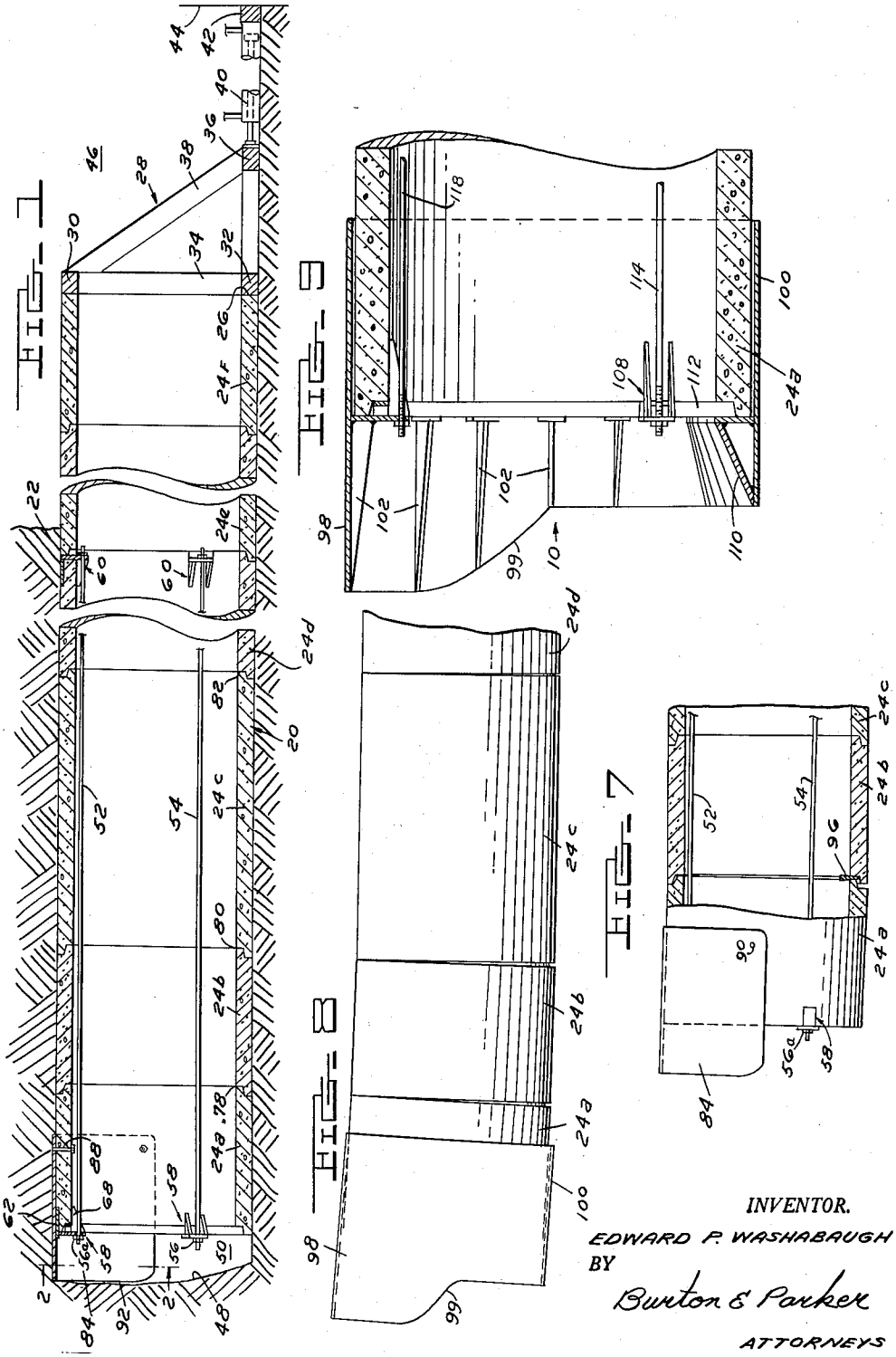
Jan. 10, 1961 E. P. WASHABAUGH 2,967,401

APPARATUS FOR JACKING TUNNELS

Filed March 16, 1955 3 Sheets-Sheet 1

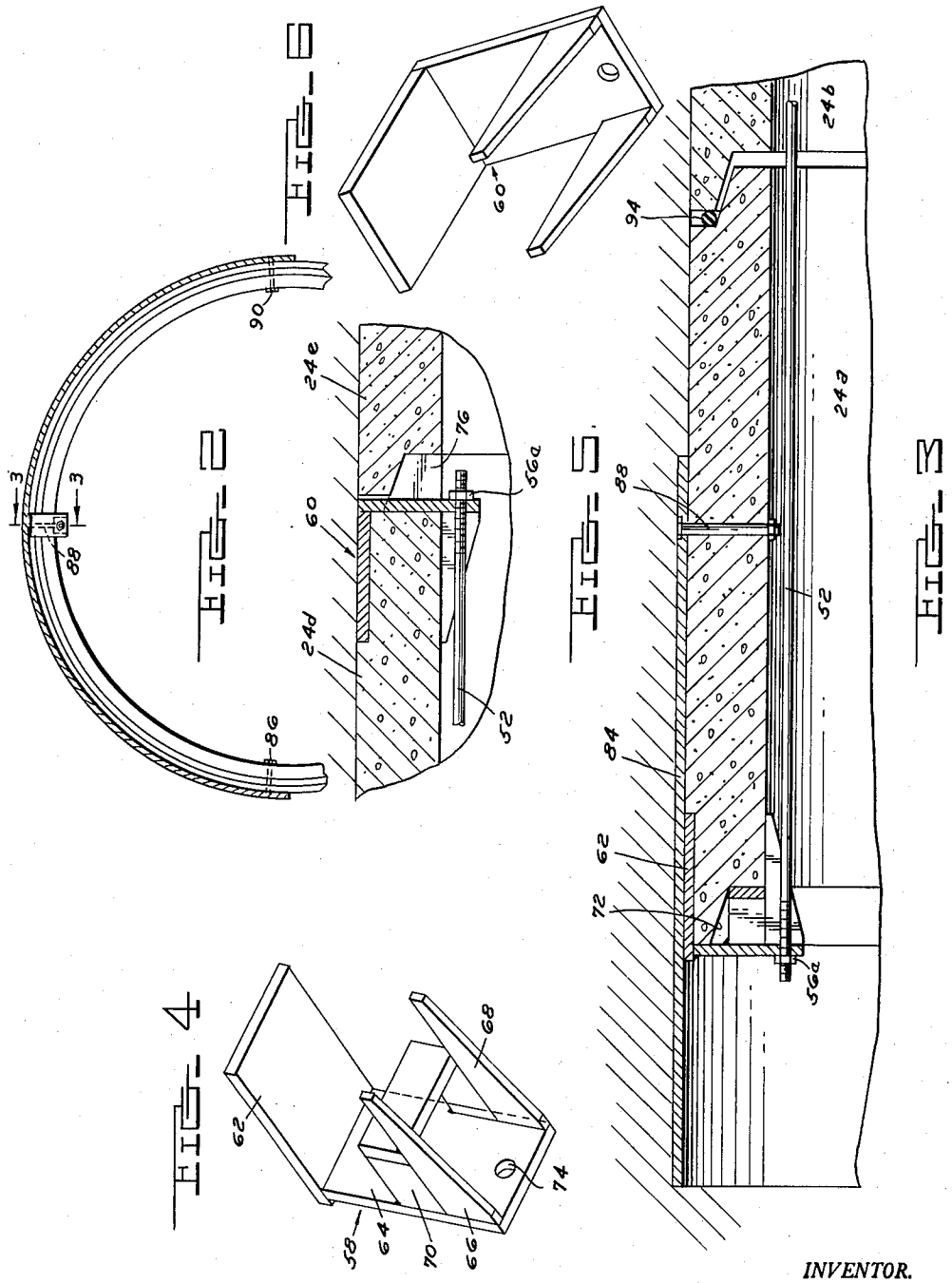


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APPARATUS FOR JACKING TUNNELS

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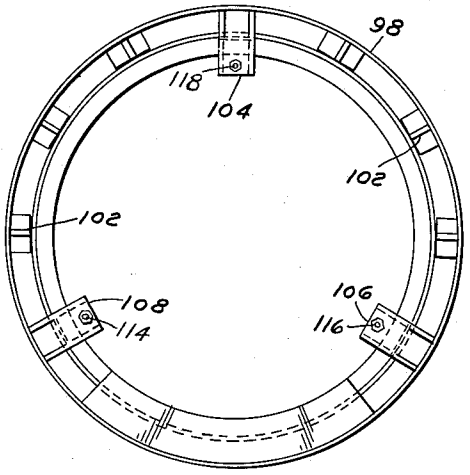


FIG. 10

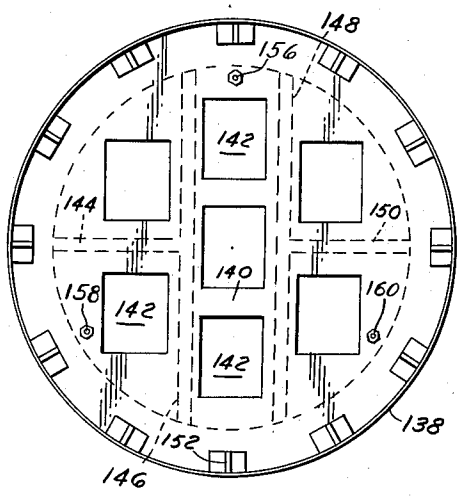


FIG. 12

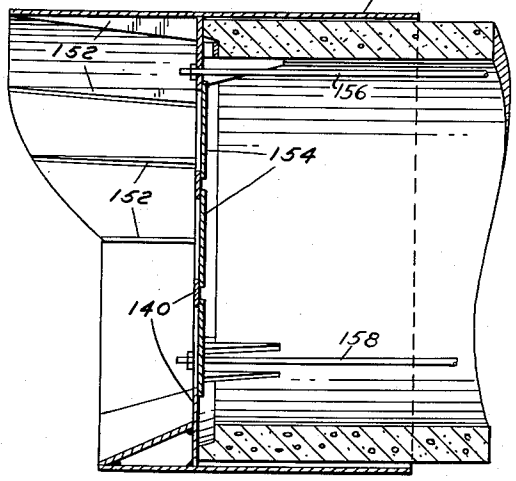


FIG. 11

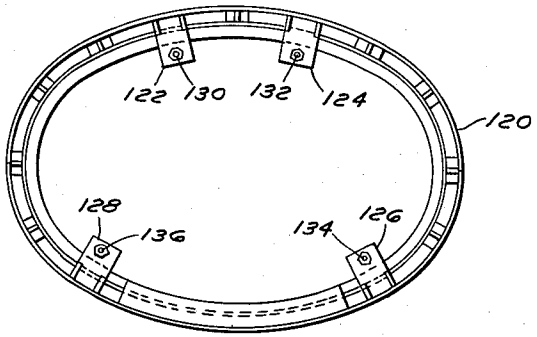


FIG. 13

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APPARATUS FOR JACKING TUNNELS

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Filed Mar. 16, 1955, Ser. No. 494,755

5 Claims. (Cl. 61—84)

This invention relates to the art of tunneling and more particularly to the construction of tunnels, sewers, or the like, by the jacking method. According to the jacking method a tubular tunnel section is pushed through the ground by means of jacks working against the rear end of the section, while the earth is contemporaneously removed by workmen working from inside the section at the leading end thereof. When the tunnel section has been jacked forward a sufficient distance, the jacks are retracted and another tunnel section is placed behind the first section and the jacking is resumed and both sections are now pushed forward through the ground. The cycle is repeated as long as it is necessary or as long as the jacks are still able to push the accumulated sections forward through the ground.

The construction of tunnels by means of the above mentioned jacking method is to be distinguished from tunnel construction where a shield is used which is jacked forward at the leading end of the tunnel. In the shield method the tunnel is built up out of segments which are secured together to form the tubular walls of the tunnel. Over the leading end of a tunnel being constructed in this fashion is placed a tubular shield. The shield is provided with jacks which bear against the leading end of the tunnel. The jacks are actuated to move the shield forward through the ground as the workmen, or miners, as they are called, dig the earth away in front of the shield. The shield may be provided with a cutting edge to facilitate its movement through the ground. The jacks in this method act only on the shield, and it is the only thing which is moved forward. The tunnel itself is constructed immediately behind the shield out of the segments above mentioned. The tubular length of the shield is generally limited so that it is at the most no longer than its diameter because a longer shield is difficult to steer.

If the steering of a tunnel shield is difficult when its tubular axis exceeds its diameter, the steering of the leading end of a tunnel being constructed by the jacking method has heretofore been almost impossible because the tubular axial dimension of the tunnel exceeds by many times the diameter of the tunnel. So difficult has it been to control the direction of a tunnel being jacked forward that the only jacking that was attempted was through very firm ground and over only very short distances. Yet the construction of at least portions of a tunnel by the jacking method is very desirable in certain instances if the jacking can be accomplished without the leading end of the tunnel wandering from its intended course. One such instance arises, for example, where a sewer is being laid through a populated area by the open trench method. According to this method an open trench is dug and the sewer sections laid in the bottom of the trench with the trench thereafter being filled in. Such open trench method, however, cannot be continued when the tunnel must pass beneath a building or a roadway. Either the tunnel must be constructed beneath the building or roadway by the jacking method, or the

ground must be dug away and shored up, particularly the roof of the tunnel-like excavation, and the sewer sections then laid in place. The expense of laying a sewer beneath a building or roadway by digging a tunnel-like excavation and shoring up the walls and roof thereof is extremely expensive and is therefore avoided whenever possible. If practical, the jacking method is employed because then it is unnecessary to shore up the walls or roof of the tunnel-like excavation. The tunnel sections are merely jacked forward through the ground with the miners working inside the tunnel sections to dig out the heading as the sections are pushed forward. However, the attendant difficulty of steering the leading end of the tunnel as it is urged forward, frequently requires resort to the older method of digging the tunnel-like excavation and shoring up its walls and roof and then laying in the tunnel sections.

At the commencement of the jacking method it is possible to steer the first one or two tunnel sections that are jacked forward by increasing the thrust at one side or the other at the rear end of the tunnel to cause a turning moment on the sections which tends to keep them moving in a straight path. But after a number of sections are added to the tunnel it is thereafter impossible to steer the leading end by simply increasing the thrust of the jacks at one side or the other at the rear of the tunnel. Where the ground is at all soft, there is a marked tendency for the leading section to deviate or wander downwardly from its intended path, and once this deviation has begun, the succeeding tunnel sections follow along and no amount of increased thrust on the lower edge of the rear end of the tunnel will persuade the leading section to return to its proper course.

The primary object of the present invention is the provision in the art of tunneling by jacking of a method of and apparatus for steering the leading end of the tunnel during its forward movement through the ground.

Another object of the invention is the provision of a method of and apparatus for steering the leading end of a tunnel being constructed by jacking, where the tunnel comprises a plurality of tunnel sections loosely fitted together at their spigot and hub ends but otherwise not permanently secured together in fixed relation.

Another object of the invention is the provision of a method of and apparatus for steering the leading end of a tunnel being constructed by the jacking method and where the tunnel sections are formed of pre-cast concrete and have a tubular axial dimension substantially equal to their diameter.

Another object of the invention is the provision of apparatus for steering the leading end of a tunnel being constructed by the jacking method in which the leading end of the tunnel comprises a plurality of articulated tunnel sections, with simple and efficient means associated with the articulated sections for effecting the steering thereof as they are urged forward through the ground. A concomitant object of the invention is the provision of a steerable front end for a tunnel being constructed by the jacking method, and which front end comprises a plurality of articulated tunnel sections which themselves are a part of the tunnel.

Another object of the invention is the provision of apparatus for steering the leading end of a tunnel being constructed by the jacking method in which the leading end of the tunnel comprises a plurality of articulated tunnel sections, with means associated with the sections for urging the sections together along their tubular axes at determined points about their periphery. A concomitant object is the provision of an articulated leading end portion for a tunnel being constructed by the jacking method, in which the articulated portion is more flexible near

the leading edge of the tunnel than it is more remote from such leading edge.

Another object of the invention is the provision of resilient means disposed between the meeting spigot and hub ends of the articulated sections to aid their articulated movement.

Still another object of the invention is the provision of apparatus for the purpose described which includes an improved cutting shield adapted to be received over the leading end of the tunnel and which will cut its way through the ground about a portion of its perimeter as the tunnel is urged forwardly.

Other objects, advantages, and meritorius features will more fully appear from the specification, claims, and accompanying drawings, wherein:

Fig. 1 is a cross sectional view taken along the tubular axis of a tunnel being constructed by the jacking method and showing my improved method of and apparatus for steering the leading end of the tunnel;

Fig. 2 is a cross sectional view through one form of a shield taken on the line 2—2 of Fig. 1;

Fig. 3 is an enlarged fragmentary cross sectional view taken on the line 3—3 of Fig. 2;

Fig. 4 is a perspective view of a tension rod bracket adapted to be received over the hub end of a tunnel section;

Fig. 5 is a fragmentary cross sectional view showing a tension rod bracket received over the spigot end of a tunnel section;

Fig. 6 is a perspective view of a tension rod bracket adapted to be received over the spigot end of a tunnel section;

Fig. 7 shows the method of wedging the accumulated sections apart to increase the angular relationship therebetween;

Fig. 8 is a side view of the leading end of a tunnel provided with a modified form of shield;

Fig. 9 is a cross sectional view taken on the tubular axis of Fig. 8 and showing the construction of a modified form of the shield;

Fig. 10 is an end view of the leading end of the tunnel as shown in Fig. 9 and looking in the direction of arrow 10;

Fig. 11 is a cross sectional view similar to Fig. 9, but showing another modification of the shield having a ported bulkhead;

Fig. 12 is an end view of the construction of Fig. 11 looking in the direction of arrow 12; and

Fig. 13 is an end view of the leading edge of a tunnel of generally elliptical shape and showing four instead of three tensioning rods.

A method of and apparatus for constructing a tunnel by the jacking method, and steering the leading end of such tunnel as it is being jacked forward, is shown in connection with a tunnel formed of a plurality of pre-cast concrete tunnel ring sections of both circular and elliptical shape. However, it will become apparent as the description proceeds that my invention is equally applicable to tunnels constructed of pre-formed metal tunnel sections.

Shown in Fig. 1 is a tunnel being constructed by jacking and wherein my invention is employed. The tunnel is generally indicated at 20, and the earth through which it is being jacked, at 22. The tunnel comprises a plurality of tunnel sections 24–*a*, 24–*b*, 24–*c*, 24–*d*, 24–*e*, and 24–*f*, and as many additional sections as is necessary or feasible. The hub and spigot ends are interfitted as shown and as more fully described hereinafter.

The leading end of the tunnel is shown at the left hand side of Fig. 1 while the rear end is shown at the right hand side. The rear edge of the tunnel is indicated at 26, and against this rear edge is disposed a frame 28 formed of heavy timbers, and adapted to distribute the thrust of the jacks evenly over the rear end of the tunnel. Horizontal upper and lower timbers 30 and 32 abut the upper and lower spigot end of the rearmost section 24–*f*, and are held spaced apart by a pair of vertically extending timbers 34 (only one of which is shown), which abut the rear edge of the tunnel at the opposite sides of section 24–*f*. Parallel horizontally extending timbers 35 (only one of which is shown) extend from cross piece 32 to a jack abutting cross timber 36 and serve to space timbers 32 and 36 apart. A pair of angularly disposed members 38 (only one being shown) are disposed at each side of the frame 28 in the position shown. Bolts or any other suitable means are employed to secure the respective timbers together and form a strong, rigid, unitary frame.

One or more jacks 40, which may be hydraulically operated as is the jack schematically shown, abut at one end the cross timber 36 and at the other end a timber 42 which may be placed against a wall 44 of an access shaft 46 from the bottom of which the tunnel is being driven. Upon operation of the jack 40, the entire tunnel 20 is urged forward or toward the left side of Fig. 1, and against the fore wall 48 of the head 50.

In carrying out the objects of my invention, I provide an articulated leading end for the tunnel and means for shifting the tunnel sections comprising such articulated end, so that such leading end may be steered to guide the tunnel during its movement through the ground. In precasting concrete tunnel sections, such as those shown at 24, it is very difficient to form perfectly planar spigot and hub ends which will interfit without any tendency of the sections so joined from shifting relative to each other about axes extending perpendicular to their tubular axes. I make use of this imperfection in carrying out one form of my invention, and rely upon the spigot and hub ends of the sections being imperfectly planar. In providing an articulated leading end for the tunnel which will meet the necessary requirements of adequate flexibility. I provide two tunnel sections 24–*a* and 24–*b* each of whose axial tubular dimension is less than its diameter. In Fig. 1 this relationship is substantially ⅔:1. To the rear ends of these two sections are two more tunnel sections of the usual length employed in the tunnel construction. Each of these may have a tubular axial dimension substantially 5/12 again as long as the diameter of the section. These four tunnel sections comprise the leading and steering end of the tunnel and serve to guide the succeeding sections of the tunnel as the same is jacked forward through the ground.

In order to articulate these four leading tunnel sections and control the direction of movement of the leading edge of the tunnel, I provide, in one form of the invention, three tensioning rods 52, 54, and 56 which extend through these four sections and are adapted to hold them together as more fully described hereinafter. Each of these rods is threaded at its opposite ends, with the ends received through brackets or anchors 58 and 60 shown particularly in Figs. 1, 3, 4, and 6, with nuts 56–*a* threaded over the ends of the rods to bear against the anchors. Anchor 58 is adapted to overlie the hub end of the leading tunnel section 24–*a* and is provided with a plate 62 adapted to overlie the outside of the leading tunnel section. A tension rod receiving plate 64 is welded to plate 62 and extends inwardly therefrom and is provided with a pair of tines 66 and 68 which, as shown in Fig. 3, overlie the inner surface of the leading tunnel section. A step or shoulder 70 is welded between the tines and the plate 64 to brace the same and form a bearing surface adapted to be received in interfitting engagement with the inwardly extending shoulder 72 at the hub of the leading section. A tension rod receiving aperture 74 extends through plate 64 as shown. The bracket or anchor 60 is of the same construction as anchor 58 except that anchor 60 does not include the shoulder or step 70. To fit anchor 60 over the spigot end of section 24–*d*, the shoulder 76 of the spigot is cut

away sufficiently to permit the anchor to be disposed as shown in Fig. 5, with the succeeding section 24–*e* abutting in interfitting engagement the shoulder 76 of the spigot of section 24–*d*.

In the operation of the tensioning rods to steer the leading end of the tunnel, and assuming that during the jacking, the tunnel has a tendency to drift downwardly off its intended course, the two lower rods 54 and 56 are loosened by backing off the nuts 56–*a* at one or both ends of the rods, and the upper tensioning rod 52 is tightened by threading the nuts 56–*a* thereon farther inwardly. This unequal tensioning of the rods sets up a compressive force parallel to the tubular axes of the four leading tunnel sections along the top of the sections while the bottoms of the sections are free to spread or separate at their meeting hub and spigot edges. In other words the sections are tensioned toward each other, or compacted together, along one side of the tunnel in the leading end thereof, while the opposite sides of the sections are permitted to separate or spread. With the normally imperfect fitting of the spigot and hub edges of the sections, this unequal tensioning of the sections tends to shift them upwardly and lift the leading edge of the tunnel so that upon continued jacking, the upper leading edge of the tunnel bites into the earth along a rising path. In other words the leading section is bent out of the tubular axis of the tunnel and in the direction in which it is desired to steer the tunnel.

When the upper rod 52 is initially tensioned and the lower rods loosened, relative shifting between the four sections may not be immediately apparent because the earth surrounding the sections tends to prevent shiftable movement. However, as the jacking continues with the meeting edges of the sections along the route thereof being tensioned together, and the meeting edges at the opposite side of the sections being separable, visible signs of relative shifting between the sections is apparent by a widening of the joint between the sections as at the points 78 and 80 between the first, second, and third sections. It is to be noted that the greatest amount of shiftable movement or bending of the leading end of the tunnel occurs between these three leading sections at the points indicated because the two leading sections 24–*a* and 24–*b* are of lesser tubular axial dimension than sections 24–*c* and 24–*d*. This shorter tubular dimension of sections 24–*a* and 24–*b* presents a shorter length of tunel section against which the surrounding earth may act in proportion to the force that the tension rods 52 exert tending to shift the sections relative to each other. Relative shifting also occurs between sections 24–*c* and 24–*d* at point 82, but here it is not as noticeable.

A balance between the tension on rod 52 and rods 54 and 56 may be achieved upon adjustment of nuts 56–*a* so that the tunnel will follow its intended course during the jacking operation. If the earth is very soft, with a resultant pronounced tendency for the leading end of the tunnel to movement downwardly, it may be that the rod 52 must be very taut while rods 54 and 56 are very slack in order to have the tunnel follow a horizontal course. The adjustment of the rods to achieve the proper path of travel for the leading end of the tunnel is dependent upon the condition of the earth through which the tunnel is being jacked and no fixed rule can be established other than that if the ground is soft, the upper rod 52 will require a substantially greater tension than when the ground is firm.

In addition to compacting for a vertical drift of the leading end of the tunnel from its intended course, the rods may be adjusted to compensate for a horizontal drift to one side or the other. In this case the two rods 54 and 56 are adjusted as necessary to steer the tunnel horizontally. It is apparent that drift which is both horizontal and vertical can also be compensated for by suitable adjustment of the rods.

After the tunnel has been jacked the intended distance, the rods are uncoupled from the anchors 58 and 60, and are removed along with anchors 58. The four tunnel sections 24–*a*, 24–*b*, 24–*c*, and 24–*d* form an integral part of the entire tunnel after the jacking operation has been completed, and therefore are not removed but are left in place and suitably sealed in the wall of the tunnel by mortar or the like.

It is now apparent that I have provided a method of steering the leading end of a tunnel being constructed by jacking, in which I shift the angular inclination of the leading end of the tunnel with respect to the remainder of the tunnel, with such inclined leading end serving to lead the remainder of the tunnel along the inclined path which the leading end is required to take. Such inclination of the leading end is accomplished by employing an unequal force along opposite sides of the articulated sections comprising the leading end. The apparatus shown for shifting the articulated sections comprising the leading end is obviously of simple design and is not readily susceptible to damage which might occur with more complicated forms of apparatus.

According to another form of my invention the leading end of the tunnel may be provided with a shield indicated at 84 in Figs. 1, 2, 3, and 7. This shield is similarly cylindrical in shape and is securely fastened to the leading tunnel section 24–*a* by bolts 86, 88, and 90, with the shield overlying the plate 62 of the tension rod anchor 58, and with the forward edge of the shield overhanging the leading edge of the tunnel. Upon shiftable movement of the leading tunnel section 24–*a*, as above outlined, the shield is also moved. The shield prevents the roof of the heading from falling in on the miners working at the forward end of the tunnel, and also serves as a cutting edge at the leading end of the tunnel. This cutting edge aids in steering the leading end of the tunnel when the upper rod 52 is tightened, because the cutting edge 92 digs into the earth and tends to lead the section 24–*a* along an upward path when the tunnel is jacked forward.

To permit greater articulation between the tunnel sections 24–*a*, 24–*b*, 24–*c*, and 24–*d*, a resilient compressible ring 94 may be slipped over the spigot end of the sections, such as shown in Fig. 3. This ring will permit the sections to be shifted to a greater extent when the rods 52, 54, and 56 are tensioned or slackened, than where the imperfect surfaces of the spigot and hub ends of the sections are relied upon to permit the articulated movement. Such a resilient compressible ring will also serve to seal the joint between the hub and spigot ends of the sections.

Shown in Fig. 7 is a wedge 96 which may be driven into the joint between the interfitting hub and spigot ends of the sections to increase the angular relationships between the sections. When the wedge is driven in place it serves to tension the sections apart, and when the upper rod 52 is tensioned this serves to tension the sections together at that side opposite the wedge. The use of such wedge may be found desirable where an unusual amount of angular relationship between the sections is desired, or where for some other reason the sections do not apparently shift as readily as desired during the jacking operation. The wedge may also be used where the meeting hub and spigot ends are too perfectly matched to permit adequate articulation by simply tightening the rod 52 and loosening rods 54 and 56.

Fig. 7 is also exemplary of the cooperation of the sections and of the tension rods. As above mentioned, the rods may be used to articulate the sections by tightening the rods, for example, tightening up rod 52 while slackening off rods 54 and 56. However, even with rods 54 and 56 slackened off, they still serve to hold the sections together and prevent them from becoming disengaged. This is particularly true when the wedge 96 is driven in between the sections or when the sections are being urged through very wet or very soft ground. Without the

provision of the rods, when the wedge is driven in, the sections would merely be wedged apart, and no angular movement between the sections could be accomplished.

Another form of the invention is shown in Figs. 8, 9, and 10 wherein the shield **98** is received over the leading edge of the tunnel. The shield **98** is cylindrical in cross section with its leading and cutting edge **99** shaped as shown in Figs. 8 and 9. The skirt portion **100** of the shield is received over the leading tunnel section **24**–*a*, with the inside diameter of the skirt exceeding the outside diameter of the section to permit articulation of the shield relative to and upon section **24**–*a*. That portion of the shield forward of section **24**–*a* is internally reinforced by knees **102**, with the rear ends of the knees abutting the leading edge of section **24**–*a*. Tension rod anchors **104**, **106**, and **108** are welded to the shield equidistantly spaced apart around the inside thereof as shown in Fig. 10. At the lower edge of the shield an angular arcuately shaped scoop plate **110** is welded to the leading edge of the shield and extends upwardly rearwardly and is welded to a vertically extending plate **112**, which plate is co-extensive with the arcuate extent of plate **110** and is itself welded to the shield. Plate **112** abuts the leading edge of the section **24**–*a* along the lower edge of the section.

The shield **98** is adapted to cut its way through the ground and form a tubular cut ahead of the tunnel. The shield forms this cut with a greater outside diameter than the outside diameter of the following tunnel sections. Because the cut through the ground made by the shield is greater than the diameter of the tunnel, the earth will not bind the tunnel as much rearwardly of the shield during the jacking operation.

As shield **98** is urged forward through the ground ahead of the tunnel, the angularly upwardly extending plate, or scoop **110**, scoops the earth up into the tunnel where the miners may readily remove it. With the shield shown in Fig. 1, the lower leading edge of the tunnel presents a substantialy resistance to forward movement of the tunnel unless the heading is kept clear ahead of it. With shield **98** the cutting edge **99**, which extends completely around the periphery of the tunnel at its leading edge, will not offer this resistance to forward movement of the tunnel. Because of the shape of such cutting edge, i.e., with it extending farther ahead at the top than at the bottom, the angle of repose of the earth ahead of the tunnel may be readily maintained. The overhanging upper edge of the shield prevents the earth at the top of the heading from sliding down and filling the heading end of the tunnel. In some instances it may be necessary to have this overhang of a greater length than shown if the earth has a tendency to run freely, as, for example, where the tunnel is being jacked through sand.

Tension rods **114**, **116**, and **118** similar to rods **52**, **54**, and **56**, and extending through suitably provided apertures in anchors **104**, **106**, and **108**, extend into brackets similar to brackets **60** which are received over the spigot end of section **24**–*d*. Upon tensioning the rods, as above described, the four leading sections together with the shield may be shifted relative to each other to bend the leading end of the tunnel and cause it to travel along a different course, or adhere to its intended course. Because the shield is articulated on the leading end of the tunnel, a greater amount of articulated movement at the front of the tunnel may be accomplished with this modification than with the modifications heretofore mentioned by the use of tightening or loosening the tension rods alone. Shield **98** also provides a greater overhang beyond the leading edge of the tunnel sections and therefore offers more protection for the miners working in the heading. The shield also materially reinforces the leading edge of the tunnel, and because of its manner of mounting upon leading section **24**–*a*, does not impose as great a strain upon the section as do the three bolts disclosed in connection with shield **84**. Shield **98**, through its knees **102** and the plate **112**, bears against the leading edge of section **24**–*a*.

The articulated movement of shield **98** upon the leading section **24**–*a* is accomplished by the uneven character of the hub end of section **24**–*a*. Certain of the knees **102** will therefore bear against the leading edge and certain of the knees will not, and those not bearing against such edge will permit tilting or tipping of the shield relative to section **24**–*a*.

In Fig. 13 another shield is shown which is similar in all respects to shield **98**, except that this latter shield, indicated at **120**, is elliptical in cross section and is provided with four, instead of three, tension rod anchors. Such anchors are indicated at **122**, **124**, **126**, and **128**. This shield is adapted for use with elliptically shaped tunnel ring sections. Four tension rods **130**, **132**, **134**, and **136** extend rearwardly from the shield and are secured by anchors **60** to the rear end of tunnel section **24**–*d*, after the fashion shown in Fig. 5. This shield operates in the same manner as shield **98** except that four tension rods, instead of three, determine the angle of inclination of the shield with respect to the tunnel, and the angular relationship between the leading four sections of the tunnel. The principle of operation of the shield is the same as that hereinabove described.

In Figs. 11 and 12 another modification of a shield is shown. This shield, indicated at **138**, is particularly adapted for use when the tunnel is being jacked through soft or wet ground which would flow in through the leading end of the tunnel upon the miners and fill the tunnel, if any of the above mentioned shields were used. Shield **136** is provided with a transversely extending bulkhead **140** having a plurality of ports **142** therein. The bulkhead is reinforced by transversely extending braces **144**, **146**, **148**, and **150**. The bulkhead is welded to the cylindrical wall of the shield and is adapted to bear against the leading edge of the tunnel, with knees **152** abutting the bulkhead. This shield is in other respects similar to shield **98**.

Closure **154** mounted in any convenient manner for slidably closing ports **142** are adapted to regulate the flow of the earth into the leading end of the tunnel. With the ports closed, when the tunnel is jacked forward, the wet ground is forced against the bulkhead and resists forward movement of the tunnel. By opening a port, this earth will flow through the port and may be caught in suitable receptacles and carried back out of the tunnel. With one or more of the ports open, the tunnel may be jacked ahead with the wet earth pouring in through the open port. By means of the tension rods **156**, **158**, and **160**, which extend through the bulkhead and through anchors similar to those shown at **104**, **106**, and **108**, in Fig. 10, the shield may be angularly shifted on leading section **24**–*a*, and the articulated leading sections of the tunnel may be shifted relative to each other to steer the course of the tunnel during the forward jacking thereof. In addition, by opening a port, for example, the port at the top of the bulkhead, the earth will flow in through the port and relieve the pressure near the top of the shield. The tunnel will tend to move in the direction of this reduced pressure, and therefor will tend to move angularly upwardly during continued jacking of the tunnel. If the upper tension rod **106** is tightened as well as having the uppermost port in the bulkhead open, this combination very satisfactorily tends to elevate the leading end of the tunnel as it is jacked through the moist ground and either steer the tunnel along an upwardly extending course or maintain it on its intended course.

What I claim is:

1. A flexible leading end for a tunnel being constructed by the jacking method comprising: a plurality of articulated tunnel sections disposed in tubular alignment, mechanism extending throughout the tubular length of the sections along opposite sides thereof and including

adjustable bearing means extending the entire length of said plurality of sections and connecting the mechanism to the forward and rearward tunnel sections, said mechanism being extensible and retractable along opposite sides of the sections to shift the sections relative to each other and to different angularly related positions.

2. A flexible leading end for a tunnel being constructed by the jacking method comprising: a plurality of articulated tunnel sections disposed in tubular alignment, adjustable mechanism extending throughout the tubular length of the sections and inside the sections spaced radially inwardly from the walls thereof and including bearing means at opposite ends connected to the opposite end sections of said plurality of sections, said mechanism disposed at spaced intervals around the periphery of the sections adjacent the walls thereof and being extensible and contractable along directions paralleling the tubular axes of the sections to shift the sections relative to each other and to different angularly related positions.

3. Apparatus for the purpose described comprising: a tubular tunnel having a plurality of articulated tunnel sections at its leading end, at least one of said sections adjacent the leading end of the tunnel having a shorter tubular length than sections rearwardly thereof, extensible and contractable mechanism extending through the inside of the sections at opposite sides and adjacent the walls thereof from the leading section to the rearmost section and including adjustable means at each end connected to such leading section and to the rearmost section, said mechanism being extensible and contractable in directions parallel to the tubular axis of the tunnel and adapted to be contracted along one side of the tunnel and extended along the opposite side of the tunnel to flex the articulated sections in determined directions.

4. A flexible leading end for a tunnel being constructed by the jacking method comprising: a plurality of articulated tunnel sections, a shield articulated at one end of the plurality of sections, a plurality of tensioning rods extending longitudinally through the sections in spaced apart relation around and adjacent the walls of the sections, adjustable means connecting the rods at one end to the shield and at the other end to the end section remote from the shield, said means being operable to selectively tension some of the rods and slacken other of the rods to urge the shield at one end of the rods and

the end section remote from the shield at the other end of the rods toward each other along one side of the sections while permitting limited separation of the sections and of the shield along the opposite side, whereby the shield and the sections are flexed relative to each other to bend the leading end in a determined direction.

5. A flexible leading end for a tunnel being constructed by the jacking method comprising: a plurality of tunnel sections having a hub and spigot at opposite ends of each section to loosely join said plurality of tunnel sections loosely joined at their hub and spigot ends, a resilient ring encircling the spigot of each section and adapted to tension the sections apart at their meeting ends, a plurality of tensioning rods extending longitudinally through the sections in spaced apart relation around and adjacent the walls of the sections, adjustable means connecting the rods at opposite ends to the opposite end sections of said plurality of sections, said means being operable to selectively tension some of the rods and slacken other of the rods to urge the opposite end sections of said plurality of sections toward each other along one side of the sections and compress said resilient rings between the meeting ends of the sections while permitting limited separation of the sections along the opposite side, whereby the sections are flexed relative to each other to bend the leading end in a determined direction.

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