No. 706,380. Patented Aug. 5, 1902.

J. BREUCHAUD.

METHOD OF CONSTRUCTING TUNNELS.

(Application filed Feb. 24, 1902.)

(No Model.) 4 Sheets—Sheet 1.

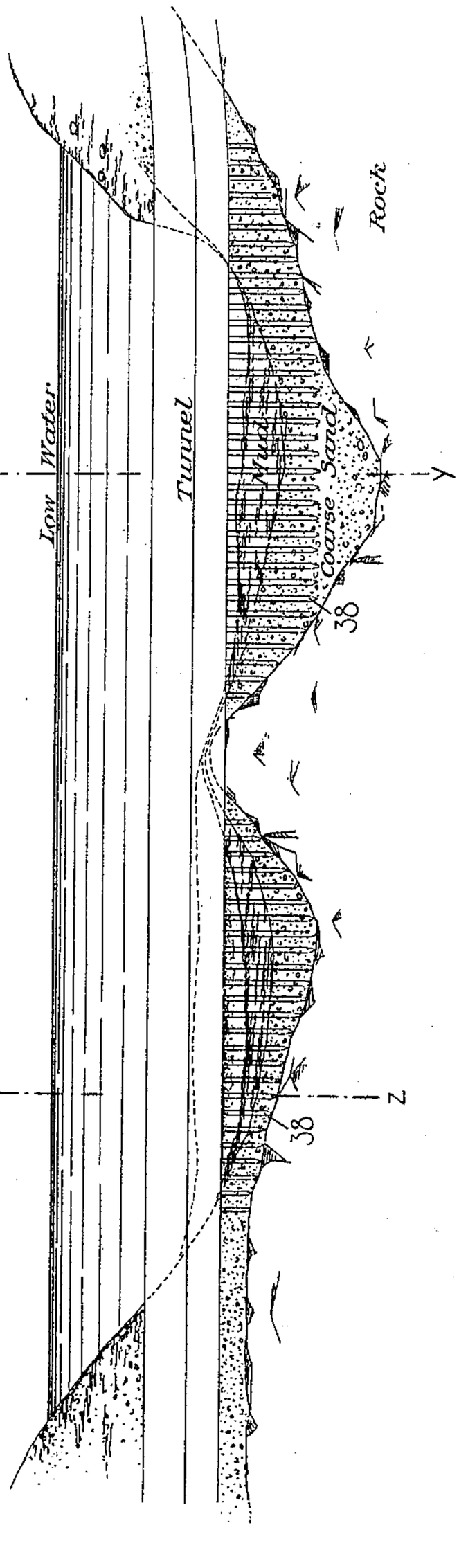

Fig. 1.

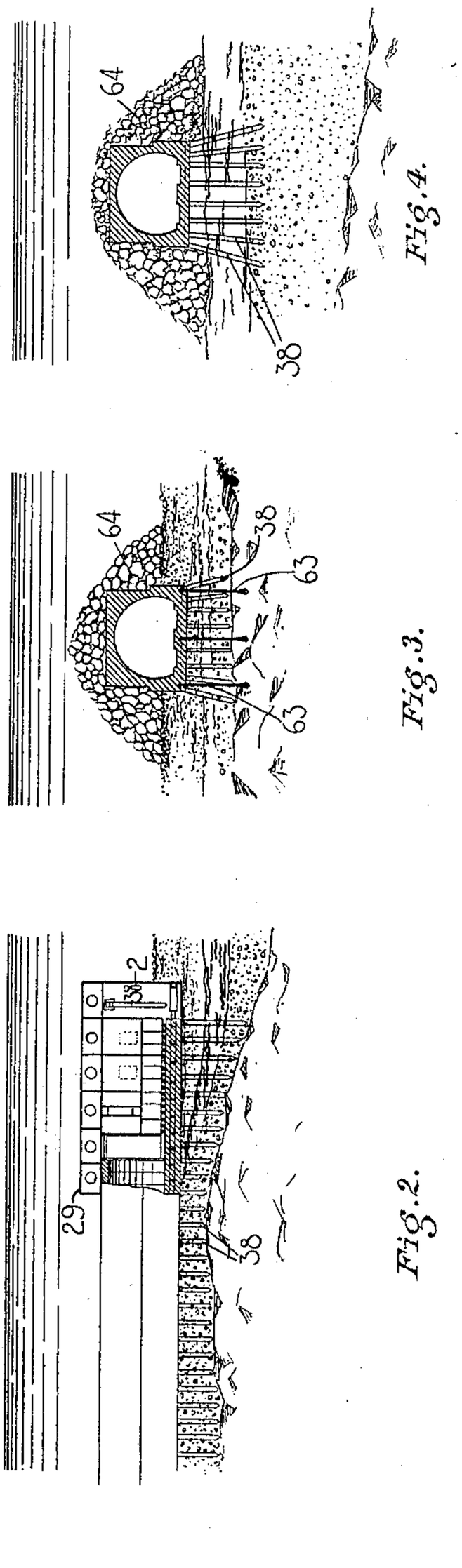

Fig. 3.

Fig. 2.

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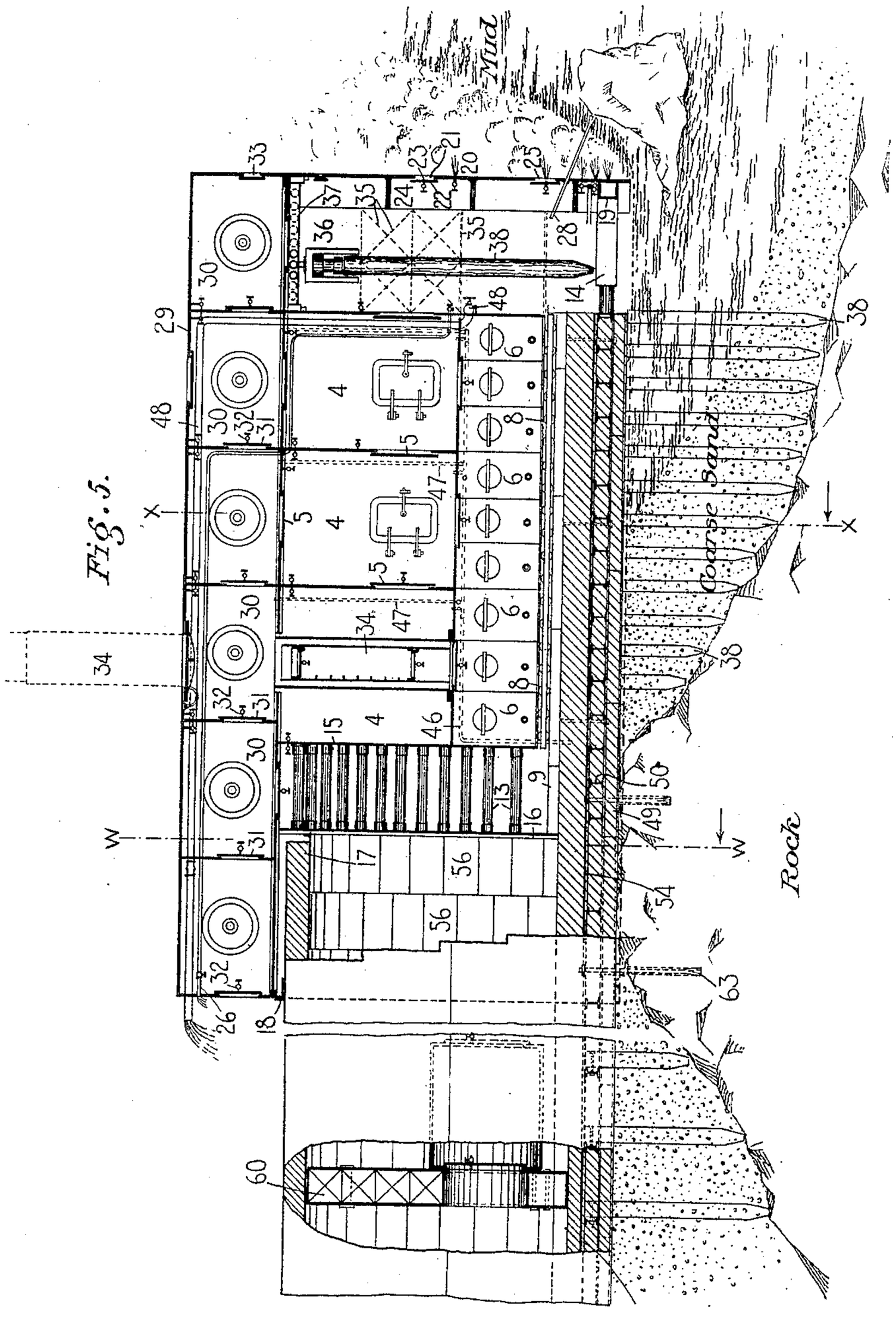
(No Model.) 4 Sheets—Sheet 2.

Fig. 5.



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(No Model.) 4 Sheets—Sheet 3.

Fig. 9.

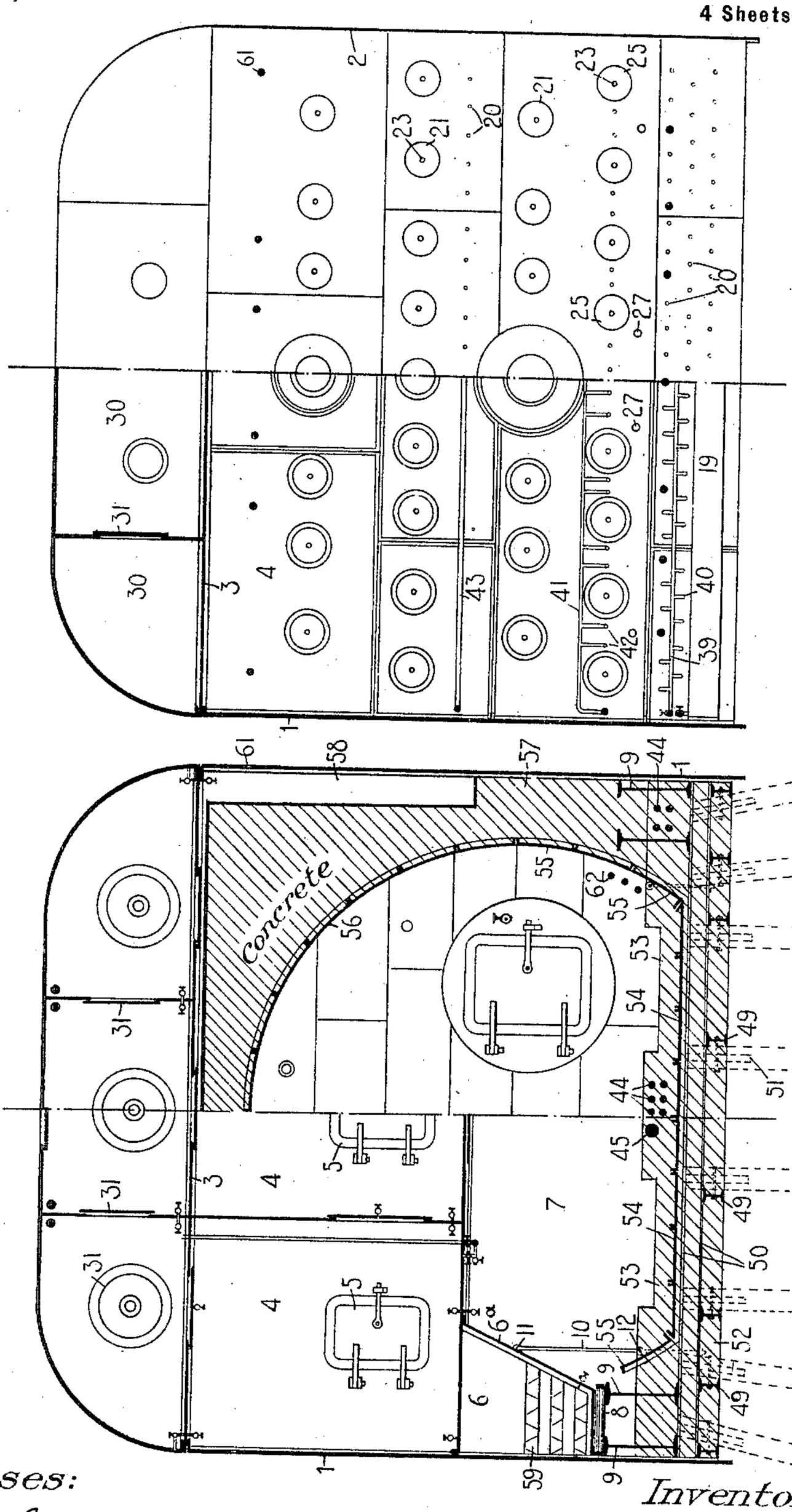

Fig. 8.

Fig. 7.

Fig. 6.

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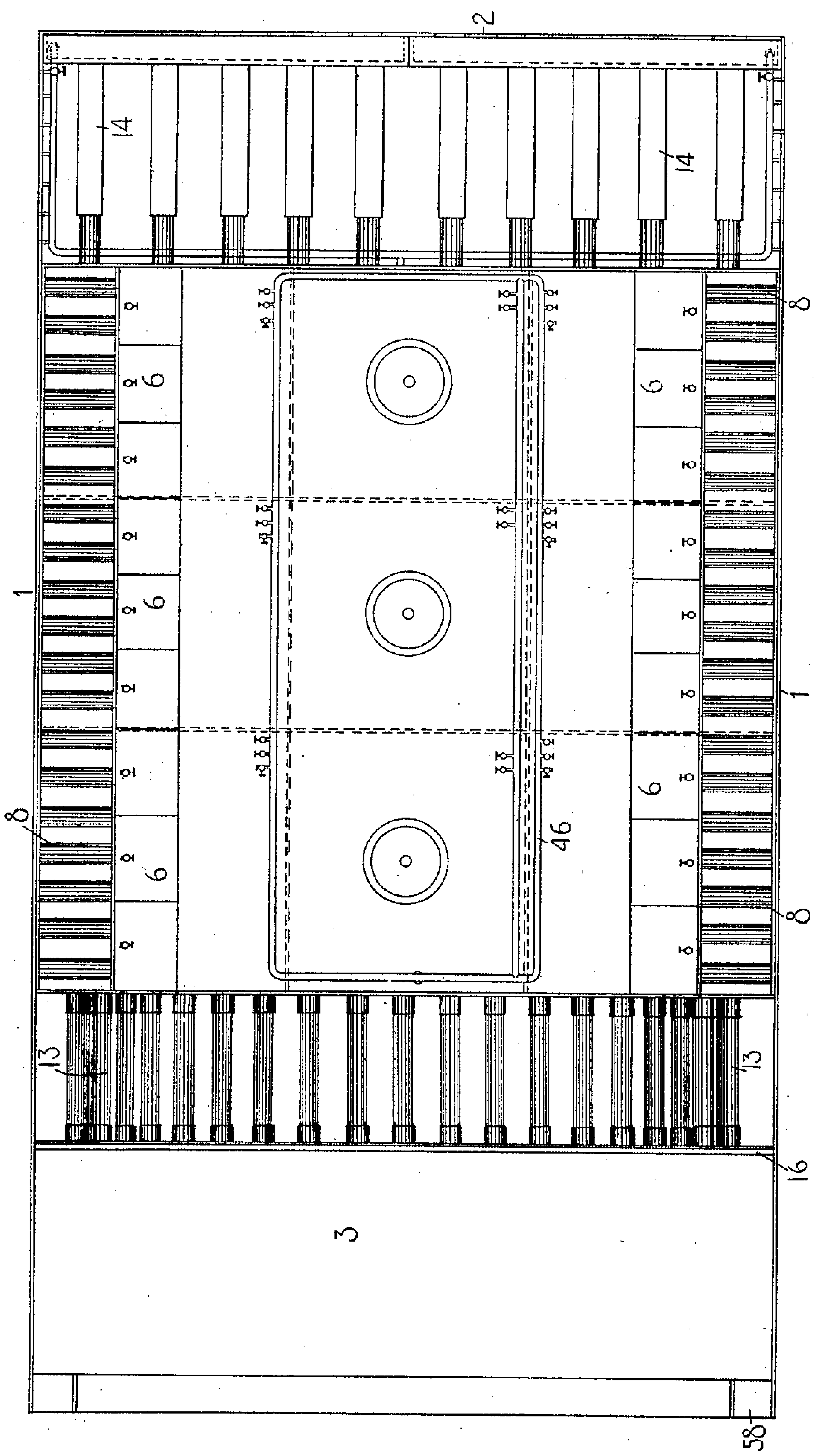
(No Model.)

4 Sheets—Sheet 4.

Fig. 10.



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THE NORRIS PETERS CO. PHOTO-LITHO., WASHINGTON, D. C.

UNITED STATES PATENT OFFICE.

JULES BREUCHAUD, OF YONKERS, NEW YORK.

METHOD OF CONSTRUCTING TUNNELS.

SPECIFICATION forming part of Letters Patent No. 706,380, dated August 5, 1902.

Application filed February 24, 1902. Serial No. 95,330. (No model.)

To all whom it may concern:

Be it known that I, JULES BREUCHAUD, a citizen of the United States, and a resident of Yonkers, in the county of Westchester and State of New York, have invented certain new and useful Improvements in Methods of Constructing Tunnels, of which the following is a specification.

My invention relates to the construction of subaqueous tunnels, aqueducts, pipe-lines, bridges, piers, docks, or other analogous submerged structures.

As shown herein, the shield has been devised and equipped more especially for the construction of the foundations and walls of a subaqueous tunnel and from within the working chamber of the shield itself, arrangements being made for the forming of an air-tight connection at the sides and walls of the tunnel, so as to permit of a horizontal movement of the shield in the direction of the line of the tunnel upon wheels or rollers properly placed on the foundation formed from within the shield, hydraulic jacks or other power being employed to advance the shield progressively as the foundation-work is constructed. The air-tight connection between the outer walls of the tunnel and the shield may be maintained by means of a suitable packing or calking composed of a plastic substance, preferably stiff clay. Within the walls of the tunnel are placed suitable air-tight partitions provided with air-locks for maintaining a connection between the shield and the completed portion of the tunnel and for the passage of the men and the bringing in and sending out of material and for all other purposes and requirements of the workmen. The forward or leading end of the shield is provided with means for excavating and displacing and removing mud, silt, or other obstructions that may be in the line of travel of the shield. Foundations constructed from within the shield may extend through water and over, through, or under soft material, so as to provide trestles, bridges, or foundations or supports for the structure to be built, the shield traveling step by step over and on the permanent artificial foundation built from within its own walls, thus enabling the shield to travel safely in a true line and be guided by the portion of the completed work over which it travels, and thereby making it possible to build tunnels and other subaqueous structures in places hitherto impossible. Heretofore it has been necessary in tunneling under rivers to have firm material, such as rock or stiff clay, through which to drive the tunnel. To obtain this condition, it often necessitates going to a great depth, which requires objectionable steep inclines and long approaches in order to get under the soft material forming the bed of the river. According to my invention it is required only that the tunnel be located at a sufficient depth for the safe navigation of the streams or other bodies of water under which the tunnel is to be built, since I am enabled to construct the tunnel in mud, silt, or other like soft material previously considered quite impracticable. Being able now to build the tunnel in and through soft materials, the work of constructing it is thereby greatly facilitated and cheapened. The shield is adapted to penetrate through and remove the mud in the line of its travel by the use of air and water jets and other apparatus hereinafter described.

The shield may be provided with a detachable superimposed caisson provided with numerous air and water tight compartments, thus providing accessible and convenient places for the carrying of necessary weight to overcome the buoyancy of the shield when compressed air is used for expelling the water from the interior of the shield or chamber, water-tight compartments affording a ready means for increasing or decreasing the weight, as they can be readily filled with water or emptied, as may be necessary. Ample provision is also made for the carrying of ballast in the lower part and within compartments in the shield proper, thus enabling the shield to be operated at considerable depth beneath the water when desired. Within the shield are numerous air-tight compartments provided with suitable connections and communicating one with another, so as to afford ready access thereto. The shield is also provided with a telescopic shaft fitted with air-locks, and which shaft may be projected upward to the surface of the water to enable workmen to enter and leave the chamber therethrough and also to enable the bringing in and sending out of material. On the com-

pletion of the tunnel the traveling shield may be brought to the surface by the removal of the ballast, whereupon it will float and may be towed to any convenient place.

Various other features are provided, all of which will be hereinafter more fully described.

My invention consists in the method of building the tunnel or other subaqueous structure, all as will be hereinafter more fully described, and particularly pointed out in the appended claims.

In the accompanying drawings, Figure 1 is a longitudinal section of a subaqueous tunnel constructed in accordance with my improvements. Fig. 2 is a longitudinal sectional view illustrating the method of constructing the tunnel. Fig. 3 is a cross-section taken at the line *z z* of Fig. 1. Fig. 4 is a similar section taken at the line *y y* of Fig. 1. Fig. 5 is a longitudinal section somewhat similar to Fig. 2, but on a larger scale, so as to show more fully the construction of the shield and the mode of operating therefrom in the construction of a subaqueous tunnel. Fig. 6 is a vertical cross-section taken at the line *x x* of Fig. 5, but showing only one half of the width of the shield thereat. Fig. 7 is a vertical cross-section taken at the line *w w* of Fig. 5 and showing the other half of the width of the shield, the two views, Figs. 6 and 7, being preferably joined. Fig. 8 is an inside elevation of the front wall of the shield. Fig. 9 is an outside elevation of the front wall or head of the shield, the two views, Figs. 8 and 9, being preferably united and showing each one-half of the wall from the inside and the outside; and Fig. 10 is a bottom plan view of the shield.

In the various views the same parts will be found designated by the same numerals of reference.

It will perhaps be best to describe first the general construction of my novel shield and then subsequently the mode of using the same in the operations of building subaqueous tunnels, &c.

The most noteworthy feature to be observed is that the shield is constructed without a bottom or is open on its under side, and it is owing to this fact that I am enabled to build the proper foundation-work for the tunnel and to build the tunnel itself, as will hereinafter more fully appear.

The shield is rectangular in contour and comprises two longitudinal sides 1 1, a front side or head 2, and a top 3, there being no rear end and no bottom to the shield. At various places within the shield are constructed suitable air and water tight compartments, which may be utilized for various purposes. For example, at the upper portion of the shield are shown a series of large compartments 4, extending transversely and longitudinally of the shield, there being three such compartments extending longitudinally on each side and three in the middle, making nine altogether; but these may of course be varied in number as may be desired and in accordance with the necessities of the work in hand. These various compartments communicate one with the other through suitable doors or air-locks 5 in an ordinary manner and so that workmen may go from one compartment to another and may carry material therethrough or store it therein, as may be found necessary. Below the series of compartments 4 there are provided at each side of the shield a number of smaller compartments 6, nine in number, which may communicate with each other through doors or air-locks and which may also communicate with the main working chamber or portion 7, extending between the said compartments 4 and 6 and the head 2 and rearmost open-ended portion of the shield. The various compartments are preferably constructed of sheet iron or steel with flanged edges, at which they are securely bolted together and to the shield. Each of the lower and side longitudinally-arranged compartments 6 has its inner walls 6^a inclined or sloping downwardly and outwardly, so that the bottom portion of the compartment is narrower than the upper portion, thus giving more working room within the chamber 7, while at the same time said compartment affords a firm and substantial brace or support for the upper compartments 4. The lower portions of the compartment 6 bear upon a series of antifriction-rollers 8, which are adapted to travel on the upper surfaces of vertically-arranged I-beams 9, which are laid longitudinally upon the substructure as it is constructed and as will be hereinafter more fully explained. Tie-bolts 10 may be secured at their upper ends to eyes 11, projecting inwardly from the walls 6^a of the compartment 6, and at their lower ends to the upper ends of anchor-bolts 12, secured in the substructure at desired places as the latter is built, these tie and anchor bolts being adapted to hold the shield or caisson down and steady it during the work of constructing the tunnel and the foundations therefor, the tie-bolts 10 being removed when it may be desired to advance the shield by sliding or forcing it forward on the supporting antifriction-rollers 8.

The forward movement of the shield is preferably accomplished by one or more series of hydraulic jacks. I have shown two series of such jacks, one, 13, at the rear portion of the shield, and one, 14, at the front portion of the shield. The jacks 13 are arranged in a curve or arc conforming substantially to the contour of the tunnel. In rear of the compartments 4 and 6 is a curved plate or wall 15, against which the forward ends of all of the jacks may press to force the shield forward, the rear ends of the jacks having for their abutment a plate or head 16 at the forward end of the tunnel proper in course of construction, as shown more clearly at Fig. 5. The top and sides of the shield extend rear-

wardly from this plate and partially surround the forward end 17 of the constructed tunnel and in a manner such that the said end 17 will act as a guide to the shield when it is moved forward. The joint between the rear end portion of the shield and the forward end 17 of the tunnel is maintained air and water tight by means of suitable packing devices, as indicated at 18. The jacks 14 are arranged horizontally and longitudinally of the shield and at the lower forward portion thereof. The forward ends of the jacks 14 bear against a hollow structure or box-beam 19, secured on the rear side of the head or front plate 2 of the shield, and the rear ends of the jacks abut against the forward end or last completed portion of the foundation-work, which will presently be more fully explained.

The head of the shield, like the sides and top, is composed of separate flange-plates riveted together and is formed or provided at its lower portion with numerous small holes or apertures 20, through which air and water or either may be ejected for the purpose of agitating and loosening the mud, silt, or the like at the front side of the shield, and thus displacing such matter, so as to facilitate the advance of the shield. I have shown three transverse lines or series of apertures 20 at the lower portions of the head of the shield; but of course there may be more or less of these apertures, as may be found desirable. I have also shown at about the middle of the head a single series of similar jet-openings 20, which may be employed advantageously for the same purpose as the lower series. A system of piping communicates with these openings and with the various compartments, as will hereinafter be more fully described. The head of the shield is likewise formed with several transverse series of openings 21, provided each interiorly of the shield with a cover 22, which may be clamped or bolted over the opening. These openings 21 are provided for the purpose of enabling any material to be carried into the shield which would not be easily displaced by the jets and which might have to be otherwise removed to enable the shield to be advanced. These covers are preferably provided with central outlets 23, controlled by valves 24, and which may be used for the ejection of air or water, or both, to loosen or displace the mud or other material in advance of the head.

At suitable intervals transversely of the head of the shield are provided a series of openings 25, provided with suitable covers on the inside of the head, and these are employed in connection with a pumping or suction apparatus for the purpose of enabling material to be drawn into the shield, which may not be readily displaced and moved out laterally of the head of the shield, and such material may subsequently be either carted away or discharged through pipes at the point 26 or elsewhere, as may be found most expedient. Transversely of the head of the shield is still another series of openings 27, each of which is provided with a stuffing box or gland and through which may be introduced a drill, as 28, operable by hand or by compressed air from within the shield and for the purpose of drilling holes in rock or boulders which may be ahead of the shield and which may be necessary to blast away for the purpose of enabling the advancement of the shield.

If desired, there may be provided on the top of the shield a superimposed caisson 29, which may be bolted or otherwise secured to the shield, but which is preferably detachable therefrom. This caisson may, however, form a permanent part of the shield and in such case would constitute the top of the same. As here shown, it is formed of three longitudinal series of compartments 30, there being six compartments in each series. These compartments all communicate with each other by means of doors 31, and these doors have valve-controlled apertures 32, so as to let the air or water in from one compartment to the next when this may be desired. These compartments are to be used primarily for the storage of weight, either water or pig-iron or the like, where the shield is in operation at some considerable distance below the surface of the water and where the buoyancy of the shield is greatest. The forward chambers or compartments of the superimposed caisson may be provided with glass-covered openings or ports 33, through any one of which by the aid of an electric light applied at one of the other glass-covered openings or ports the workmen may observe the character of the material immediately in front of the shield, and, if desired, some of the lower openings 21 in the head of the shield may likewise be provided with glass covers for the same purpose.

Referring to Fig. 5, it will be observed that the rearmost compartment 4 of the middle series is provided with a telescopic tubular shaft 34, some of whose sections are adapted to pass out through one of the compartments in the superimposed caisson and be extended up above water-level, so that in case of emergency the workmen could escape through said shaft, or, if desired, material carried into the shield through the head may be elevated through said shaft to the surface of the water, at which may be located scows or the like for receiving the same. There may of course be as many of these telescopic shafts as may be necessary.

It will be observed at Fig. 5 that the plates of which the head of the shield is composed are formed with deep or wide flanges, which greatly strengthen the head; but in addition thereto I prefer to employ a series of removable or adjustable stiffening bars or braces 35 (shown in dotted lines) and which extend from said flanges in truss-like form to the front face of the upper series of compartments 4, thus effectually resisting any liability of the head buckling or distorting. At the same time this bracing serves to transmit

the force of the jacks 13 exerted through the walls, tops, and bottoms of the compartments 4 to the head of the shield, it being understood that the wall 15 is specially strengthened or stiffened to resist the pressure of the jacks, so as to prevent injury to said wall.

By referring to Figs. 5 to 9, inclusive, it will be observed that the side walls of the shield extend slightly below the lower or cutting edge of the head of the shield in order that any escape of air from the shield may be under the head or forward portion thereof, where it is desirable to displace or dissipate the material, rather than at the sides of the shield, where it may be desirable to have the material remain intact.

The initial or first work of constructing the foundation of the tunnel is performed at the forward end of the shield and near the head thereof, and for this reason there is provided at this locality a pile-driving mechanism (represented generally at 36) and which may be of any suitable construction. I have illustrated a carrier 37, which may be supported to travel transversely of the shield with the driving mechanism and so as to drive successively crosswise of the shield a line of piles 38. The driving mechanism for piles is represented as being adapted to be moved progressively longitudinally of the carrier and shield, so as to enable it to drive successive forward lines of piles until the requisite number have been driven to renew or continue the constructional work of the flooring or platform of the tunnel-foundation.

The system of piping for the various compartments and for the jet-openings, pile-driver, &c., will be readily understood and is easily installed by the hydraulic engineer, but is difficult of illustration herein. I have, however, endeavored to show such a system, although it may be varied in accordance with the detail construction of the shield and in accordance with the various working devices which may be employed therein. For the jet-openings 20 there is a line of piping 39, with branches 40 extending to said openings. For the next tier of jet-openings 20 there is a line of piping 41 and branches 42. For the topmost series of jet-openings 20 there is a line of piping 43. These transverse supply-pipes are connected by hose or like flexible connections to the longitudinally-arranged main supply-pipes 44, of which, as will be seen at Fig. 7, ten are shown. Some of these pipes are, however, used to conduct air or water at different pressures to the compartments 4, 6, 7, and 30, said main supply-pipes 44 being built into or laid in the masonry or foundation in sections as the work progresses and being connected at their outermost ends to air-compressers and water-pumps. In addition to these main supply-pipes there is a larger centrally-arranged water-pipe 45, likewise laid in sections and which is similarly connected by hose to the jet-pipes and to the pipes leading to the compartments and to any other portion of the shield or any other device therein which may require the water from this pipe. Various branch pipes, as 46 47, connect with the supply-pipes 44 and 45, so as to conduct the air and water to and from the various compartments. When it may be desired to draw in the mud or other material through the suction-holes 25 or from under the cutting edge of the shield, a suction or sand pump is placed near the bottom of the bed of the shield and connected to the exhaust-pipe 48. Said pipe may be supported on the jacking-timbers, or it may be suspended within the shield or otherwise suitably supported, and the suction end of the pipe may be either passed out through one of the holes 25 or inserted below the lower edge of the head of the shield. It is perhaps unnecessary, further, to describe in detail the arrangement of the pipes or of the valves which control said pipes or of the valves which control the passage of the air and water from one compartment to another, these systems being well understood by those skilled in the art.

Having now described specifically the construction of the shield and its appurtenances, I will now describe more particularly the manner of its use in the building of the tunnel and the foundation therefor. The shield being unprovided with a rear end is for the purpose of sinking or submerging the same temporarily provided with a rear end or wall, which may be made of timber and which may be removed after the shield has been brought down to the proper depth and in alinement with the shore end of the tunnel. To sink the shield, it is filled or partially filled with water or other weights, such as pig-iron, depending upon the depth to which the shield must be submerged, and the shield is permitted to descend until it rests upon the mud or other material below the surface of the water. It may then be necessary to excavate from under the shield in order to get it down in alinement with the shore-opening of the tunnel, and to accomplish this it may be necessary to pump air into the working chamber 7, and thus drive the water therefrom, whereupon workmen may descend into the shield and proceed with the work of excavating by suitable means, and for this purpose a sand or suction pump may be connected with the pipe 48 and the material all blown out or exhausted at 26. As the material is thus expelled from under the shield it may be necessary from time to time to add more weight to the shield to maintain it in its depressed condition and enable it to follow down on the bed of material, as will be readily understood by those familiar with pneumatic-caisson work. When the shield or caisson has finally been brought into alinement with the shore-opening of the tunnel, the latter may be built forward the required extent to connect with and enter the rear end of the shield, whereupon the temporary rear end of the shield may be removed and open communication established

between the interior of the shield and the tunnel, and the air and water pipes running through the tunnel from suitable pumps and air compressors may then be connected with the shield either at this time or subsequently, depending upon whether the pipes leading from above which were used in the sinking of the shield have or have not been disconnected. The parts are now in condition for the workmen to proceed with the operations of removing the mud, silt, &c., and building or constructing and forming a suitable foundation and bottom for the tunnel.

The order of the operations may vary under different circumstances; but ordinarily the first operation would be to drive into the mud or sand a series of transverse lines of piles to a sufficient depth to enable a foundation of the requsite strength to be built thereupon. The sinking of the said several rows of piles may be accomplished by jacks or other devices employed within the shield instead of by the pile-driver shown; but after the line of piling has been constructed up to near the forward end of the shield the piles will then preferably be driven by the pile-driver shown, and after two or three transverse rows of piles have been driven by the pile-driver and the beams and concrete or other masonry laid thereon the shield will then be moved forward, as will presently be explained. The piles may be of wood or of iron in sections. When the piles are driven, they are preferably laid on true lines longitudinally and transversely, and at the proper times longitudinal I-beams 49 are bolted to the sides thereof, as shown more particularly at Figs. 6 and 7, and transverse I-beams 50 are also bolted to the sides of said piles and additionally secured thereto by straps 51, which pass around said transverse beams and over the top of the pile, their ends being secured to the pile below the longitudinal beam. Then concrete is laid between and over said I-beams and the top portions of the piles, as represented at 52, the bed of the river or stream usually being firm enough to support the concrete between the beams and piles; but if it should be too soft buckle-plates or supports may be placed under the lower flanges of the I-beams to hold and retain the concrete. When the longitudinal and transverse beams 49 and 50 have been secured and concrete laid thereupon and therebetween, the longitudinally-arranged I-beams or rails 9 9 are laid upon the cross-beams 50, and concrete 53 is laid upon said transverse beams and also around the lower portions of the beams or rails 9 9, so as to embed them therein and maintain them in proper position for the antifriction-rolls 8. During the laying of the concrete 53 the pipes 44 and 45 are inserted or laid, and at the same time the sectional bottom plates 54 are laid transversely upon the cross-beams 50 and covered with concrete. They are, however, first bolted together and to the cross-beams. At the same time the bottom plates are put down the end plates 55 are also erected and also surrounded by concrete. These end plates project slightly above the concrete and support the series of arching plates 56, which are subsequently put in in sections and filled with concrete between their flanged ends, the said plates 56 constituting when completed the inner walls of the subaqueous tunnel. The concrete 57 on the outer side of said plates is laid to accurately conform to the contour of the rear end of the shield and which is preferably constructed so as to provide a working space at the portion marked 58. The section of the tunnel having now been built within the rear portion of the shield and just back of the jacks 13, and piles having been driven at the forward end of the shield, and longitudinal and transverse beams and flooring-concrete having been laid, and the rails 9 9 and the bottom plates 54 of the tunnel and the end plates 55 thereof and the pipes 44 and 45 having also been laid or placed in position, the next operation will be to move the shield horizontally forward a suitable distance—for example, such as that represented at Fig. 5. To do this, the water and air jets 20 are first permitted to operate on the mud or silt in advance of the shield, and if rock is to be removed drills 28 are operated. Also if some of the material is to be brought in through the shield the ports 23 are opened for this purpose or a suction-pump is employed, as before explained. When the material has been sufficiently removed or displaced from in front of the shield, the latter is moved forward by means of the jacks 13 and 14, or either of them, depending upon the resistance ahead of the shield and also the friction on the sides of the shield. The jacks 13 are always arranged in the position shown; but the jacks 14 are only placed in their positions when it becomes necessary to move the shield. It will be understood by those skilled in the art that when water is admitted to all of the series of jacks which it may be necessary to employ said jacks will operate to press the shield forward, the series of jacks 13 having for their abutment the forward end of the previously-constructed tunnel and pressing against part of the shield at the forward end thereof, and the jacks 14 having for their abutment the foundation or cribwork of the piling and pressing at their forward ends against the box-beam secured near the lower edge of the head of the shield. During this movement of the shield it is steadied and guided by the front end of the tunnel, which telescopes into the rear end of the shield, and owing to the employment of the antifriction-rollers 8, which support the weight of the shield, the resistance to the movement of the shield is greatly reduced. One of the lower compartments 6 is shown as partially filled with pig-iron 59, which may be used with other weights to keep the shield down in bearing contact with the rollers 8, and these

rollers and their tracks or rails firmly fixed in the bed-foundation built within the shield prevent any depression of the shield and insure its moving forward in the proper line or path, while at the same time the said foundation-work, including the rails, prevent any laternal movement of the shield, owing to the sides of the latter extending down to and past the flooring or covering of the foundation-piling, and which flooring or covering constitutes the bottom of the completed tunnel. The shield having been moved forward the desired extent, or to, say, the position shown at Fig. 5, and the air and water jets and other mud displacing and removing device having ceased their operations, and the jacks 14 having been removed, the operation of driving piles will again be resumed, and then the work of laying beams and concrete will be repeated until another section of the tunnel has been added. Thus the work is continued progressively until the completion of the tunnel.

As shown at Fig. 5 and as customary, the tunnel is provided with a suitable bulkhead 60, provided with an air-lock forming communication between the forward portion of the tunnel and the shield, so that workmen may from time to time pass from one structure to the other, so that piles and other material may be taken from the tunnel into the shield for the building of the foundation, and so that, if desired or necessary, excavated matter may be taken from the shield back into and through the tunnel.

If desired, openings 61 may be formed in the front and sides of the shield for ropes or cables, which from the front may extend forward from the shield to the opposite shore and be there secured, and which from the sides may be connected to anchors, all for the purpose of relieving the shield from side strains from swiftly-running or strong currents, and which might tend to displace it laterally or cause it to bind on the tunnel. Also, if desired, there may be arranged a series of temporary emergency air and water pipes 62 to connect with the various compartments from the pumps and air-compressors on the shore.

Of course if at certain places it should be desired to construct a foundation of columns instead of piles tubular iron or steel sections may be sunken into the bed of the river by the well-known pneumatic process or by the equally-well-known process involving the use of jets of air or water at the leading end of the column, and the column may be formed of sections screwed or bolted together, depending upon the depth to which it is to be sunken. After the column or columns have thus been driven they may be filled with concrete or other suitable material. In such work, of course, in lieu of the pile-driving apparatus suitable pneumatic or jetting apparatus would be employed and at about the locality at which the pile-driving apparatus is now shown as arranged.

Referring to Fig. 1, the view represents the tunnel as having been constructed from one shore to the other under the water, and said view shows in dotted lines where the mud and rock have had to be removed and also those places where it was necessary to drive piles in order to secure a firm and stable foundation for the tunnel itself.

At Fig. 2 is represented, on a small scale, the work of constructing the tunnel and the foundations from within the shield, while at Figs. 3 and 4 cross-sections of the tunnel and river-bed are shown at portions of the tunnel. (Represented, respectively, by the lines *z z* and *y y*, Fig. 1.)

As will be observed from Figs. 3 and 4, I prefer to surround or cover the completed tunnel on the top and two sides with broken rock, coarse gravel, or other suitable material 64, so as more firmly to maintain the tunnel upon its foundation and in proper position and at the same time protect the tunnel against damage—as, for instance by sunken vessels or the dragging anchors of passing boats. This covering of rock or the like preferably extends for the entire length of the submerged portion of the tunnel and may be formed by dropping the material from scows or the like anchored over or alongside of the tunnel.

At Fig. 3 anchor-rods 63 extend from the flooring or base of the tunnel down into the rock, where said rods are provided with spreaded ends which, by means of wedges, retain a firm hold in holes drilled in the rock, thus further securing the tunnel against rising or upward displacement by reason of its own buoyancy. These anchor-rods may be provided at such points as will permit of their use during the entire length of the tunnel. If desired, at various points in the structure where the nature of the river-bed will admit, screw-piles may be driven into the soil and secured at their upper ends to the bottom of the tunnel, so as more effectually to hold it in position. It will thus be seen that by the use of piling and anchor-rods ample provision is made for immovably holding the tunnel in its proper position, not only against upward movement, but lateral movement as well.

So far as I am aware no one has hitherto provided any means for constructing a subaqueous tunnel by first building therefor a suitable foundation and then progressively constructing the tunnel upon such foundation, and this mode of construction I desire to claim as broadly as possible. Moreover, no one, so far as I am aware, has previously made and employed, in connection with the building of tunnels, a bottomless shield constructed and adapted to enable workmen to construct a suitable foundation for a tunnel and to construct the tunnel progressively

from within such shield and then to advance such shield in the line of the tunnel for the building of additional foundations and additional sections of the tunnel, and this construction of shield and mode of building the tunnel I also desire to claim as broadly as possible.

While I have shown and thus far described my improvements more particularly in connection with the building of tunnels, it will be understood that they may be employed for the building of subaqueous pipe-lines and aqueducts and in connection with the construction of suitable foundations for bridges, piers, docks, and other submarine structures where the work has got to be carried on linearly and progressively. The nature of the operations from within the movable shield will of course vary according to the kind of structure and foundation to be built or provided, and it will therefore be understood that various changes in the construction of the shield and in the mode of its employment may be made without departing from the spirit of my invention.

I do not claim herein my novel construction of shield and tunnel, since the same are made the subject-matter of a divisional application filed May 29, 1902.

What I claim as new, and desire to secure by Letters Patent, is—

1. The method of constructing subaqueous tunnels which consists in building progressively an artificial foundation in the bed of the river where needed, then building a portion of the base or bottom of the tunnel upon said foundation in advance of the head of the tunnel, and in then progressively building forward the sides and top of the tunnel.

2. The method of constructing subaqueous tunnels which consists in inserting piling in the bed of the river where needed, in building thereupon a portion of the base of the tunnel to be constructed, and in then building forward on said base portion the sides and top of the tunnel.

3. The method of constructing subaqueous tunnels which consists in first adjusting or placing a movable pneumatic shield in position, in afterward building a foundation in the bed of the river from within the movable shield and in then building a forward extension to the tunnel within said shield.

4. The method of constructing a subaqueous tunnel which consists in first adjusting or placing a movable pneumatic shield in position, in afterward building in the river-bed a suitable foundation for the tunnel and from within the movable pneumatic shield, in then building an extension to the tunnel within the shield, and in then moving the shield forward for the construction of additional foundation and tunnel.

5. The method of constructing a subaqueous tunnel which consists in first adjusting or placing a movable pneumatic shield in position, in afterward building in the river-bed a suitable foundation for the tunnel and from within the movable pneumatic shield, in then building an extension to the tunnel within the shield, in then ejecting jets from the head of the shield and removing or displacing material in advance thereof and in then forcing the shield forwardly over said foundation.

6. The method of constructing subaqueous tunnels which consists in first adjusting or placing a movable open-bottom pneumatic shield in position, in afterward inserting piling into the bed of the river from within the open bottom of said pneumatic shield, in then building a portion of the bottom of the tunnel upon said piling and within said shield, in then building extensions of the sides and top of the tunnel within said shield, in then moving the shield forwardly over said bottom portion of the tunnel, and in then successively repeating said operations where necessary.

7. The method of constructing subaqueous tunnels which consists in first adjusting or placing a movable open-bottom pneumatic shield in position, in afterward inserting piling into the bed of the river from within the open bottom of said pneumatic shield, in then building a portion of the bottom of the tunnel upon said piling and within said shield, in then building extensions of the sides and top of the tunnel within said shield, in then displacing or removing material from in front of the shield, in then forcing the shield forwardly over the said bottom of the tunnel, and in then repeating the several operations where needed.

8. The method of constructing a subaqueous structure which consists in first adjusting or placing a longitudinally-movable pneumatic shield in position, in afterward building a foundation from within said shield, in then building an extension of such structure upon such foundation, in then advancing the shield, and in then repeating the operations wherever needed.

9. The method of constructing subaqueous structures, which consists in first adjusting or placing a longitudinally-movable open-bottom pneumatic shield in position, in afterward inserting piling into the river-bed from within the open bottom of said shield, in then building from within said shield a flooring or covering upon such piling, and thereby extending the said structure longitudinally, and in then moving the shield forwardly in the line of the structure so as to enable the several operations to be repeated.

10. The method of constructing a subaqueous tunnel which consists in first adjusting or placing a movable pneumatic shield in position, in then inserting piling into the bed of the river from within said shield and in advance of the tunnel, in then building a flooring or

covering upon said piling from within said shield, in then building extensions of the sides and top of the tunnel within said shield, and in then advancing the shield horizontally to enable the said several operations to be repeated.

Signed at the borough of Manhattan, city of New York, in the county of New York and State of New York, this 21st day of February, A. D. 1902.

JULES BREUCHAUD.

Witnesses:
K. V. DONOVAN,
E. M. WELLS.