June 30, 1964 M. F. KEMPER 3,138,933

METHOD OF AND APPARATUS FOR DRIVING A TUNNEL THROUGH AND SUPPORTING EARTH STRUCTURE

Filed Aug. 19, 1957 6 Sheets-Sheet 1

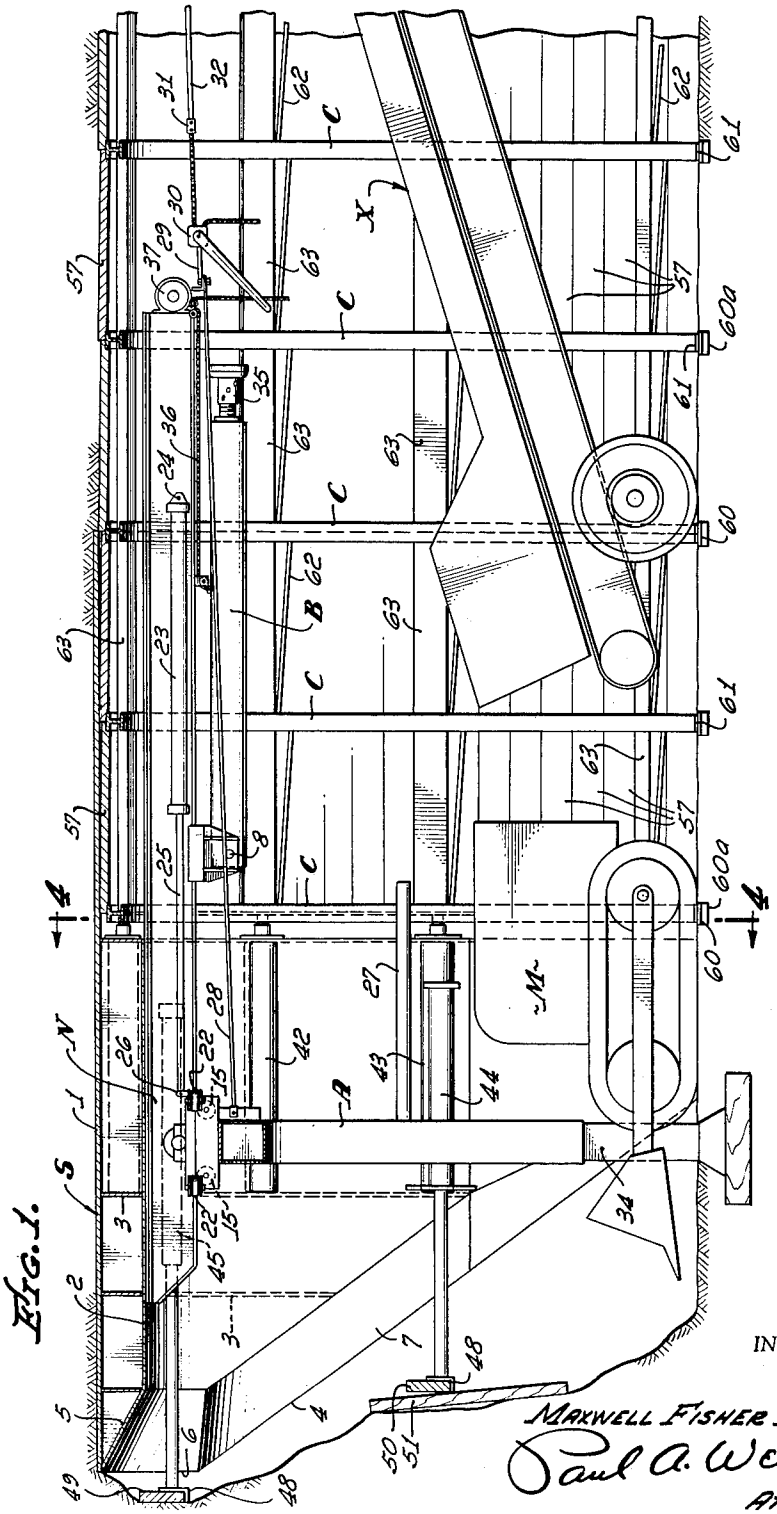


FIG. 1.

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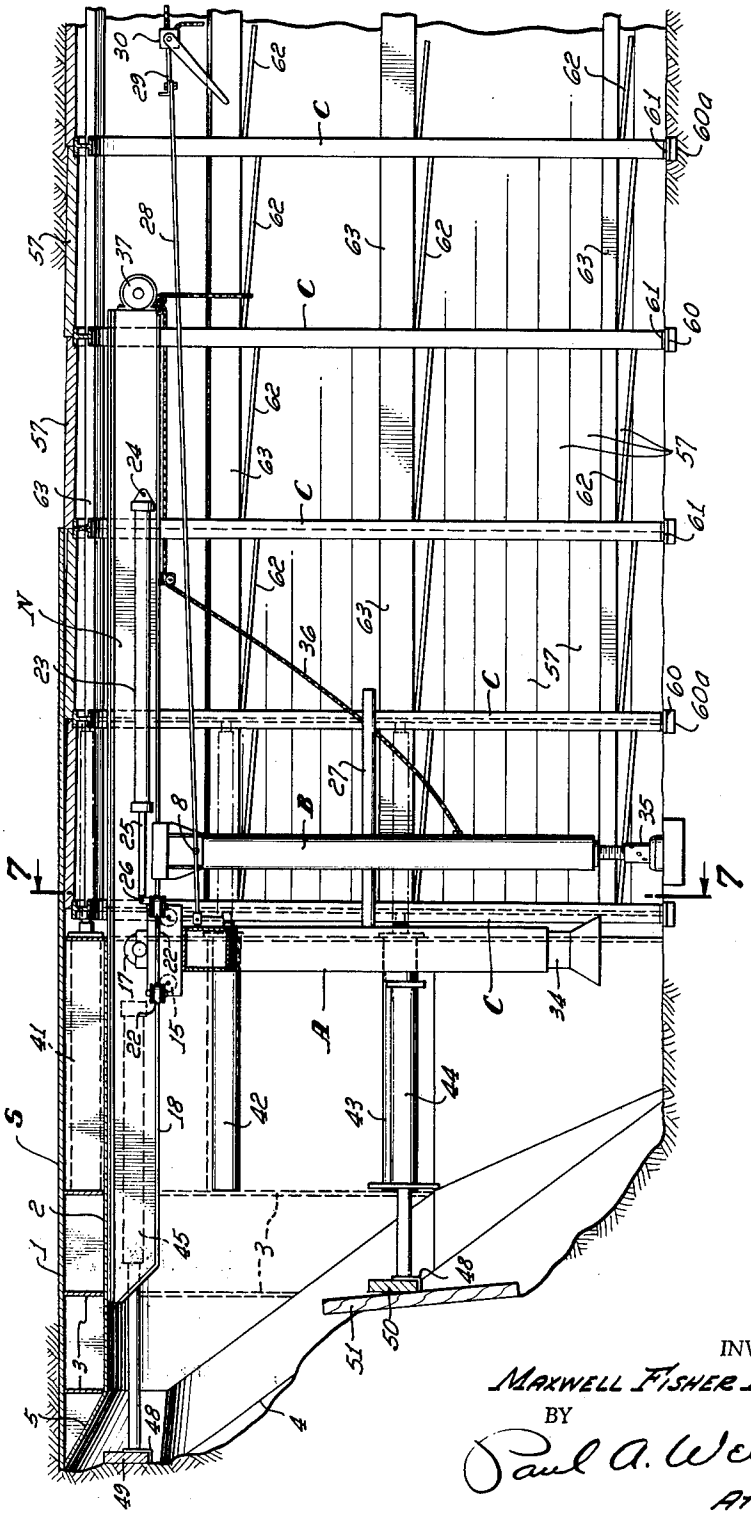


FIG. 2.

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FIG. 3.

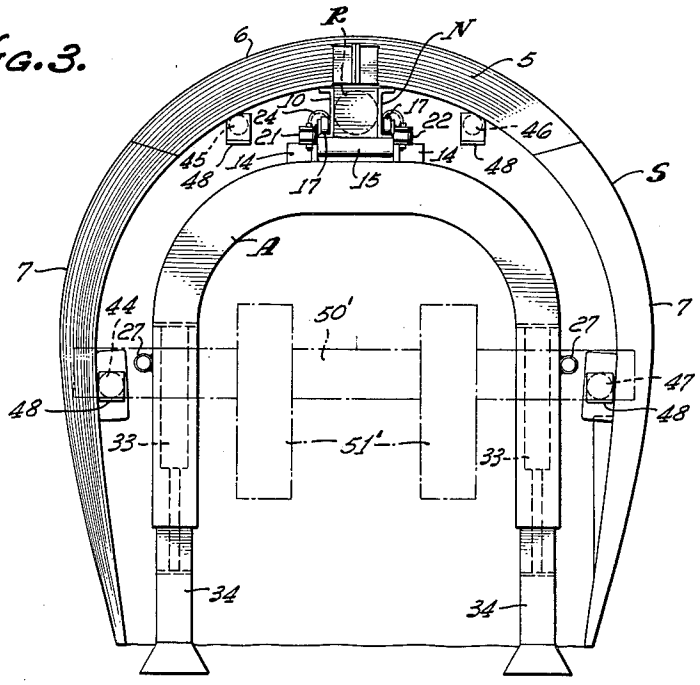
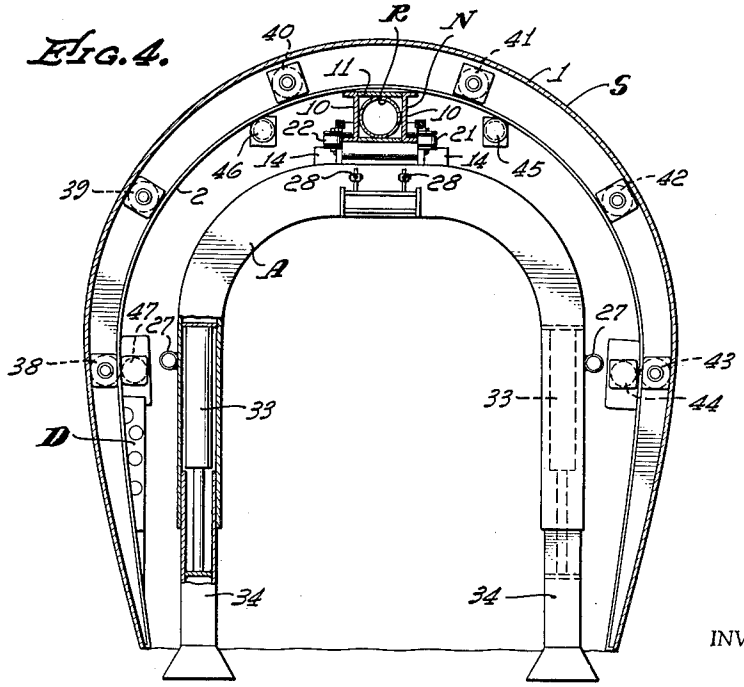


FIG. 4.



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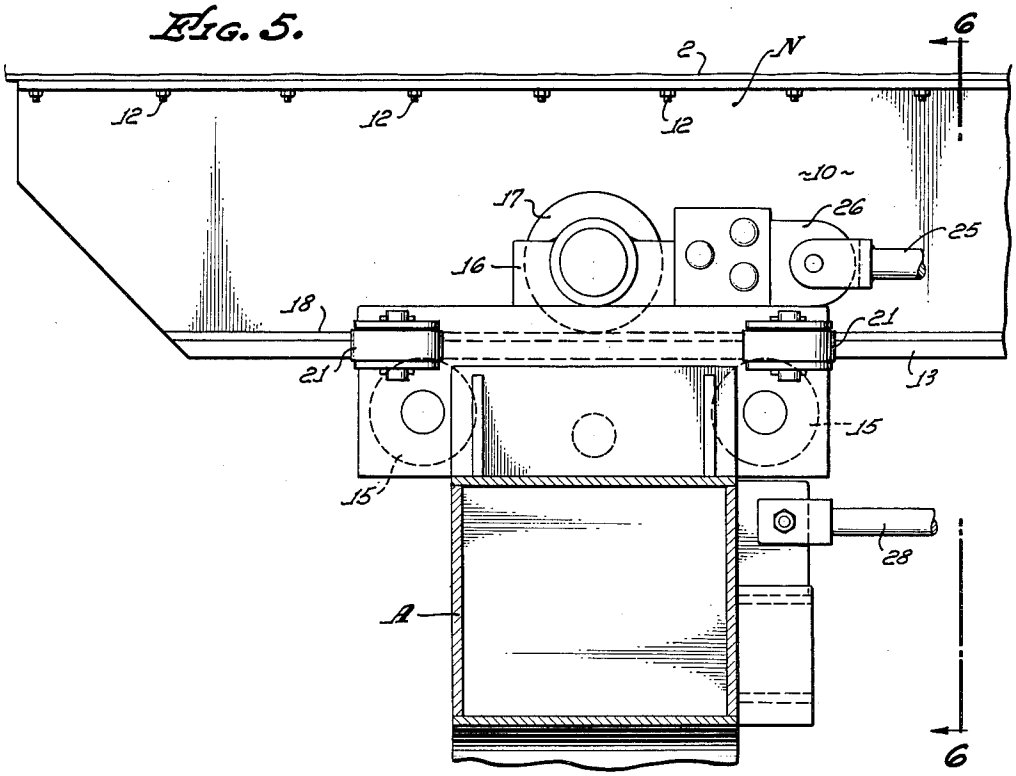
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METHOD OF AND APPARATUS FOR DRIVING A TUNNEL THROUGH AND SUPPORTING EARTH STRUCTURE

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FIG. 5.



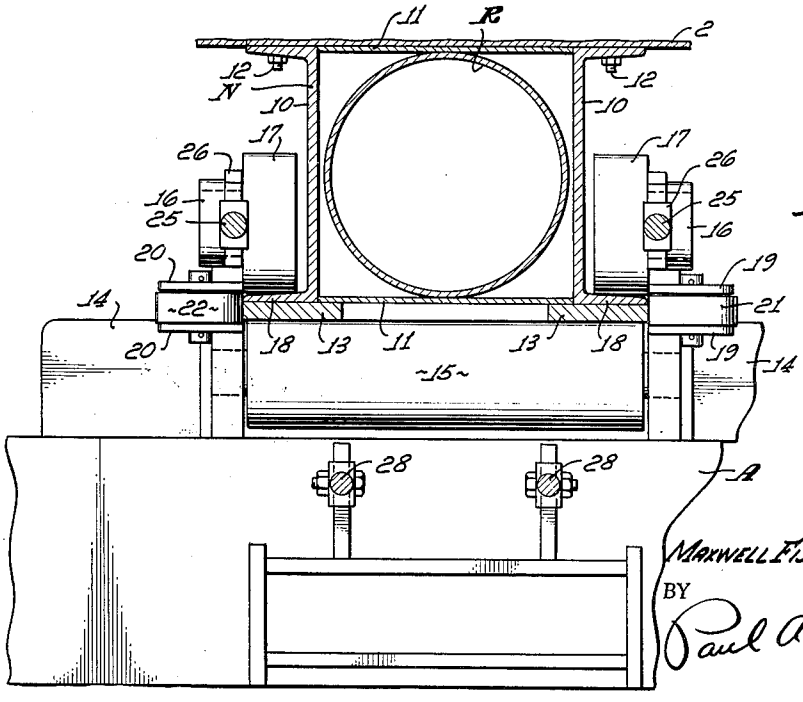


FIG. 6.

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METHOD OF AND APPARATUS FOR DRIVING A TUNNEL THROUGH AND SUPPORTING EARTH STRUCTURE

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FIG. 7.

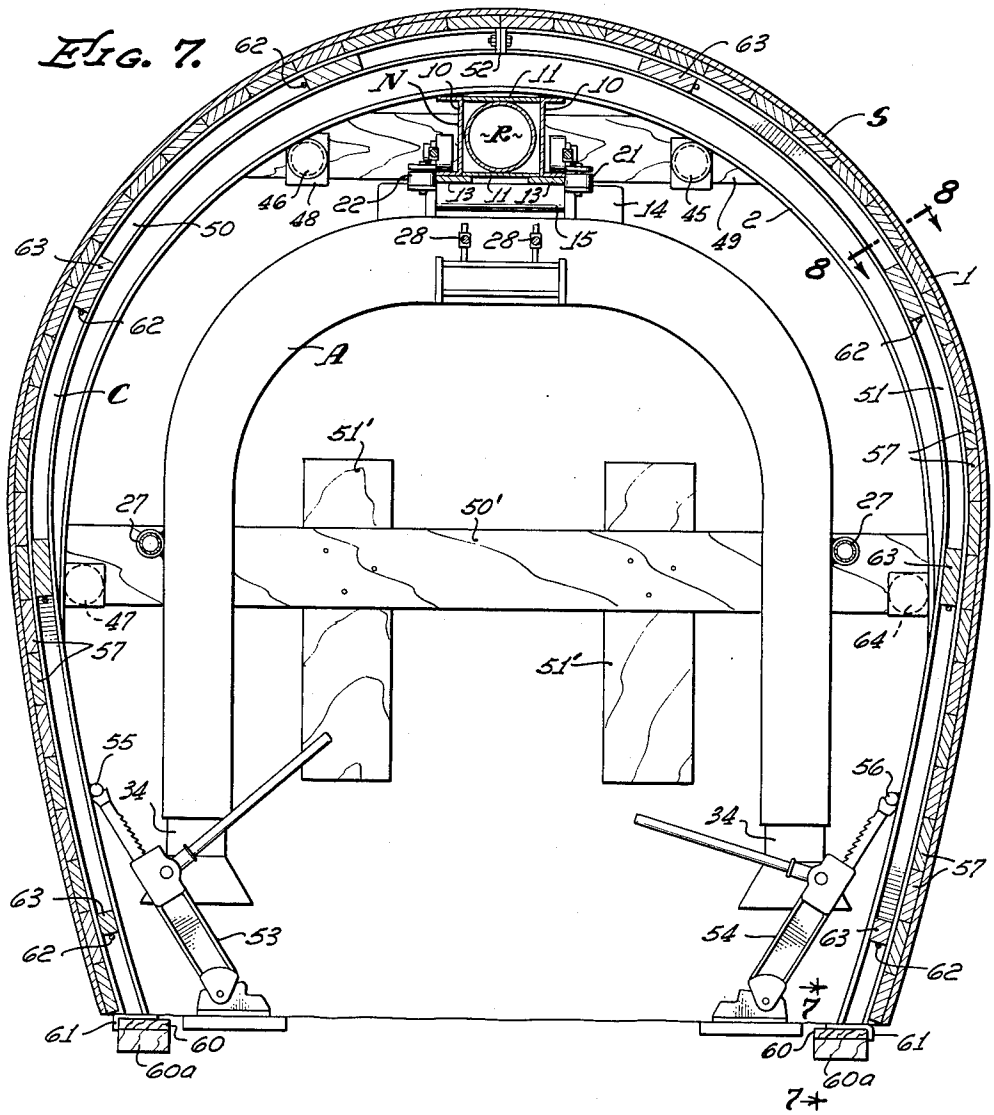


FIG. 7a.

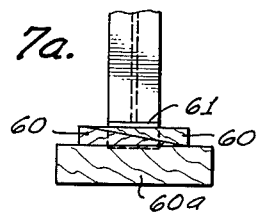
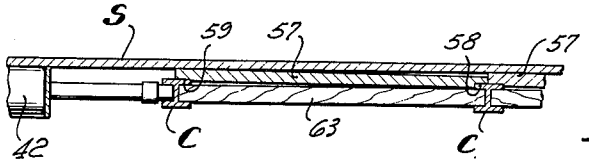


FIG. 8.



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METHOD OF AND APPARATUS FOR DRIVING A TUNNEL THROUGH AND SUPPORTING EARTH STRUCTURE

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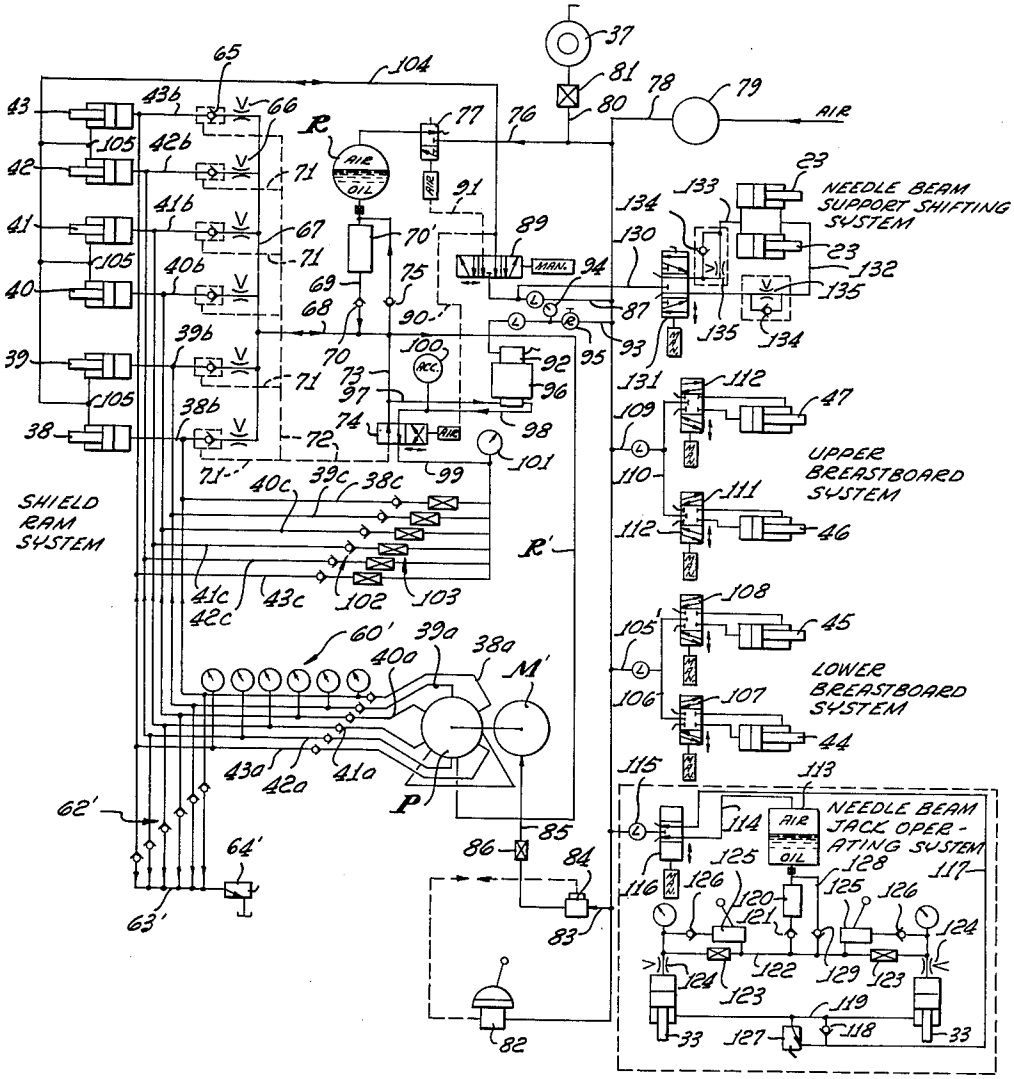


FIG. 9.

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United States Patent Office 3,138,933 Patented June 30, 1964

3,138,933

METHOD OF AND APPARATUS FOR DRIVING A TUNNEL THROUGH AND SUPPORTING EARTH STRUCTURE

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Filed Aug. 19, 1957, Ser. No. 678,993
16 Claims. (Cl. 61—85)

The present invention relates to a novel method of and an improved apparatus for driving a tunnel through earth formation, while supporting the overburden to prevent cave-in thereof.

Heretofore, it has been the practice to dig a tunnel through certain earth structures and to pour in the tunnel a concrete conduit such as might be employed for sewer or storm drainage. Conventionally such tunnels have been produced by successively supporting arched or horseshoe-shaped H beams or steel supports in spaced relation longitudinally of the tunnel as the tunnel progresses. As each beam is disposed in position and so supported, lengths of plank or spiling are driven into the face of the tunnel with sledge hammers. Obviously, this requires a great deal of manpower, and progress of such tunnels is comparatively slow. Moreover, particularly when digging a tunnel through sandy soil, driving of the spiling into the sand loosens this sand, and crevices or apertures frequently are left between adjacent spilings so that sand can commence to flow therethrough. While a small flow of sand through the supporting structure is not too significant, such a flow over a protracted period of time forms a substantial cavity in the earth structure above the tunnel, so that cave-ins in such a cavity are likely, thus possibly imposing upon the arched supports and spilings, sudden loads of substantial weight. Therefore, traditionally the arched supports and the spiling have been rather massive in order to support the loads to which they are subjected.

Despite the high cost and risks involved in digging a tunnel as just described, this has been the practice for many years in those instances where a horseshoe cross-sectional configuration is necessary from the standpoint of structural strength. In those instances where the structural rigidity of the generally horseshoe cross-section is not necessary, annular tunnels have been dug by forcing into the face of the tunnel a cylindrical shell which enables erection of an annular supporting structure within the cylindrical shell. While such cylindrical shells have afforded certain advantages, their use has also been accompanied by certain disadvantages. One of the primary disadvantages of a cylindrical shell as aforementioned, is the lack of directional control which has been a characteristic of all such shells heretofore known.

Prior to the present invention, the conventional spiling driving technique has traditionally been employed where the horseshoe type tunnel was required. This has been necessitated by the fact that while the lower side of a cylindrical shell as aforementioned affords a supporting base upon which the shell rests, a shell has not been employed in a horseshoe form for the lack of appropriate supporting means for the base of the shell.

A primary object of the present invention, accordingly, is to provide a novel method of driving a tunnel of horseshoe cross-section, this method contemplating the use of a shell of generally horseshoe cross-section adapted to be driven forcefully into the face of a tunnel as the tunnel progresses so as to enable erection of suitable supporting structure within the protective cover of the shell.

Another object of the invention is to provide novel apparatus including an elongated shell adapted to be driven into a tunnel face so as to support the overburden of earth and including novel means for supporting the shell so that the overburden of earth does not force the sides of the shell down into the earth as the shell advances.

A further object is to provide an improved method of driving a tunnel which includes driving a generally horseshoe-shaped elongated shield into the earth to permit removal of the earth at the tunnel face, assembling supporting arches or braces within the confines of the shield, installing lagging between successive arches under the protection of the shield, jacking up the arches to press the lagging into tightening conformity with the inner surface of the shield, advancing the shield further into the tunnel face while retaining the face of the tunnel against cave-in, and successively uncovering the arched and lagged tunnel-forming sections.

It should be understood that the tunnels herein referred to may be mine tunnels, in which case the horseshoe supporting structure will constitute the finished tunnel. On the other hand, however, if the tunnel is for the purpose of drainage or sewage conduction, then the horseshoe-shaped structure previously referred to will be employed as the outer form in the construction of a concrete conduit, as will become more apparent as the description progresses.

A further object of the invention is to provide a method of driving a tunnel wherein a generally horseshoe-shaped shield is driven into the tunnel face and as the shield is advanced periodically, arched H beams or "steels" are supported within the shield, these beams or arches being adapted to receive and support lagging or lengths of planking which is dapped or rabbeted at its opposite ends so as to overlie the adjacent arches or beams and in the final assembly afford longitudinal strength to the tunnel. In accordance with the invention, the lagging is engaged with a beam at one end which is pressed tightly against the lagging of the preceding tunnel section and the lagging being installed in the new section is dapped or rabbeted deeper at this end than at the opposite end of the lagging which is engaged with an arch or beam which is comparatively loosely disposed in place but which is jacked up tightly with respect to the overlying shield subsequent to the installation of a full set of lagging members.

Yet another object is to provide a method as aforesaid, wherein chocks or wedges are driven between foot plates on the ends of the H beams and a plank or other foundation member disposed in engagement with the earth. This is done before the jacks are released so that the H beam is maintained in place. An important result of this chocking arrangement is the fact that the H beam supports the trailing portion of the shield, and in the absence of a firm footing the H beam will permit sagging of such trailing shield portion and erratic shield movement.

A further object is to provide novel apparatus which is eminently suited to the performance of the method previously referred to and in this connection such apparatus preferably provides means for shiftably supporting the U or horseshoe-shaped shield, such supporting means including what will be generally referred to in this application as a "needle beam" and means for supporting a needle beam. This needle beam support comprises a structural member adapted for relative axial movement with respect to the shield whereby when the needle beam is held stationary in supporting relation to the shield, the shield may be shifted axially so as to advance into the tunnel face. As each new tunnel section is erected, an auxiliary support is employed for the needle beam while the needle beam and its main support are adjusted to permit further advancing of the shield with respect to the main support. In this connection, the needle beam support comprises an inverted U-shaped frame or arch disposed transversely of the tunnel and having jacks in

its opposite sides adapted to engage the floor of the tunnel so as to exert upward pressure upon the shield to prevent diving of the shield as it progresses into the tunnel face. As each new tunnel section is constructed and preparations are made for advancing the shield for the erection of a succeeding tunnel section, the auxiliary needle beam support is employed to enable retraction of the jacks of the main needle beam support whereupon the main needle beam support may be shifted axially with respect to the shield to a new supporting position and the jacks again put into use.

Another object of the invention is to provide novel hydraulically operated means for positively forcing a shield into the tunnel face. Such means comprising a plurality of hydraulically operated rams disposed in spaced relation about the shield and adapted upon the pumping of fluid therein to positively force the shield ahead. In accordance with one of the salient features of the invention, these hydraulic rams are supplied with fluid from a positive displacement pump of the type which will displace equal amounts of hydraulic fluid to each of the respective shield driving rams. In order to effect directional control of the shield, the hydraulic operating system for the rams is preferably provided with means under the control of appropriate valve mechanism for selectively forcing a greater volume of fluid into one or more selected ram cylinders, thus to cause extension of said selected ram or rams a greater distance than the other rams, thus causing the shield to be forced to turn in a given direction, depending upon which of the rams is furthest extended.

Broadly, then, an object is to provide means for digging a tunnel including a shield, means for exerting uniform pressure at one end of the shield, preferably at spaced points thereabout, and means for exerting additional pressure at a selected point or points for effecting directional control of the shield.

And yet another object of the invention is to provide a novel tunnel driving shield as aforesaid which is equipped with air operated breastboard rams which are adapted to be projected longitudinally of the tunnel and to support breastboarding against the tunnel face. Since these breastboard rams are air operated, they will in effect resiliently bias the breastboarding against the tunnel face and will permit axial movement of the shell into the tunnel face as the breastboard rams are forced back into their power cylinders, depending upon the contour of the face of the tunnel. In this way, cave-in of the tunnel face is eliminated.

In accordance with the preceding objectives, it is a further object to provide a method and apparatus as aforesaid which enables the dirt or earth removed from the tunnel face to be scooped up and loaded by an air operated or otherwise powered so-called "mucker" which is a front-loading, overhead-unloading type of machine, conventionally employed in the digging of tunnels, and which is adapted to dump successive scoop loads of earth onto a conveyor which may either carry the earth all the way to the tunnel mouth or may transfer the earth to a mine train rearwardly of the tunnel digging apparatus.

The novel method and apparatus hereof are possessed of other advantages and novel features which will hereinafter be more particularly pointed out, or will become apparent to those skilled in the art, and the novel features of the invention will be defined in the appended claims.

In the accompanying drawings:

FIG. 1 is a longitudinal sectional view taken through a tunnel driving apparatus which is made in accordance with the invention, and which is exemplary of apparatus ideally suited to the performance of the present method, the shield and the needle beam support being in the positions with respect to the needle beam which they would normally be in upon completion of a tunnel section and prior to forcing of the shield forwardly into the tunnel face.

FIG. 2 is similar to FIG. 1 but showing the shield in an extended position and showing the auxiliary needle beam support in a ground-engaging, needle beam-supporting position and the main needle beam supporting jacks retracted to enable the main needle beam support to be advanced to a new position with respect to the needle beam, the pistons of the shield advancing rams being shown in broken lines in a fully extended position.

FIG. 3 is an elevational view of the tunnel driving apparatus of FIGS. 1 and 2;

FIG. 4 is a transverse sectional view as taken substantially on the line 4—4 of FIG. 1;

FIG. 5 is an enlarged fragmentary detail view partly in elevation and partly in section showing the needle beam and the main needle beam support and the shiftable connection between these elements;

FIG. 6 is a view in section as taken substantially on the line 6—6 of FIG. 5;

FIG. 7 is an enlarged fragmentary detail view in section taken transversely of the tunnel driving apparatus substantially on the line 7—7 of FIG. 2 and more particularly showing the method of jacking up the successive hoseshoe shaped or arched supporting H-beams or "steels" into tight engagement with the shield prior to shifting the position of the needle beam support and further driving of the shield;

FIG. 7*a* is a fragmentary elevational view on an enenlarged scale, as taken on the line 7*a*—7*a* of FIG. 7.

FIG. 8 is an enlarged fragmentary detail view in section as taken on the line 8—8 of FIG. 7 and more particularly showing the novel method of dapping or rabbeting the lagging planks to enable their insertion between adjacent arched steels or beams; and

FIG. 9 is a diagrammatic view of the hydraulic and pneumatic system for operating the various instrumentalities of the novel apparatus hereof.

Like reference characters in the several figures of the drawings and in the following detailed description, designate corresponding parts.

Referring particularly to FIG. 1, novel apparatus is shown for accomplishing the method of the present invention.

In accordance with the invention, the apparatus comprises a generally U-shaped shield S, having an outer skin plate 1 extending rearwardly of the body of the shield so as to provide an elongated skirt, and an inner plate 2, which are suitably reinforced and interconnected with structural members 3. At its forward extremity, the shield S is provided with a cutting edge 4. The inner wall of the shield S is provided with an angularly disposed forward section 5 providing somewhat of a plain surface. The shield S has an arcuate upper leading edge 6 which is disposed substantially transversely of the tunnel and with a pair of downwardly extending sections 7 constituting side walls of the shield, which side walls recede toward the rear of the shield from the top towards the bottom thereof. Centrally mounted and longitudinally disposed within and secured to the shield S is a needle beam N which will be more particularly described hereinafter. The needle beam is provided with a pair of needle beam supports, namely a main support A which is generally arched or U-shaped in form and which is adapted to be shifted with relation to the needle beam N relative thereto; and an auxiliary support B which is pivotally mounted on the beam as at 8 and which is adapted to be moved from an inoperative position paralleling the needle beam as shown in FIG. 1, to an operative position in ground engaging needle beam supporting relation as shown in FIG. 2.

In the use of the apparatus, an air or other power operated front-loading overhead-unloading machine or "mucker" M is adapted to move between the opposite laterally spaced sides of the main needle beam support A so as to scoop up earth and transfer the same overhead to a conveyor assembly X as shown in FIG. 1. The conveyor assemblies are conventional elements and need

not be further described since their operation is well known to those skilled in the art and they are commonly employed in the tunnelling field.

As previously mentioned, the needle beam support A and the needle beam N are shiftable with relation to one another and, as more particularly seen in FIGS. 5 and 6, the needle beam N is preferably composed of a pair of U-shaped structural members **10, 10** disposed back to back in spaced relation and interconnected at their extremities by transversely extended plates **11, 11**. At its upper side, the needle beam N is bolted as by bolts **12** to the inner plate **2** of the shield S and at its base the needle beam N has welded or otherwise suitably secured thereto a pair of longitudinally extended rails **13**. The needle beam support A has secured to its upper end and substantially at its midpoint, a pair of laterally spaced upstanding roller supports **14, 14** in which are suitably journalled a pair of rollers **15, 15** which extend transversely of the needle beam and are in rolling contact with the rails **13** previously referred to. In addition, the roller supports **14** have a pair of upwardly projecting bearing blocks **16, 16** thereon which are adapted to rotatably support a pair of rollers **17, 17** which are rotatably mounted on axes parallel to the axes of the rollers **15, 15** and to rollingly engage with the lower flanges **18, 18** of the U-shaped structural members **10, 10**. Furthermore, the roller supports **14** are provided with opposed pairs of outstanding ears **19, 19** and **20, 20** in which are respectively mounted a pair of rollers **21** and **22** which latter rollers are disposed on axes normal to the axes of the rollers **15** and **17**. The rollers **21** and **22** are adapted to rollingly engage the outside edges of the rails **13, 13**. Accordingly, it will be noted that the rollers **15, 17, 21** and **22** completely support the needle beam support A upon the needle beam for relative movement of these parts.

In order to effect such relative movement of the needle beam support A with relation to the needle beam N, a pair of fluid pressure operated rams **23** are connected at one end to the needle beam N at opposite sides of the latter as at **24**, and each ram **23** includes an operating rod **25** which is connected to an upstanding bracket **26** on the needle beam support A.

The rams **23** will act to shift the needle beam support A to the left as seen in FIG. 1 with respect to the needle beam and the shell and therefore means are also provided for limiting such movement. Such means is preferably in the form of a pair of rods **28** which extend rearwardly of the needle beam astraddle auxiliary needle beam support B, and which are interconnected as by a yoke member **29** to a come-along **30**. The come-along being connected as at **31** to a pair of rods designated **32** which are adapted to be connected at their end to any suitable fixed support.

As is best seen in FIGS. 3 and 4, the needle beam support A is provided in its opposite sides with a pair of fluid pressure operated jacks **33** and with telescopic legs **34** adapted to engage the ground at the floor of the tunnel upon expansion of the rams **33** so as to jack up the needle beam N and the shield S. The jacks **33** also serve to raise the legs **34** as shown in FIG. 2, so that the needle beam N may be supported on the auxiliary needle beam support B to a new supporting position. The auxiliary needle beam support B is also provided with a jack member **35** which is shown as being of the screw type but which, of course, without departing from the invention, may also be hydraulically operated. In any event, however, the jack **35** may be manipulated to exert upward pressure upon the shield S to support the same as the legs or jacks **34** of the main needle beam support A are elevated and the support A is shifted to a new position.

In order to facilitate movement of the auxiliary needle beam support B from the supporting position shown in FIG. 2 to a raised inoperative position as shown in FIG. 1, a chain **36** is preferably connected to the needle beam support B and is operatively engaged with driving means powered by a motor **37** of the air or hydraulically driven type which is secured at the rear extremity of the needle beam N, and which is adapted to feed the chain **36** through the driving means so as to swing the latter about the pivot **8** to the inoperative position aforesaid.

In order to advance the shield S from the position shown in FIG. 1 to the one shown in FIG. 2, the shield has mounted therein a series of substantially equidistantly spaced latitudinally extended rams or fluid pressure operated actuator cylinders as are best seen in FIG. 4, these cylinders being designated respectively **38, 39, 40, 41, 42** and **43**. The pistons of these actuator devices are adapted to be backed up by a means which will hereinafter be more particularly described, while the cylinders of said devices are rigidly connected to the shield S, so that upon the admission of fluid from a source of supply, the cylinders will be shifted axially with respect to the pistons and consequently the shield S will be urged axially into the face of the tunnel. The motive fluid for these actuator cylinders **38** through **43** is preferably a hydraulic fluid supplied thereto from a reservoir R consisting of a cylindrical tank recessed within the needle beam N, as is best seen in FIGS. 4 and 6.

As the shield S progresses into the tunnel face, the latter would normally tend to cave-in, and accordingly, in conformity with one of the salient features of the invention, the shield preferably carries a plurality of breastboard retaining cylinders **44, 45, 46** and **47**. The cylinders **44** and **47** are, as is best seen in FIG. 3, preferably disposed substantially at the "spring line" of the tunnel, while the cylinders **45** and **46** are disposed adjacent the top of the shield on opposite sides of the vertical center of the latter. Each of the breastboard supporting actuator cylinder devices is provided at the free end of its piston with a generally L-shaped supporting bracket **48** adapted to support thereon in transversely extending relation, upper and lower breastboards **49** and **50'**, respectively, which are adapted to engage the tunnel face and to prevent substantial cave-in thereof. In addition, a suitable number of vertically arranged planks as indicated at **51'** may, if desired, be interposed between the breastboard **50'** and the tunnel face, so as to further retain the tunnel face against collapse. As will hereinafter more fully appear, the breastboard actuator cylinders **44** through **47** are preferably air operated so that the shield S, upon which the cylinders of the breastboard actuator devices are carried, advances into the tunnel face, the respective pistons may be forced back into the cylinders thus compressing the air and thereby tending to yieldably be retained against the tunnel face by virtue of the compressed air within the actuators.

In operation in accordance with the method of the present invention, and assuming the apparatus to be as shown in FIG. 1, fluid is admitted to the shield driving hydraulic actuator devices **38** through **43** from the reservoir R so as to force the shield S axially into the face of the tunnel while the breastboard supporting actuator devices **44** through **47** serve to resiliently retain the breastboard arrangement against the tunnel face to prevent substantial cave-in. When the shield has progressed to the point shown in FIG. 2 with the pistons of the actuator devices **38** through **43** substantially fully extended as shown in broken lines in this view, each of the successive horseshoe shaped supporting means C shown in FIGS. 1 and 2 are installed in the same manner as now to be described, with particular reference to FIG. 7, and FIG. 8.

The arched H beam or "steel" half sections **50** and **51** would ordinarily be dispose in an out of the way position adjacent to the conveyor X so that when the pistons of the actuator devices **38** through **43** have been retracted to the positions shown in full lines in FIG. 2, the respective half sections **50** and **51** may be elevated into an initial position and bolted together at the midpoint of the beam as at **52**. A pair of jacks **53** and **54** are

respectively engaged with jack-engaging projections 55 and 56 on the arched H beam half sections 50 and 51, and the arched beam C is thus held in its initial position, whereupon, commencing at the bottom at each side of the arched beam support, planks or lagging generally designated 57 are set into place longitudinally of the tunnel so as to span the space between the preceding arched support or rib C and the one presently being installed. In order to facilitate installation of lagging in the crown of the tunnel, arms 27 are preferably supported at one end upon the legs of the needle beam support A and extend longitudinally of the tunnel. These arms afford supporting means on which a platform or scaffolding may be disposed.

As is best seen in FIG. 8, the opposite ends of each lagging or plank 57 are notched or dapped with the end of each lagging or plank which is first to be inserted, rabbeted or dapped as at 58 to a greater extent than the opposite end of the lagging or planks as at 59. Since the previously installed arched H beam or rib C is firmly pressed and secured in position against the lagging which in turn is pressed against the outer skin 1 of the shield S. This differential dapping of the ends of the lagging 57 facilitates insertion of the deeper dapped end 58 into the space between the last mentioned rib C and the shield S. As is clearly illustrated in FIG. 8, by virtue of this arrangement, the arched wall formed by the lagging is not in uniform frictional engagement with the outer skin 1 of the shield S, thus substantially reducing the force required to shift the shield.

Following the insertion of the lagging 57, the jacks 53 and 54 are employed to jack the arched beam C into firm engagement with the ends 59 of the lagging. Chocks or wedges 60 are driven between foot plates 61 at the lower extremity of the respective half sections 50 and 51 of the beams C and a plank 60*a* which is disposed in engagement with the ground and affords adequate supporting area for the ribs C, whereby they will be tightly held in place by the chocks 60. This will preclude the shield S from sagging at the rear during forward movement thereof. It should be noted that prior to final tightening of the arched beam C being installed, a series of tie bolts 62 are extended between adjacent H beams or ribs C so as to rigidly tie the same together in uniformly spaced relation, the tie bolts 62 being preferably substantially equidistantly spaced about the extent of the tunnel section. In addition, closely adjacent to each of the tie bolts 62, a plurality of collar braces 63 are installed, these collar braces being adapted to fit within the flanges of the H beam as shown in FIG. 8 at the respective opposite ends of the collar braces. As is best seen in FIGS. 1 and 2, the collar braces 63 constitute an elongated reinforcing member backing up the respective shield driving actuating devices 38 through 43, the pistons of which, as previously mentioned, are backed up against the last installed arched beam support C as shown in FIGS. 1, 2 and 8.

Following final tightening up of the arched beam supports C just installed as shown in FIG. 7, the auxiliary needle beam support B will be lowered to the position shown in FIG. 2 and the jack 35 actuated to exert upward force upon the needle beam N, thus relieving the load upon the main needle beam support A. Thereupon, the telescoping legs 34 of the needle beam support A are elevated by the fluid pressure operated jacks 33 therein, as also shown in FIG. 2. Upon such elevation of the legs 34, the actuator devices 23 may be pressurized to shift the needle beam support A to the position shown in FIG. 1. However, in order to effect such movement of the needle beam A, tension on the yoke retaining means 28 must be relieved through the action of the comealong 30 and after the repositioning of the needle beam support A has been effected, the comealong may be employed to retention the yoked links 28 so as to prevent further forward movement of the needle beam support A.

At this time, the telescopic legs are jacked back down into engagement with the earth surface and the jack 35 is relieved of supporting engagement with the ground and the fluid operated motor 37 may then be controlled to pull the chain 36 rearwardly so as to elevate the auxiliary needle beam support to the position shown in FIG. 1.

Referring to FIG. 4, at the lower left hand side of the assembly, there is shown a control panel D, and all of the foregoing operations are preferably effected manually from this control panel which is part of a housing containing suitable control valves and operating mechanism which will hereinafter be more particularly described for controlling the operation of the fluid pressure circuitry shown diagrammatically in FIG. 9.

Passing now to FIG. 9, the jacks 33, 33 of the main needle beam support A are so designated in the diagram. Likewise the breastboard cylinders 44 through 47 are so designated, as are the needle beam support shifting actuators 23 and the shield shifting actuator devices 38, 39, 40, 41, 42 and 43. The reservoir R in the needle beam N is shown in the diagram also.

Diagrammatically illustrated in FIG. 9, is a positive displacement pump P of the radial reciprocating piston or other appropriate type which is driven by a motor M' and which is capable of pumping from the reservoir R through a line R' upon each revolution of the pump, equal volumes of hydraulic fluid through lines 38*a*, 39*a*, 40*a*, 41*a*, 42*a* and 43*a*, these lines respectively leading to the actuator cylinder devices, 38 through 43 respectively through branch lines 38*b*, 39*b*, 40*b*, 41*b*, 42*b* and 43*b*, for forcing the shield S axially. Each of the lines 38*a* through 43*a* is respectively provided with a pressure gauge as generally indicated at 60' and in addition, if desired, each of these lines is also provided with a branch leading to a check valve 62', these branch lines being manifolded as at 63' to a relief valve 64' of an appropriate type. Branch lines 38*b* through 43*b* are also provided with check valves 65 and throttle valves 66, and are manifolded through line 67 to a supply line 68 which is in turn connected to a reservoir R through a line 69 which is preferably provided with a check valve 70 and preferably a filter 70'. Lines 38*b* through 43*b* are also interconnected with exhaust lines 71 shown in broken lines in FIG. 9, these exhaust lines being manifolded through exhaust line 72 to a return line 73 leading to the reservoir through a four-way air operated valve 74, the operation of which will be hereinafter more particularly described. Preferably interposed in the line 73 is a check valve 75.

In order to combine the compressiveness of air with the positive displacement characteristics of liquid or oil, the system shown in FIG. 9 is preferably a combination air and oil system, and as shown in this view, the reservoir R is partially filled with oil and partially filled with air. Air is supplied to the reservoir through a line 76 via an air operated valve 77 from a supply line 78 which is connected to a suitable source of air under pressure, such source may be located rearwardly of the structure previously described and within the tunnel as at 79. A suitable separator or filter may be installed in the air feed line or if desired both of such elements may be installed therein.

It will be noted that the air motor 37 previously referred to which serves to feed the chain 36 through a drive mechanism, as previously described, is interconnected with an air supply line such as the line 76, through a branch line 80 having a control valve 81 therein for controlling the operation of the air motor 37.

The air supply line 78 is connected through a conventional regulator 82, through a branch line 83 leading to a booster 84 and a line 85, with the motor M' which is preferably of a known air driven type. The line 85 preferably is provided with a shut-off valve as at 86. Thus, it will be seen that air under pressure admitted into the system through line 78 serves to provide motive power to the motor M' and also to provide a source of pressure

for pressurizing the oil contained in the reservoir R.

In addition, there is branch line 87 connected to the air line 78 which is adapted to be selectively connected through a manually operated four-way valve 89, selectively, with air operated valve 74 through a line 90, or with air operated valve 77 through a line 91. Thus, the valve 89 will serve the dual purpose of controlling the admission of air under pressure into the reservoir and controlling the return flow of fluid from the shield rams 38 through 43, through the return lines 71, manifold 72 and line 73 in which valve 74 is installed. Valve 74 serves a further function with respect to controlling the selective injection of additional volumes of fluid into selected rams of the series of shield actuating devices 38 through 43. In this connection, it will be noted that an air motor 92 is adapted to be driven by air supplied through line 93 which is interconnected between the motor 92 and the supply line 78, the line 93 being preferably provided with a lubricator as at L, a gauge 94 and having therein a regulator 95 for controlling the operation of the air motor 92. The motor 92 drives a booster pump 96 having an inlet line 97 interconnected through lines 73, 68 and 69 as well as through check valve 70 with the oil in the reservoir R. The booster pump 96 also has an outlet line 98 which is adapted to be selectively placed into communication with a line 99 through the air operated valve 74 just referred to above, when the air operated valve 74 is in one position responsive to appropriate manipulation of manually controlled valve 89. In addition, the line 97 may be provided with an accumulator 100 for maintaining a constant pressure upon the fluid in the line 99 when the valve 74 establishes communication with the latter line and line 97.

Accumulator 100 is adapted to maintain a pressure greater than the pressure in fluid lines 38*b* through 43*b*, as may be determined by the gauges 60 previously described and a gauge 101 in line 99 which is connected to a series of lines 38*c*, 39*c*, 40*c*, 41*c*, 42*c*, and 43*c* which are respectively connected to the lines 38*b* through 43*b*. The lines 38*c* through 43*c*, respectively, are preferably provided with a check valve as collectively designated at 102, as well as with a manually controlled shut-off valve, such shut-off valves being collectively designated at 103. As the result of this arrangement, it will be noted that under the selective control of valves 103, additional oil under pressure may be directed to the respective shield driving rams 38 through 43 so that any of these rams either singly or in combination may be provided with extra fluid to force such rams to expand somewhat further than the other rams. Therefore, in the event that during a tunnel digging operation, it should appear that the shield is beginning to veer off course, directional control of the shield may be effected through selective advancement of the respective rams. In practice, a surveying instrument such as a transit is employed in the tunnel to take a sight on the direction of travel of the shield following the installation of each successive rib or steel C. In this manner, any deviations of the shield during each successive section construction, may be compensated for as the shield progresses.

In order to retract the pistons of the rams 38 through 43 prior to the installation of a rib or steel C, as previously described, a line 104 is connected to the respective actuator devices through lines 105, this line 104 also being connected through manually controlled valve 89 to line 87 previously referred to, which is in turn connected to air supply line 78. Thus, when the manual control valve 89 is shifted from a shield shifting position to a ram retracting position, the rams will be retracted.

It is desired that the breastboard actuator cylinders be supplied with air to resiliently bias the breastboards against the tunnel face, and accordingly, these cylinders are also connected to the air supply line 78. The lower breastboard cylinders 44 and 45 are interconnected to the lines 78 through a branch line 105' having a lubricator therein, the line 105 being connected through a line 106 via a pair of manually controlled four-way valves 107 and 108. Upon shifting of these valves 107 in opposite directions, it will selectively effect communication between the line 106 and the opposite sides of the piston of the ram of the actuator cylinder 44 with an exhaust port, as will be well recognized by those skilled in the art. Valve 108 functions in the same manner as valve 107 so as to control the projection and retraction of the piston of actuator cylinder 45. The upper breastboard cylinders 46 and 47 are connected to air supply line 78 through a line 109 via a line 110 which feeds through a pair of manually controlled four-way valves 111 and 112 for controlling the projection and retraction of the cylinders 46 and 47 in the same manner as the pistons of cylinders 44 and 45 are actuated under the control of valves 107 and 108.

As has been previously pointed out, prior to shifting the needle beam supporting arch A, the telescopic legs 34 thereof are retracted by the fluid pressure operated jacks 33, as shown in FIG. 2 of the drawings. As shown in FIG. 9, the system for operating the actuator devices 33 is also a combined air and oil system in its preferred embodiment and preferably includes a reservoir 113, the air being supplied to the reservoir through a line 114 which is connected to a line 115 leading from the air suply line 78 previously referred to through a manually controlled valve 116. The manually controlled valve 116 also controls the connection of the fluid supply line 78 to a line 117 which is connected through a check valve 118 to a line 119 which is interconnected with both of the actuators 33 at the outer side of the piston so as to effect retraction of the piston within the cylinder 33. Oil is supplied under pressure imposed thereon by the air in the upper part of the reservoir 113 through a filter 120, a check valve 121 and a line 122 which is interconnected with the actuator cylinders 33 through a pair of shut-off valves 123, 123, and a pair of throttle valves 124. Inasmuch as the air pressure which causes expansion of the rams 33 through the oil in the system is compressible, whereas rigid support of the needle beam support A is desired during operation, the rams 33 are initially expanded by the air pressure and the valves 123 are then closed off, thus trapping fluid in the rams 33. In order to further expand the rams, each branch of the hydraulic circuit for operating the rams 33 is provided with a manually or otherwise operated high pressure pump 125 which is connected to the actuator cylinders 33 through a check valve 126 and thence through the throttle valves 124 at the closed off side of the respective shut-off valves 123. Accordingly, with the valves 123 closed, the pumps 125 may be manually operated, or if desired such pumps may be power operated; but in any event the function of the pumps is to inject additional volumes of hydraulic fluid under high pressure into the rams 33.

During elevation of the legs 34, which may be simply effected merely by opening shut-off valves 123 and operating manually controlled valve 116 to permit the passage of air through line 117 into line 119, any excess pressure in line 119 being bled off through a relief valve, as indicated at 127, hydraulic fluid in the actuator cylinders 33 will, of course, pass back into the reservoir 113 through a line 128 having a check valve 129 therein and interconnecting line 122 with the reservoir 113.

With the legs 34 so elevated and in accordance with the present method, the needle beam support A will then be shifted forwardly of the shield towards the tunnel face by the needle beam support shifting cylinders 23 which, as shown in the diagram now being described, are air-operated through a line 130 which is suitably connected to the air supply system as by connection with the line 87. The line 130 is provided with a manually controlled four-way valve 131 which is adapted to establish communication between line 130 and one side of the pistons of the actuator cylinders 23 through a line 132 and with the other side of said pistons through a line 133. One of the

latter lines leads to the expansion side of the piston and the other of said lines leads to the retraction side of the piston. Each of the lines 132 and 133 is preferably provided with a flow-controlling valve assembly including a check valve 134 and a throttle valve 135, whereby movement of the pistons of these actuator cylinders 23 in opposite directions is cushioned by the action of the throttle valves 135.

It will be aparent to those skilled in the art that without departing from the invention, variations may be resorted to in the hydraulic system shown in FIG. 9.

It should now be recognized that with the apparatus hereof in the condition shown in FIG. 1, such apparatus will be operated in the performance of the present method as follows:

Valves 123 of the needle beam jack operating system will be closed so that fluid in the cylinders of the jacks 33 is trapped therein, but if desired, this fluid column in the actuators may be supplemented by the operation of the high pressure pumps 125. The throttle 82 is then operated so as to effect operation of the motor M whereby pump P will supply fluid under pressure to the respective shield rams 38 through 43, in equal volume per revolution of the pump. However, should it be desired to correct for any deviation of the shield which may have occurred during prior operations, the valves 74 and 89 will be manipulated so that the booster pump 96 will supply fluid selectively through the lines 38c through 43c so as to inject additional volumes of fluid into one or more selected cylinders of the cylinders 38 through 43, thus effecting a steering action of the shield S as it progresses.

During progression of the shield S, air is continuously supplied through supply line 78 to the upper and lower breastboard cylinders through their respective control valves 107, 108, 111 and 112, so as to resiliently maintain the breastboards 50 and 51 in engagement with the face of the tunnel, thus preventing undue cave-in thereof. After the shield has been fully extended so that the pistons of the shield rams 38 through 43 are in the positions shown in broken lines in FIG. 2, then the halves of the arched H-beam or steel support C will be bolted together and the rib C will be installed in position for supporting the lagging between it and the last installed H-beam support or steel C.

The lagging will be installed preferably working from the bottom upwardly at each side of the tunnel with the deeper dapped end of each lagging being inserted first into engagement between the last installed H-beam support C and the skirt of the shield, the other end of the lagging then being easily slipped into position loosely lying on the H-beam support which is in the process of installation between the latter and said shield skirt. The jacks 53 will then be employed to firmly urge the H-beam support or rib into tight engagement with the lagging and press the lagging up against the skirt of the shield S, with the collar braces 63 disposed between and acting as spacing means for the previously installed H-beam support C and that being installed. The tie rods 62 will then be tightened so that the newly installed H-beam support is well secured, whereupon the auxiliary needle beam support B will be released and swung down to the position shown in FIG. 2, the screw jack 35 being operated to relieve the load from the main needle beam support or arch A. The valves 123 will then be opened, and valve 116 will be operated to supply air under pressure through line 117, so as to raise the legs 34 of the needle beam support A. With the legs 34 so elevated, comealong 30 will be operated to relieve tension in the links 28, so that the arched support A is free for movement towards the face of the tunnel. Thereupon, valve 31 of the needle beam support shifting cylinder system will be operated so as to project the pistons from the cylinders of the actuator devices 23 to shift the needle beam support to the position shown in FIG. 1.

Thereafter, line 117 will be exhausted through valve 116, and valves 123 opened so as to again force the legs 34 downwardly into engagement with the base of the tunnel. The valving for the needle beam jack operating system will then be set as previously described. Air motor 37 will then be supplied with air through valve 81 in line 80 so as to elevate the screw jack or auxiliary needle beam support B to the position shown in FIG. 1 where it will be resecured. With each new tunnel section the above described operation is, of course, repeated.

It will now be apparent, that the present invention provides substantial improvements in the art of digging or driving tunnels where a protective shield is employed to support the overburden of earth as a permanent supporting structure is being erected within the protection of the shield. If desired, the tunnel may be left as is, that is with the earth supported solely by the ribs C and lagging thereon, or if desired suitable forms may be disposed within the frame structure to enable the injection of hydraulic concrete within the space between the form and the supporting structure so as to provide a concrete conduit.

Moreover, while the specific details of the present method and apparatus have been herein shown and described, changes and alterations may be resorted to without departing from the spirit of the invention as defined in the appended claims.

I claim:

1. The method of driving a tunnel in the earth comprising: driving a shield into the earth; removing the earth from the shield at the tunnel face; constructing a reinforcing structure within the shield while supporting the overlying earth on the shield; advancing the shield to expose the reinforcing structure; supporting the overlying earth on the reinforcing structure; driving the shield with a plurality of substantially identical spaced hydraulic fluid rams; and forcing equal volumes of hydraulic fluid into each of said rams from a separate source of hydraulic fluid under pressure for each ram.

2. The method of driving a tunnel in the earth comprising: driving a shield into the earth; removing the earth from the shield at the tunnel face; constructing a reinforcing structure within the shield while supporting the overlying earth on the shield; advancing the shield to expose the reinforcing structure; supporting the overlying earth on the reinforcing structure; driving said shield with a plurality of substantially identical hydraulic rams; and forcing equal volumes of hydraulic fluid into each of said rams from a separate source under pressure for each ram while forcibly injecting an additional volume of fluid into selected ones of said rams to effect directional control of the shield.

3. In a tunnel driving apparatus, a movable tunnel cutting shield; means for driving said shield forwardly through the earth; retaining means for supporting the earth at the face of said tunnel, said retaining means being carried by said shield and comprising earth engaging members adjacent the front of said shield and means yieldably reacting rearwardly against said earth engaging members and forwardly against said shield for maintaining pressure on said earth engaging members.

4. The method of constructing an arched tunnel reinforcing structure comprising: erecting an arched rib support in spaced but supporting relation to an overlying shield; erecting a second arched rib support in aligned spaced relation to the first mentioned rib, forwardly thereof and in underlying spaced relation to said shield; placing lagging between said ribs and said shield and spanning the space between said ribs with said lagging; jacking up said second rib to force said lagging into tight supporting engagement with the shield; and securing said second rib in place.

5. The method as defined in claim 4 comprising: dapping the opposite ends of said lagging and disposing the ends of said lagging between said ribs and said shield

with a portion of said lagging between the dapped ends between opposed surfaces of said ribs.

6. The method as defined in claim 4 comprising: dapping said lagging at its opposite ends deeper at one end than at the other end of the lagging; and inserting the deeper dapped end of the lagging between the first mentioned rib and the shield and the other end of the lagging between the second mentioned rib and the shield.

7. The method as defined in claim 6 including: installing collar braces between the two ribs; and advancing said shield with respect to the reinforcing structure to expose the latter to the overlying earth with hydraulic rams backed up against the second rib in alignment with said collar braces.

8. Apparatus for forming a tunnel in the earth comprising: a generally horseshoe-shaped elongated shield; means shiftably supporting said shield for axial movement; and fluid pressure operated means for advancing said shield axially; wherein said means for shiftably supporting said shield comprises an elongated member disposed longitudinally of and underlying said shield and secured thereto; a supporting member disposed beneath said elongated member; means shiftably interconnecting said elongated member and said supporting member; and a second auxiliary supporting member movably connected to said elongated member for selective movement into and out of supporting position beneath said elongated member, one of said supporting members being rearwardly of the other relative to the advancing end of said shield, each of said supporting members being extensible for effecting engagement with the tunnel floor.

9. Apparatus for forming a tunnel in the earth comprising: an elongated tunnel cutting shield; means shiftably supporting said shield for axial movement; means for advancing said shield, including a plurality of substantially identical spaced hydraulic rams bearing against said shield; and means for forcing into each of said rams equal volumes of hydraulic fluid.

10. Apparatus for forming a tunnel in the earth comprising: an elongated shield, means shiftably supporting said shield for axial movement including a vertically disposed member; means for advancing said shield, including a plurality of substantially identical spaced rams; means for forcing equal volumes of fluid under pressure to each of said rams with each ram receiving its fluid from a separate source under pressure; and means for controlling the direction of movement of said shield.

11. Apparatus as defined in claim 10, wherein said direction controlling means includes means for forcing additional hydraulic fluid to selected rams.

12. A tunnel forming shield comprising: an elongated body of arched cross section; said body having an open bottom; supporting means engageable with the floor of a tunnel and engaged with said body for supporting said body; said body including a needle beam carried by said body at the crest of the arch thereof; said supporting means comprising a member depending from said needle beam for engaging the floor of the tunnel and in shiftably supporting engagement with said beam for movement thereon; and a second supporting member movably connected to and carried by said beam for movement into a depending position for supporting the beam and out of beam supporting position, one of said members being rearwardly of the other relative to the advancing end of the body.

13. A tunnel forming shield comprising: an elongated body of arched cross sections; said body having an open bottom; supporting means engageable with the floor of a tunnel and engaged with said body for supporting said body; said body including a needle beam carried by said body at the crest of the arch thereof; said supporting means comprising a first member depending from said needle beam; means shiftably connecting said member to said body including rollers coengaged with said needle beam and said member; and a second member pivoted to said needle beam for movement into and out of position to engage the floor of the tunnel, one of said members being rearwardly of the other relative to the advancing end of the body.

14. A tunnel forming shield comprising: an elongated body of arched cross section; said body having an open bottom; means engageable with the floor of a tunnel and engaged with said body for supporting said body; said body including a needle beam carried by said body at the crest of the arch thereof; said means engageable with the floor of the tunnel comprising a member depending from said needle beam and in shiftably supporting engagement therewith; said member being disposed transversely of the shield and having laterally spaced legs for accommodating an earth moving machine therebetween; and a supporting member movably connected to said needle beam and selectively engageable with the floor of the tunnel, one of said members being rearwardly of the other relative to the advancing end of the body.

15. In a tunnel driving apparatus a tunnel forming shield and means for driving said shield forwardly into the earth, said means comprising a plurality of substantially identical hydraulically operated rams bearing against said shield, means for supplying, from a separate source for each ram, equal volumes of hydraulic fluid under pressure to said rams to drive said shield into the earth; and means for supplying from a source separate from said first named sources an additional volume of hydraulic fluid to a selected ram to effect directional control of said shield.

16. A hydraulic pressure system as defined in claim 15, wherein the means supplying equal volumes of hydraulic fluid to said rams comprises a multi-cylinder pump; and means establishing fluid communication between each of said rams and a respective one of said cylinders.

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