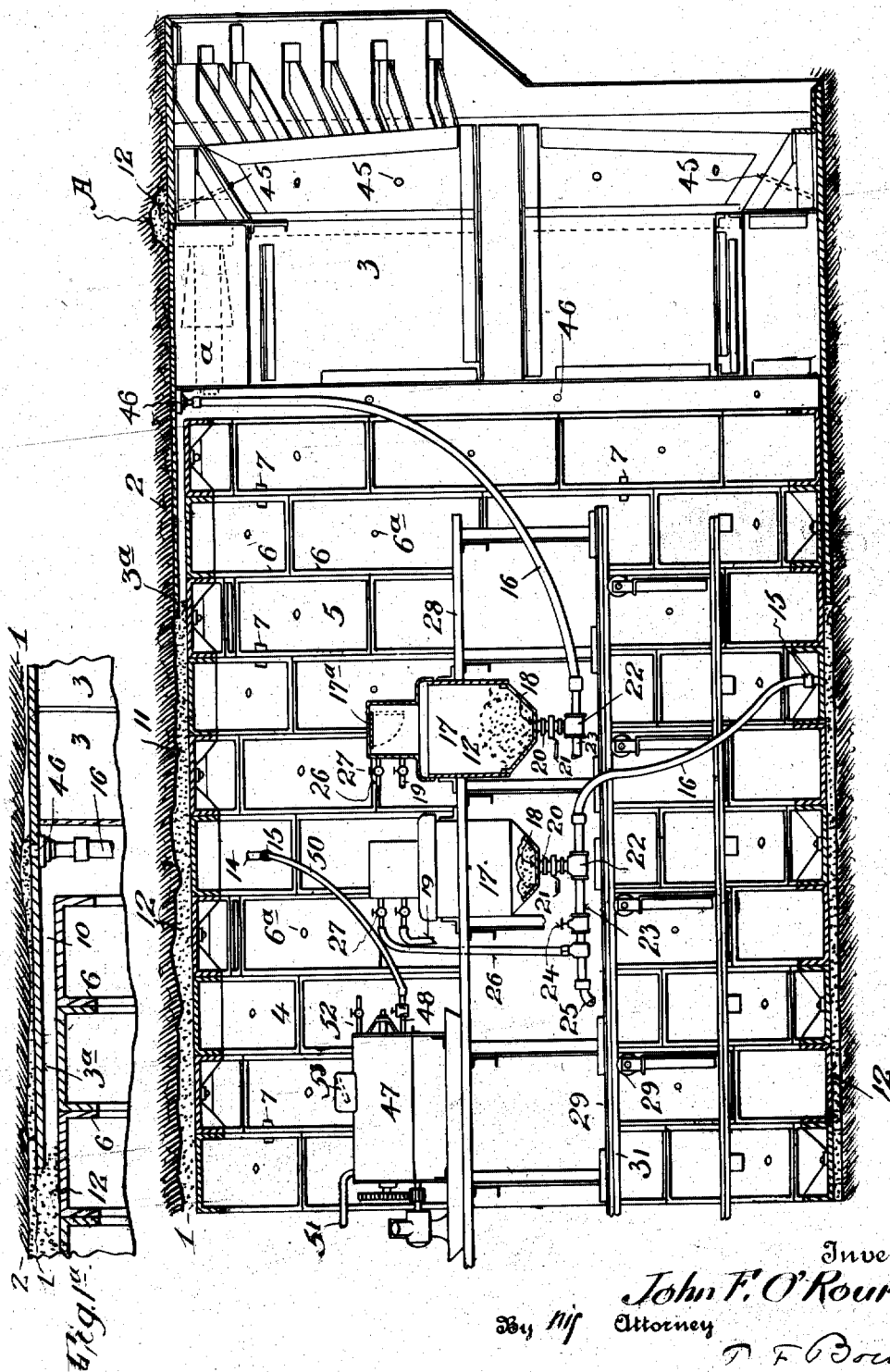


J. F. O'ROURKE.
METHOD OF TUNNEL CONSTRUCTION.
APPLICATION FILED NOV. 17, 1915.

1,235,233.

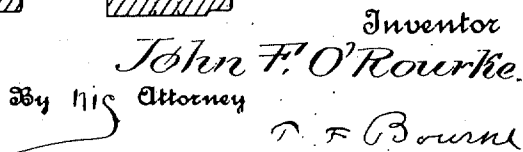
Patented July 31, 1917.
4 SHEETS—SHEET 1.



Inventor
John F. O'Rourke.
By *W. F. Bourne* Attorney

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4 SHEETS—SHEET 2.

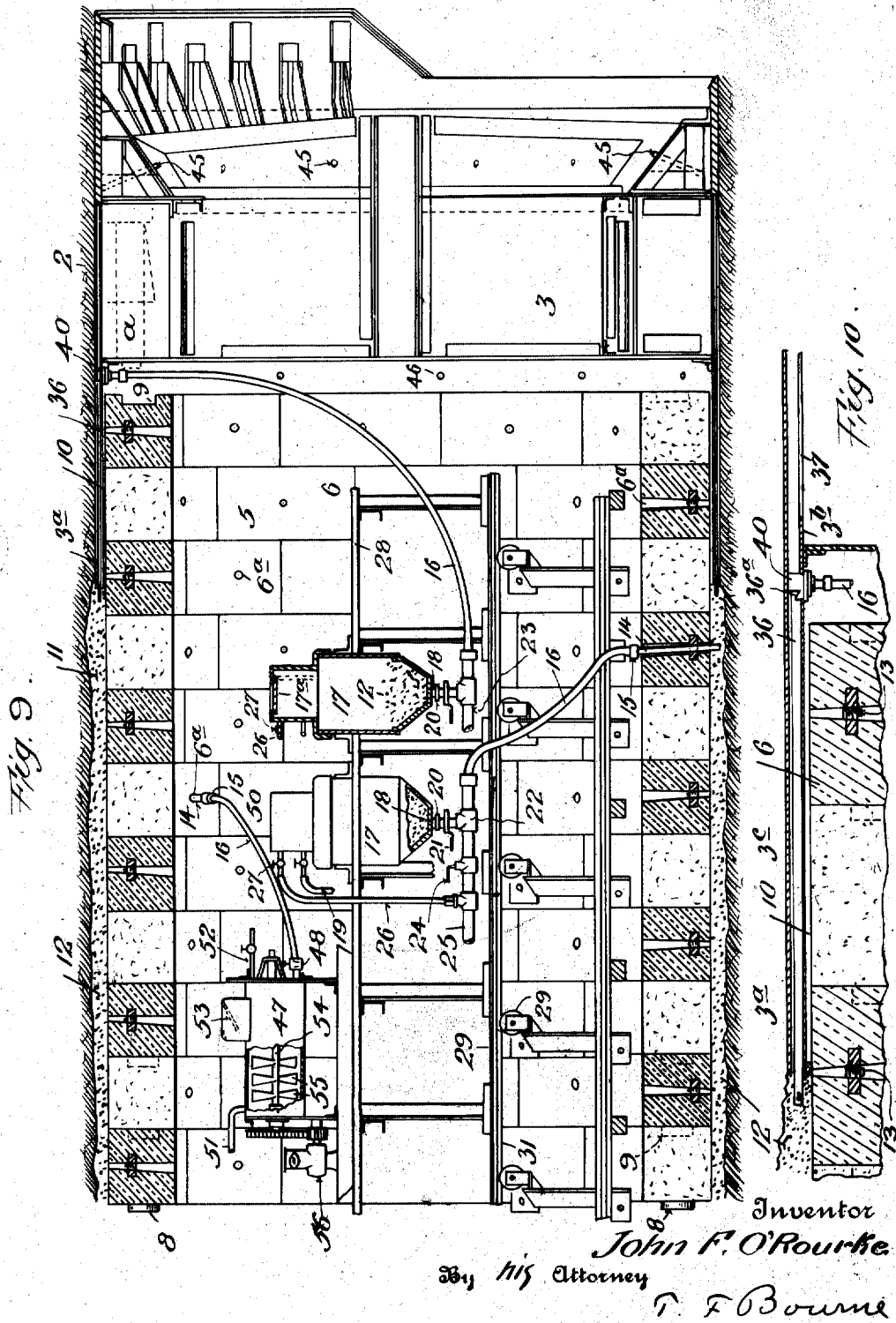


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4 SHEETS—SHEET 3.



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4 SHEETS—SHEET 4.

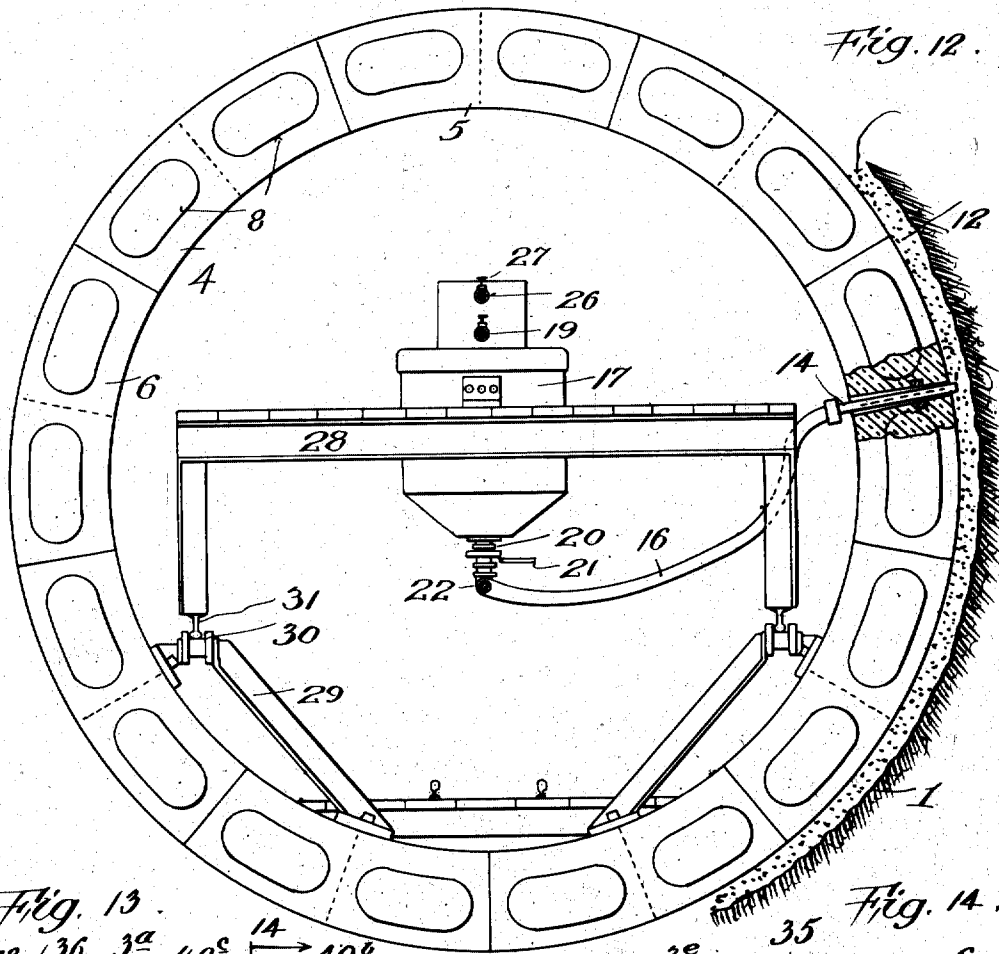
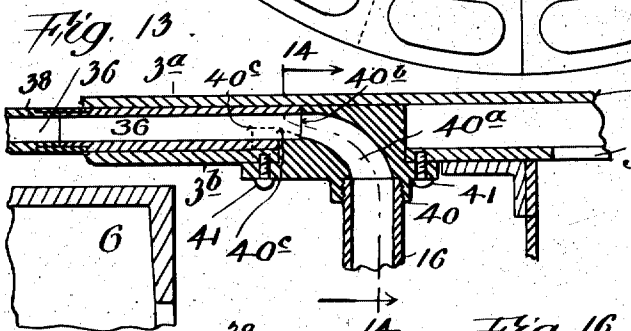
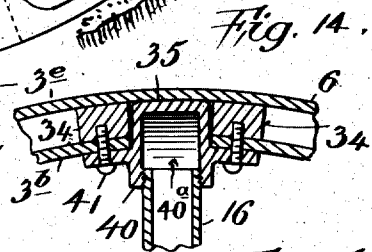
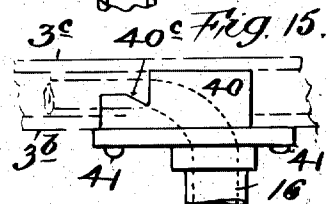
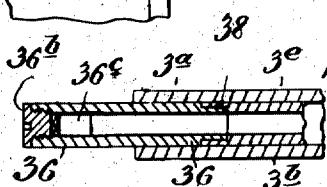
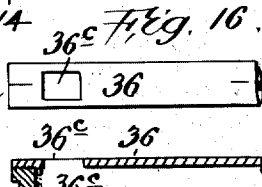


Fig. 18.

Fig. 17.

John F. O'Rourke.

By his Attorney

D. F. Bowne

UNITED STATES PATENT OFFICE.

JOHN F. O'ROURKE, OF NEW YORK, N. Y.

METHOD OF TUNNEL CONSTRUCTION.

1,235,233.

Specification of Letters Patent.

Patented July 31, 1917.

Application filed November 17, 1915. Serial No. 61,897.

To all whom it may concern:

Be it known that I, JOHN F. O'ROURKE, a citizen of the United States, and resident of New York city, borough of Manhattan, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Tunnel Construction, of which the following is a specification.

10 In constructing tunnels having linings it frequently happens that the ground over and at the sides of the tunnel boring settles or falls into the space between the lining and the wall of the boring, thereby permitting the settling of the ground above the tunnel. Where tunnels are constructed beneath streets and roads, and beneath or adjacent to buildings or sub-surface structures, such settlement is liable to endanger or destroy the pavements of the roadways and sidewalks and injure or destroy the structures above and below the surface upon or adjacent to the tunnel. Also, in constructing tunnels under rivers, bays and the like, and particularly where the tunnel boring passes through lighter soils, such as quicksand or mud, or where the level of the tunnel closely approaches the bed of the water, or even is required to be bored at some places through the bed of the water, where revetted blankets of clay and rock on the bottom have been placed, it is of great advantage to prevent the settlement of the adjacent mud or the like into the space surrounding the tunnel, so that such material will not be disturbed or unduly distorted from its natural condition. Further, when compressed air is used, the usual method of grouting this space fails to prevent long air passages backward along the tunnel from connecting with upward passages to the surface which in turn grow into blowouts.

The object of my invention is to facilitate and render less dangerous the operations involved in shield tunneling by compactly filling with solid material the space formed between the tunnel lining and the wall of the tunnel boring, such as the space excavated for the shield that is not filled by the tunnel lining, such solid material serving to prevent the earth, rock, mud and the like over or around the tunnel lining from settling or falling into such space, whereby to preserve substantially undisturbed the earth, rock and the like adjacent to the tunnel boring.

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A further object of my invention is to reduce or retard, by means of the aforesaid filling of solid material, the escape of compressed air (that may be used during the construction of the tunnel) from a tunnel shield, whereby a minimum amount of compressed air may be required, and the air pressure required may also be greatly reduced, since the filling of the aforesaid space with solid material serves to oppose the rapid diffusion of the compressed air escaping from the tail of the shield without enough resistance otherwise to hold the compressed air, and also to keep the pressure below that required by the immersion if directly felt.

In carrying out my invention I blow into the space between the wall of the tunnel boring and the tunnel lining, and in some instances in a space outside of a shield, a strong current of highly compressed air carrying gravel, sand, or other solid filling material with it, to provide in such space a filling of solid material compacted between said wall and lining or shield, to prevent settlement of the surrounding rock, earth etc., in such space and to cut off the escaping air from the tunnel at the point filled when compressed air is used in making the excavation. As tunnel linings are frequently made of rings secured together at their edges, which rings usually comprise sections of iron, concrete or the like, I preferably convey the gravel, sand or other like solid material into the space surrounding such rings with such force as to compact it solidly, just after the ring has been cleared by the shield, to anticipate settlement of the ground before such settlement begins, although it may be that some loose earth or rock may settle in the space surrounding the ring before the sand, gravel or the like is compacted in such space, in which event the sand, gravel or the like will be forced into the space left by such falling loose earth or rock. Where a tunnel is constructed by the use of a shield, the rings of the tunnel lining are usually erected within the tail of the shield, and

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when the shield is pushed forward, step by step, the space left behind the tail of the shield between the adjacent ring or rings and the surrounding wall of the tunnel boring, is forcibly charged with the solid material, before referred to. Preferably, such solid material will be charged in said space during the time that the shield is being pushed forwardly in the tunnel boring, and after it has stopped, until the space is filled, so that the space around the tunnel lining will be compactly filled with solid matter outside of each ring successively as the shield is moved forwardly. The solid material may be filled in the space around the rings by blowing the material through holes in the sections of the rings, or by blowing the solid material under pressure through openings provided in the outside wall or tail of the shield, whereby such material may be blown into the space behind the shield as fast as the latter is moved forward. Hence, it will be understood that my improved method may be utilized in either of the manners stated, according to the circumstances of the case, as occasion may require. Since compressed air is frequently used within shield-driven tunnels, such compressed air usually finds its way out of the tunnel boring through the space between the shield and the tunnel rings erected therein, and becomes dissipated or diffused through the surrounding ground, usually along well maintained air passages between the lining and the ground which connect to openings leading to the top of the ground. Greater quantities of compressed air at higher pressures than desirable must be used, with consequently greater dangers from its use under the high pressures, to avoid which is one of the objects of this invention. By reason of the packing or compressing of solid matter around the tunnel rings at or adjacent to the tail of the shield, as described, the compressed air used within the tunnel lining and shield is checked by such solid matter adjacent to the tail of the shield from going farther along the line of the tunnel than near to the point of its first escape. By this means a minimum amount of compressed air may be used within the shield and tunnel lining, and, furthermore, the pressure which otherwise would be required may be reduced because the escape or rapid diffusion of air is retarded, thereby rendering such work under air pressure more safe, and reducing other damages as well, that are caused by its excessive use.

My invention further comprises novel details of improvement and combinations of parts that will be more fully hereinafter set forth and then pointed out in the claims.

Reference is to be had to the accompanying drawings forming part hereof, wherein,

Figure 1 is a vertical sectional view of a portion of a tunnel and shield illustrating

my improvements, the tunnel lining being indicated as comprising metallic rings;

Fig. 1^a is an enlarged detail of part of Fig. 1;

Fig. 2 is an enlarged transverse detail section of part of the tunnel lining of Fig. 1;

Fig. 3 is a cross section on the line 3, 3, in Fig. 2;

Fig. 4 is a similar view on the line 4, 4, in Fig. 2;

Fig. 5 is an enlarged detail of part of Fig. 2; illustrating the nozzle in position;

Fig. 6 is an enlarged sectional detail of part of the nozzle;

Fig. 6^a is a view at right angles to Fig. 6;

Fig. 7 is a detail of a plug;

Fig. 8 is an enlarged sectional detail of air and gravel controlling devices shown in Fig. 1;

Fig. 9 is a side elevation, partly in section, of a portion of a tunnel and shield illustrating the rings formed of concrete blocks, and illustrating a modification of the shield;

Fig. 10 is an enlarged detail section of Fig. 9;

Fig. 11 is an enlarged detail section of one of the ring sections of Fig. 9, illustrating the nozzle in position;

Fig. 12 is a transverse view partly in section of the tunnel illustrated in Fig. 9;

Fig. 13 is an enlarged detail section illustrating means for connecting a nozzle with a supply pipe in the shield of Fig. 9;

Fig. 14 is a section on the line 14, 14, in Fig. 13;

Fig. 15 is a detail side view of parts shown in Fig. 13;

Fig. 16 is a detail side view of a portion of a nozzle adapted to be used in the shield of Fig. 9;

Fig. 17 is a section on the line 17, 17, in Fig. 16, and

Fig. 18 is a sectional detail illustrating the nozzle of Figs. 9, 16 and 17 in position at the tail of the shield.

Similar numerals of reference indicate corresponding parts in the several views.

In the accompanying drawings the numeral 1 indicates a boring in the earth for a tunnel. At 3 is indicated, generally, a shield which may be of any usual or suitable construction, adapted to be used in constructing the tunnel. At 4 is indicated a tunnel lining installed within the tunnel boring and shown comprising rings 5, having any desired number of sections 6 fitted together in a usual or desired manner. In the example illustrated in Figs. 1 to 6, the tunnel lining is formed of metal sections, flanges of the sections being secured together by bolts indicated at 7, while in Figs. 9 to 12 the tunnel lining is represented as formed of rings comprising concrete-block sections 6 having complemental projections

8 and recesses 9 fitted together in a well-known manner, such as illustrated in Letters Patent granted to me Nov. 5, 1912, No. 1,043,348. As illustrated in the accompanying drawings, and as customary in constructing tunnels of the class herein referred to, the shield is installed in the tunnel boring, and one or more rings of the tunnel lining are erected within the tail 3^a of the shield, and secured to the previously set rings, the shield being pushed forwardly through the tunnel boring, step by step by means of jacks *a*, after the rings are placed in position, in accordance with the desired practice. Between the tail 3^a of the shield, and the adjacent ring or rings of the tunnel lining, is a space 10, and since the rings usually rest upon the tail of the shield, the space 10 is wider at the top of the rings than at the bottom, and is graduated in dimensions from the top to the bottom. Into such space, and preferably that indicated at 11 behind the tail of the shield and between the rings and earth 2, I blow solid material, with compressed air, such as gravel, sand and the like, indicated at 12, to solidly and compactly fill such space around the tunnel lining, to at once support the tunnel lining and hold back the surrounding ground. The gravel, sand or the like may be blown into the space 11 through apertures 6^a in the ring sections, which apertures are usually provided in cast iron sections and maintained closed by plugs 13 (Figs. 1 and 7); or through pipes, tubes or nozzles leading along the tail of the shield, or through both. The plug in the appropriate aperture 6^a of one or more ring sections may be removed and a suitable nozzle, hose or pipe may be connected thereto, which is in communication with a source of air pressure and a source of supply for gravel, sand or the like. For such purpose I have shown a nozzle at 14 adapted to be connected by any suitable coupling, as 15, with a hose or pipe 16, communicating with sources of compressed air, gravel, sand or the like. In the example illustrated I have shown a tank or the like 17, located within the tunnel, provided with an outlet 18 at its bottom for solid matter, such as gravel, sand or the like 12. An outlet fitting 20 connected with tank outlet 18 is shown provided with a cock or valve 21 to control the flow of solid matter from tank 17. Said fitting is connected with hose or pipe 16, said parts being shown connected with a T-fitting 22 which in turn is connected with an air supply pipe 23, provided with a suitable valve 24. Pipe 23 may be connected with an air supply pipe line 25 utilized in the tunnel for supplying compressed air in a well-known manner. Tank 17 is shown provided with a lid or cover 17^a adapted to permit the tank to be charged with gravel, sand or

the like, which lid or cover is adapted to be closed by air pressure within the tank. While air pressure from pipe 23 may enter the tank through the fitting 20 to pass up through the solid matter in the tank, I preferably connect an air supply directly with the upper portion of the tank by means of by-pass pipe 26, shown connected with the air pipe line and provided with a valve 27, whereby the pressure in the tank may be kept uniform, and the air supply at the top of the tank causes quick closing of the lid or cover. When the tank has been charged with the solid material to be used, a suitable quantity of water may be placed in the tank as through pipe 19, before the air pressure is admitted to the tank. Whenever the ground contains sufficient water to mix with and puddle the inserted material water may be omitted from tank 17.

Tank 17 may be carried upon a suitable frame 28 mounted upon supports 29 within the tunnel, said supports being shown provided with rollers 30 upon which the runners 31 of said frame are adapted to rest, whereby the frame and tank may be moved along in the tunnel as required.

The nozzle 14 may be of any suitable construction having a bore adapted to permit the outflow of gravel, sand or the like into the space surrounding the tunnel lining. By preference, said nozzle is provided with openings 14^a on opposite sides, and said nozzle preferably may be set in the ring section so that the openings face in the direction of the curvature of the ring. Preferably the nozzles are provided with closures 14^b at their outer ends, which closures have inwardly projecting portions 14^c (Fig. 6) opposing the corresponding openings 14^a, whereby the gravel, sand or the like will be directed through openings 14^a. By preference the side faces 14^d of portion 14^c of said plug are in concavo form to direct the solid material through openings 14^a in a direction around the tunnel ring. When desired the nozzle may have one opening 14^a and one face 14^d opposing the same. By preference the end of the nozzle is capped, such as by means of the flange 14^e at the end of plug 14^b to prevent injury to the threads at the end of the nozzle which connect the plug thereto. Nozzle 14 is shown provided with threads at 32 to engage corresponding threads in the apertures 6^a of the rings, whereby the nozzle may be securely fitted to the ring sections to secure the nozzle in place and to prevent leakage of air from the connection. Where metal sections are used for the tunnel rings the plugs 13 may be removed and the nozzles 14 screwed into the openings 6^a that are threaded in such section, but where concrete ring sections are used, such as indicated in Figs. 9, 10 and 11, the openings 6^a of the sections may be made

of suitable dimensions and nuts 33 are embedded in the sections, into which the nozzles 14 may be screwed after the plugs 13 have been removed from such nuts. In both instances, it will be understood that the openings 14^a are located beyond the threaded portion 32 of the nozzle, so as to protrude beyond the outer surface of the ring section into the space between the ring and the earth, and the usually closed outer end of the nozzle prevents the impact of the out-flowing gravel, sand or the like under pressure against the opposing wall of the tunnel boring, although the nozzle may be used with an open end. It will be understood that one or more tanks 17 may be utilized in the tunnel lining, and one or more nozzles 14 may be connected with either tank, and in turn connected with the appropriate opening 6^a of the tunnel rings, as may be desired, to expedite the work.

In the form illustrated in Figs. 9, 10 and 13 to 17, I provide means for blowing solid material, such as gravel, sand or the like, into the space behind the shield through the tail of the shield. For such purpose I have illustrated the tail of the shield provided with inner and outer spaced walls 3^b, 3^c having spacers 34 therebetween (Fig. 14) providing spaces 35 between said walls, in any desired number of which spaces nozzles or pipes 36 may be placed, and extended from the shield, to direct a blast of gravel, sand or the like under air pressure through the tail of the shield into the space surrounding the tunnel rings adjacent to the tail of the shield. The inner wall 3^b is shown provided with openings 37 to permit the insertion of the nozzles or pipes into the spaces between the walls of the shield, so that such nozzles or pipes may be pushed toward the tail of the shield. The nozzles 36 may have a plug 36^b at the end and one or more side openings 36^c, (Figs. 16-18) to direct the gravel, sand or the like circumferentially around the tunnel lining, or the nozzles may be provided with the projecting part 14^a shown in Figs. 6 and 6^a. The nozzles or pipes may have joints as illustrated at 38 (Figs. 13 and 18) for coupling different lengths of the same together. After the nozzles or pipes have been placed in the spaces between the walls of the shield they may be connected to the means for delivering the compressed air and gravel, sand or the like. Any suitable means may be provided for connecting pipes 36 with the supply pipes or hose 16. For this purpose I have illustrated a fitting 40 adapted to be secured by screws 41 to the inner wall 3^b of the tail of the shield and adapted to be operatively united to the adjacent end of the pipe or nozzle 36. The fitting 40 is shown provided with a bore 40^a, leading to a side outlet 40^b, the edges at 40^c of which

outlet are formed in an angular direction to receive the correspondingly angularly formed edges 36^a of nozzle or pipe 36, (Figs. 10, 13 and 15). After the nozzle or pipe 36 has been set in place the fitting 40 may be inserted in the corresponding opening in the wall of the shield, so that its edges 40^c will coact with the edges 36^a to make a substantially tight fit when the fitting is secured to the shield wall. The coacting edges 40^c and 36^a serve to keep the nozzle or pipe 36 from displacement. Pipe 16 may be screwed to fitting 40 after or before the latter has been placed in position and secured by the screws 41. When more than one nozzle or pipe 36 is fitted within the tail of the shield a fitting 40 may be applied to each of such nozzles or pipes and the corresponding pipe 16 may be connected with one or another tank 17, to be supplied with highly compressed air carrying gravel, sand or the like in a manner before described, or in any other suitable manner.

When the solid material is to be blown or compressed in the space around the tunnel lining, according to the arrangements shown in Figs. 1 to 6, one or more plugs 13 may be removed from the corresponding ring section or sections, the corresponding nozzle or nozzles 14 inserted with their outlets projecting beyond the ring or rings and facing in the direction of the curvature of the ring behind the tail section, and the tank or tanks 17 having been charged with gravel, sand or the like, and with water, when desired, the corresponding cocks 24 and 27 will be opened and substantially simultaneously therewith the cock or cocks 21 will be opened, whereby the compressed air flowing through fitting 22 to pipe 16 will carry along with it the gravel, sand or the like that flows from tank 17, and such gravel, sand or the like will be blown from the nozzle or nozzles 14 into the space surrounding and at the rear of the corresponding tunnel ring, thereby compacting such material into the space between the tunnel ring and the wall of the tunnel boring. The operation just described may be carried out within the time that the shield is being shoved forward, or after the shield has been shoved forward, or both, so as to fill the space left behind the tail of the shield as rapidly as possible.

It is not always necessary to introduce water with the material, especially where the spaces being filled contain water in sufficient quantities to render the operation successful.

Where the form of structure is used as illustrated in Figs. 9 to 12, the same procedure of blowing the compressed air carrying the gravel, sand or the like with it is carried out, and in such case the solid material, by being blown from the tail of the

shield, will fill the space therebehind in the manner described with respect to Fig. 1. It will be understood that the gravel, sand or the like may be blown through the openings 6^a in the rings and also from the tail of the shield simultaneously, if desired. After the space around a given ring or rings is charged in the manner stated, the nozzle or nozzles 14 will be removed and the plugs 13 placed in the corresponding openings 6^a, and the charging of the space around the tunnel lining will proceed, ring by ring, after they have been set. The wall of the tunnel boring surrounding the ring will be immediately supported upon the tunnel lining by such compacted solid material before settlement of the adjacent ground begins, and such filling of such space may be done in such a solid manner as to prevent or retard air at the tail of the shield from going farther along the tunnel lining than adjacent to the tail of the shield itself.

Where a shield is given a "lead" in a direction different from that of the line of a tunnel, as where the propelling jacks in the bottom, top or sides of the shield are used separately in such manner as to incline the shield to an upward, downward or lateral direction of forward motion, a space or cavity will be left between some portion of the shield and the wall of the tunnel boring, due to the forcing of the shield sideways into the ground away from the direct line, thereby leaving a space on the outside of the shield away from the direction in which it was diverted. In order to fill such space at the forward portion of the shield with gravel, sand or the like, I provide any desired number of passages, tubes or nozzles 45 in the forward end of the shield, to which one or more pipes 16 from tank 17 may be attached, by means of a nozzle 14 if desired, and this space is filled as the same is produced by the lateral motion of the shield. At 46 the shield is provided with any desired number of openings, to which pipes 16 or their nozzles may be attached, to be used for the same purpose as that described with respect to openings 45, but at the rearward portion of the shield, since an opening produced by the lateral, upward or downward motion already referred to would extend substantially the entire length of the shield. In some cases where the shield is not given a "lead", and is moved forward directly into the excavation produced at its forward face, the ground above the face of the shield may fall in for some distance, thereby causing a cavity, which may be partly filled from the face of the shield in the ordinary manner, and any remaining cavity at the time that the forward motion of the shield reaches the point, as at A, Fig. 1, when the filling of the cavity may be completely perfected by the solid ma-

terial forced through a corresponding opening 45 in the shield. Any remaining cavity around the shield may be filled by the solid material from the nozzle through one or more of the openings 46.

In case the tunnel is being bored through unstable ground, such as through mud, quicksand and the like, it may be desirable to force grout into the ground around the forward portion of the shield, so that such grout may more or less harden and aid in holding back surrounding soft material of the earth, whereby to prevent undesired falling in of the ground before the space behind the tail of the shield or outside of the shield can be packed with gravel, sand or the like. Such grout may be forced through the openings 45 or 46 of the shield, or through the nozzle 36 at the tail of the shield, for which purpose any suitable means may be provided. I have illustrated a tank or chamber 47 mounted upon frame 28 and having a valve-controlled outlet 48 connected with pipe or hose 50, which may be connected by a nozzle 14 or 36 with the desired opening into the tunnel boring. At 51 is a pipe connected with tank 47 through which water may be supplied to said tank, and at 52 is a valve-controlled pipe leading to said tank, whereby high pressure air may be admitted into the tank. The tank is shown provided with a door 53 adapted to permit the admission of cement and sand, which door is adapted to be closed by air pressure within the tank. At 54 is a shaft in tank 47 having paddles or the like 55, which shaft may be rotated in any suitable manner, as by a suitable motor 56 geared thereto. After the desired quantity of water, sand and cement have been placed in tank or chamber 47 and shaft 54 has been rotated to mix the materials as desired, compressed air may be admitted to the tank through pipe 52 to cause the grout to be forced under pressure from the tank into the space surrounding the tunnel lining or the shield, as the case may require. While I have referred to the use of air pressure for forcing solid material into the space outside of a tunnel lining or shield, it will be understood that other fluid, such as water, under pressure may be used if desired.

By means of my improvements I am enabled to facilitate and render less dangerous the operations involved in tunneling by the use of shields, by reason of the compact filling with some solid material of the space excavated for the shield, which space is necessarily not filled by the tunnel lining. Where a space is left around the tunnel lining behind the shield as it is shoved forward, as has heretofore been the practice, the surrounding earth by settling in such space, enables the more ready outflow of compressed air from the tunnel during prog-

ress of the work, thereby requiring the use of an excess amount of compressed air, at higher pressure than is desirable, and such settlement of the earth, particularly under streets and near sub-surface structures, is of great disadvantage, since the streets must be relaid and stability of adjoining buildings is endangered. Many advantages are gained by means of my invention, because by compacting solid material in the space around the tunnel lining, thereby preventing the settlement of the surrounding earth and consequent falling in of street and roadway surfaces and danger to adjacent structures, I am enabled to utilize a minimum amount of compressed air and considerably reduce the air pressure usually required, since such filling around the tunnel lining opposes diffusion of the air along the lining for considerable distances, and out through existing, holes, through which such air would often flow for a considerable distance. It will also be understood that whenever ground settles its capacity for resisting compressed air is greatly reduced, and in a tunnel passing through the lighter soils, such as quicksand or mud, such filling of the voids about the lining performs the two-fold function of preventing the mud, quicksand or other ground from losing its own consistency, and, at the same time, since the compressed air may be kept at a lower pressure, what are called "blow-outs" may be largely avoided. In the event of using revetted clay blankets over the weaker portions of the ground or water bottom, both the ground and the blankets are preserved with all their original strength and tightness, both of which properties would be seriously affected in the event of settlement of the ground. A further, and very important, advantage gained by the use of my invention is the saving of health and life which are risked almost always when tunneling under water at considerable depths is being done, and where no means is provided for keeping the air pressure below that of the water pressure, due to the depth at which the work is carried on, since the air pressure must be kept high to resist the outflow of air through the shield to the space between the shield and tunnel lining into the surrounding mud, muck and the like. Hence, by filling the space around the tunnel lining with highly compressed solid material, as before described, thereby serving to prevent undue escape of air from the shield, and keeping the surrounding mud and muck from displacement, thus enabling the use of lighter air pressure within the shield and tunnel lining, gives an advantage of great importance to the workmen employed and reduces the danger of mud and water flowing into the work, enabling the men to work under less pressure. As difficulties of the last

named character are mostly confined to sub-aqueous tunneling, the importance of my invention is as great to meet such difficulties under bays and rivers as under streets.

As tunnel linings are frequently constructed of circular rings, or of segments of circles or other curves or planes forming roofs, sides and bottom of tunnels, which tunnels are not circular in cross section, but in which the linings are installed in whole or in part with the use of shields, I have confined the illustrations whereby my invention may be carried out to the circular form of tunnel lining having successively disposed rings constructed in sections, and it will be understood that my invention is not limited to use in connection with tunnel linings of circular ring-like form, as my invention may be carried out in connection with tunnel linings of any desired form.

Having now described my invention what I claim is:—

1. The method of preventing settlement of earth into a space outside a tunnel consisting in inserting material in said space and forcing it by impact to an initial density to withstand pressure of the exterior ground.

2. The method of constructing a shield driven tunnel consisting in projecting and densely packing loose solid material into a space outside the tunnel lining to prevent settlement of ground into said space.

3. The method of constructing a shield driven tunnel consisting in conveying gravel or similar material into a space outside the tunnel lining and immediately compacting such material in said space to such density as will at once prevent settlement of adjacent ground into said space.

4. The method of preventing settlement of the ground into a space around the lining of a tunnel consisting in delivering a blast of air carrying material into said space and immediately compacting by impact said material between the lining and the wall of the excavation to such density as will at once prevent settlement of surrounding ground into said space.

5. The method of constructing tunnels consisting in making a tunnel boring for a shield, erecting a tunnel lining within the tail of the shield, advancing the shield along said lining, and blowing a current of air carrying loose solid material into the space outside of the lining behind the tail of the shield against the lining and the wall of the boring, compacting said material to at once support the surrounding ground.

6. The method of preventing the settlement of the earth into a space around the lining of a tunnel consisting in delivering a blast of highly compressed air carrying gravel or similar material and water into said space, immediately compacting said ma-

terial to approximately the same degree as the surrounding earth, whereby said settlement is substantially obviated.

7. The method of filling a space surrounding a tunnel lining consisting in inserting material in said space and forcing it by impact to a density approximating

that of the surrounding earth to at once support the tunnel lining and the ground above the lining.

Signed at New York city, in the county of New York, and State of New York, this 16th day of November, A. D. 1915.

JOHN F. O'ROURKE.