

S. LAKE.
METHOD OF BUILDING SUBAQUEOUS TUNNELS.

APPLICATION FILED FEB. 9, 1903.

NO MODEL.

4 SHEETS—SHEET 1.

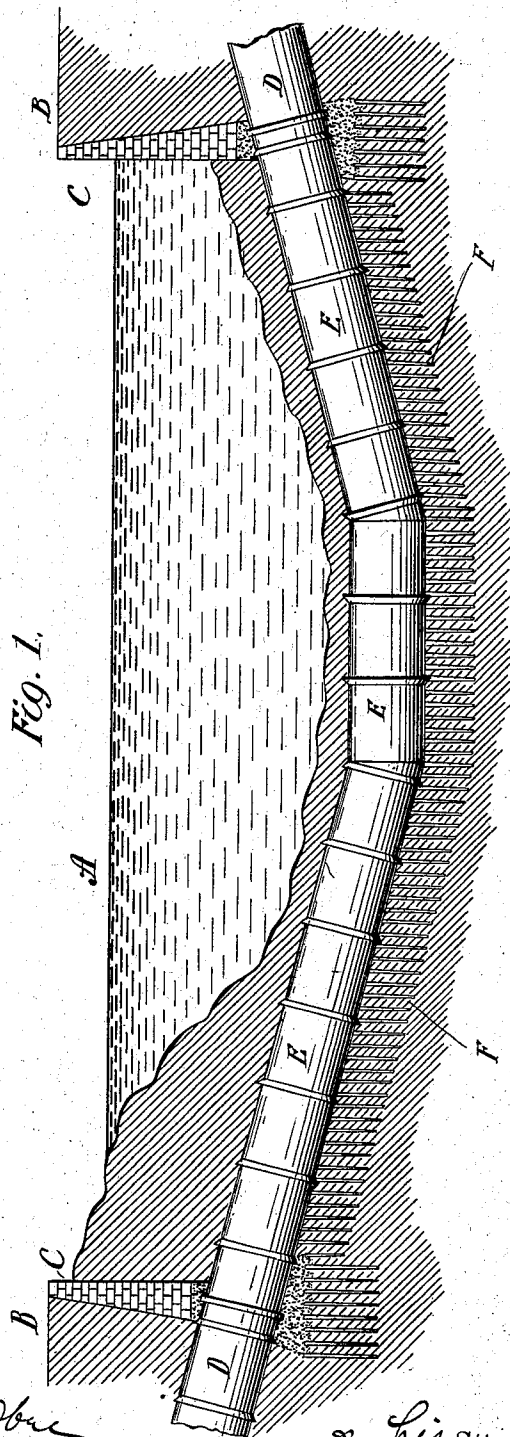


Fig. 1.

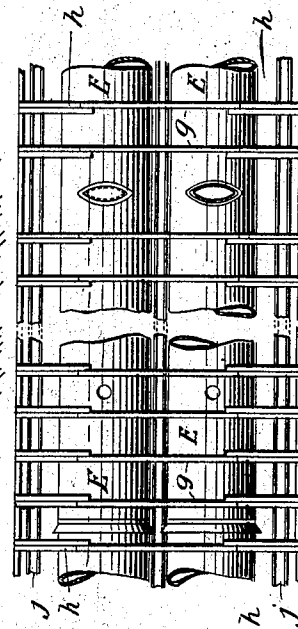


Fig. 4.

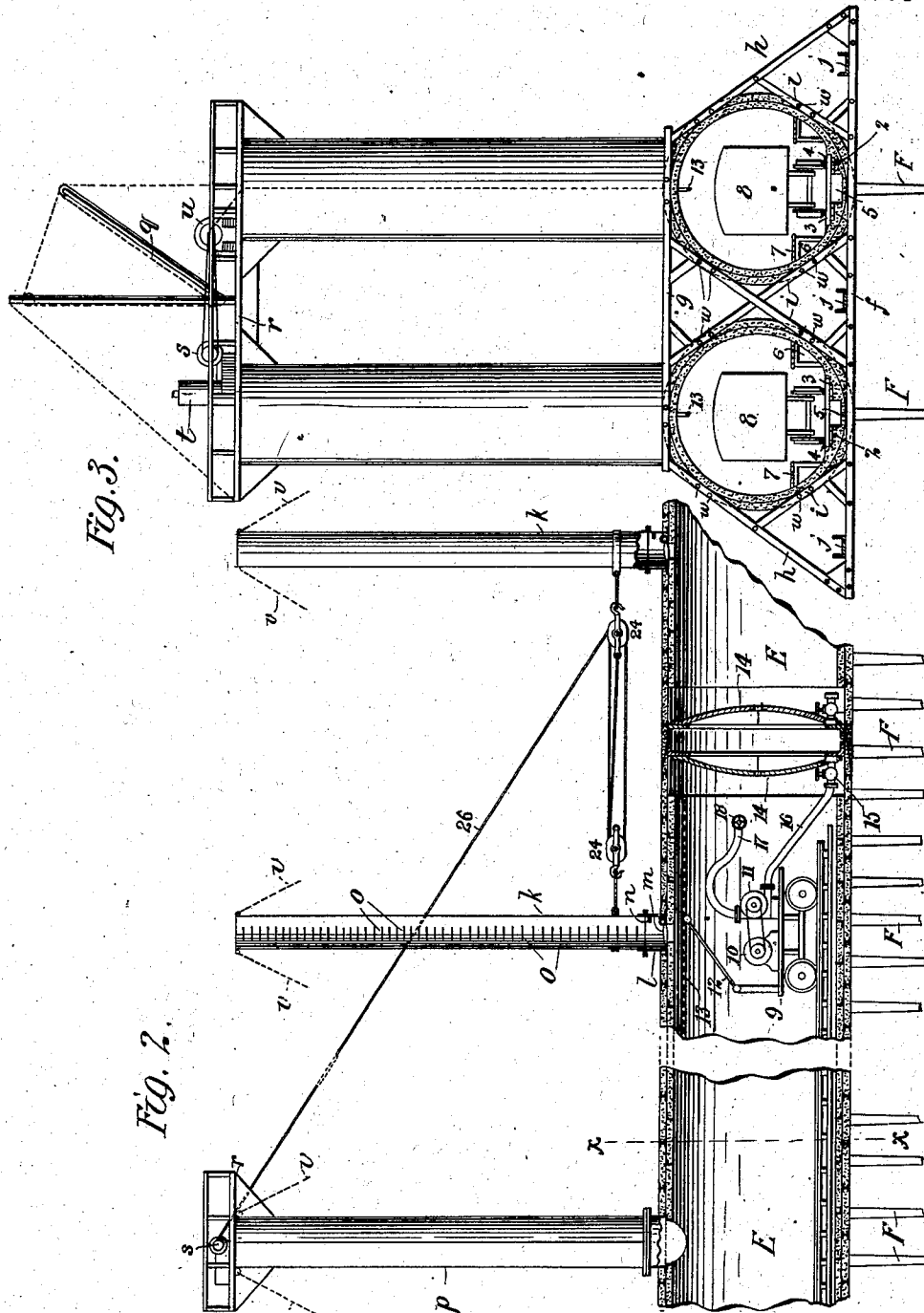
Witnesses
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4 SHEETS—SHEET 3.

Fig. 5.

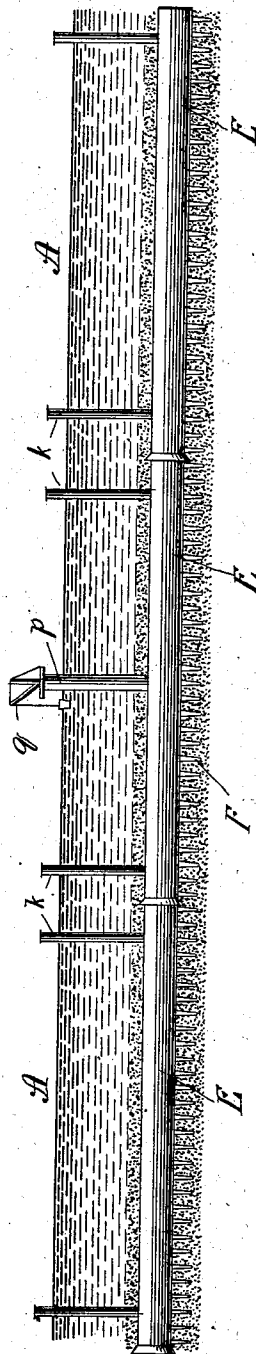
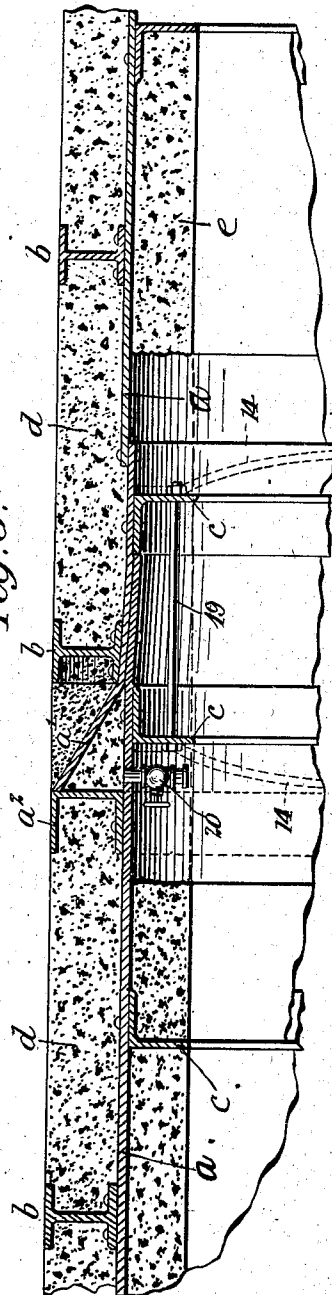


Fig. 6.



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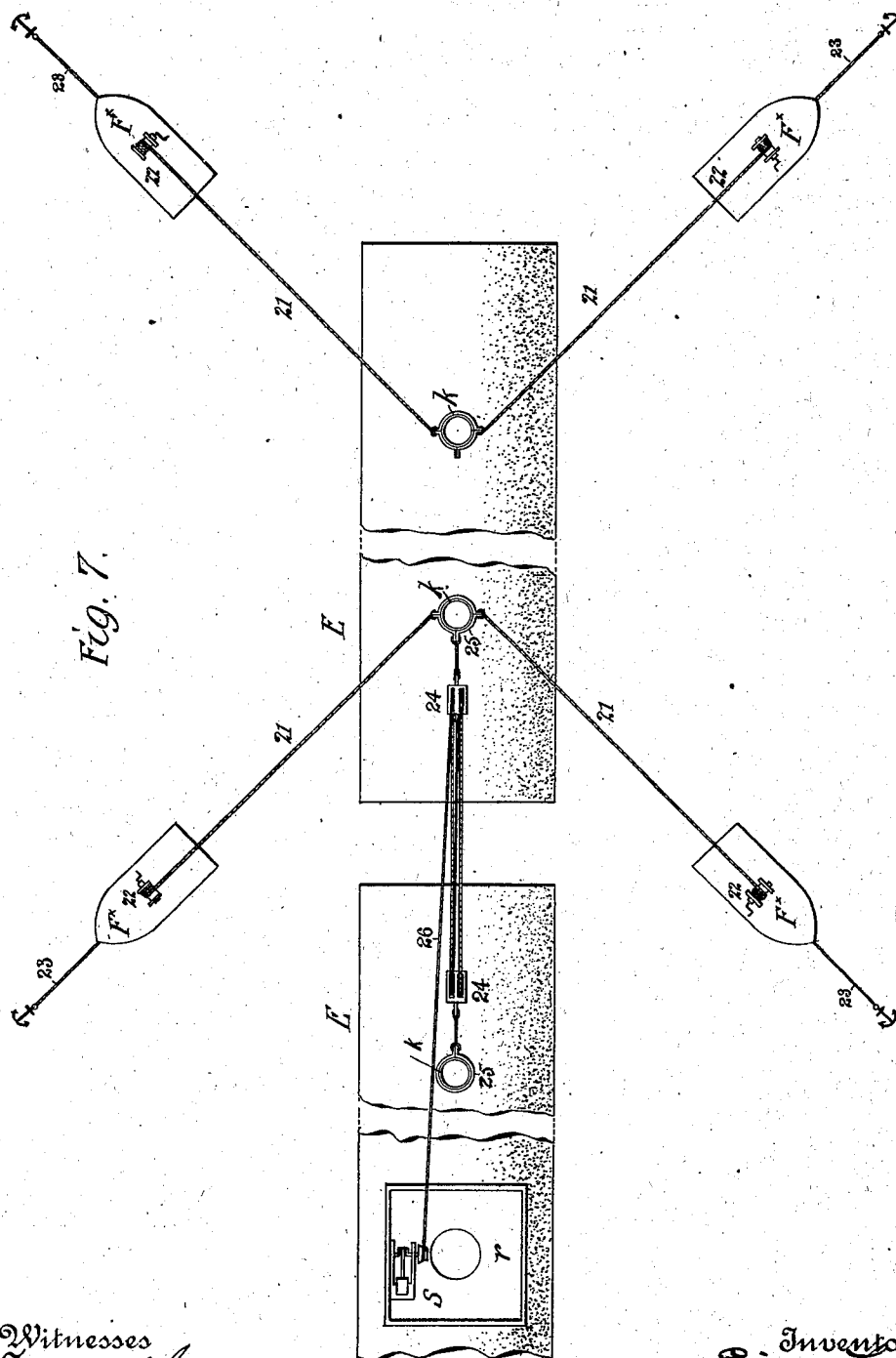
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4 SHEETS—SHEET 4.



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UNITED STATES PATENT OFFICE.

SIMON LAKE, OF BRIDGEPORT, CONNECTICUT.

METHOD OF BUILDING SUBAQUEOUS TUNNELS.

SPECIFICATION forming part of Letters Patent No. 730,135, dated June 2, 1903.

Application filed February 9, 1903. Serial No. 142,640. (No specimens.)

To all whom it may concern:

Be it known that I, SIMON LAKE, a citizen of the United States, residing at Bridgeport, in the county of Fairfield and State of Connecticut, have invented certain new and useful Improvements in Methods of Building Subaqueous Tunnels, of which the following is a specification, reference being had therein to the accompanying drawings.

This invention relates to a method of constructing that class of subaqueous tunnels which are formed of a series of tubular sections built upon the land and provided each with temporary bulkheads to enable them when launched to be floated to the vicinity of the site upon or beneath the water-bed which they are designed to occupy, then sunk to the required position and connected with the adjacent section or sections and their bulkheads finally removed to establish communication between such adjacent sections.

The invention has for its object not only to increase the efficiency of the operation of building this class of tunnels, but to provide a method whereby such tunnels may be built with the greatest safety to the workmen employed in preparing the water-bed therefor, placing the several sections in position, and connecting together and establishing communication between them, and whereby the tunnel may be constructed in much less time than has been practicable with methods of tunnel construction heretofore proposed.

The present improvement consists in the method of building such tunnels, herein shown and described, as set forth in my pending application, Serial No. 109,589, filed May 31, 1902, which has for its subject the constructive features which I prefer to adopt in the practice of the present invention.

In the drawings, Figure 1 is a sectional elevation, considerably distorted for purposes of illustration, showing in conventional manner a completed tunnel under a waterway, indicating the tunnel-tubes in external view, but with certain details omitted. Fig. 2 is a sectional elevation, upon a larger scale, of the middle and one end portion of a central tubular tunnel-section and the contiguous end portion of the adjoining section in telescopic relation therewith, both sections being provided at the ends with bulkheads separating their

interiors and also with apparatus employed in the installation of such tunnel-sections in their respective positions; and Fig. 3 is a transverse section on the line xx in Fig. 2, indicating the manner of trussing together two parallel tunnel-sections. Fig. 4 is a plan view showing the middle and end portions of a compound tunnel-section formed of two parallel tubes united by transverse trusses or frames, the tubes being similar in diameter to those represented in Fig. 1. Fig. 5 is a sectional elevation similar to Fig. 1, but upon a smaller scale, showing the middle portion of the tunnel with the temporary standing leveling-pipes at the ends of each section and the middle upright shaft or inlet-tube of the central section still remaining in position; and Fig. 6 is a detail longitudinal sectional view, upon a greatly-enlarged scale, showing the method of construction of the joints between the adjacent sections. Fig. 7 is a diagrammatic plan view illustrating the method of placing the tunnel-sections in position upon the water-bed.

The opposite banks or shores B of the waterway A are provided, as usual, with sea-walls C, to and through which the land-terminal portions D of the tunnel are extended in the usual manner to connect with the intermediate subaqueous portion, shown herein in the connected views as consisting of series of continuously-arranged tubular sections E. Each of these tunnel-sections is formed of a long inner shell consisting of a metallic tube a , encircled by a series of I-angle rings b , securely attached to the exterior of the same by rivets, and a series of internal L-angle rings, c similarly secured in position within the interior in a plane transverse to the axis of the tube. Each section is or may be built up of a series of short tubes secured together by rivets similarly to a cylindrical steam-boiler shell, as indicated in Fig. 6, in which the end portion of the right-hand section is shown terminating in a flaring or conical hub a' , into which the adjacent cylindrical end of the adjoining section (constituting the spigot of the connection) projects and forms a tight joint, the extreme end of the flared portion a' abutting against the channel-ring a'' , disposed near the cylindrical end of said adjoining section. The spaces intermediate the metallic tube a and

the I-angle rings *b* are filled with cement or artificial stone *d*, and a similar filling *e* is interposed between such tube and the rings *c*, such non-metallic fillings being flush with the outer and inner peripheries of the rings *b* and *c*, respectively. A similar filling is introduced into the annular channel formed between the flared portion *a'* of the tube *a*, the end of the tube entering the same and the angle-rings *a*² and *b* at the opposite ends of such flared portion *a'*.

Each tunnel-section is provided with a series of transverse metallic frames or trusses spaced at close intervals apart, and in case the tunnel is formed of two parallel tubes, as indicated in Figs. 3 and 4 of the accompanying drawings, the double tubular sections *E* of equal length are rigidly tied together by such frames or trusses, which latter are shown formed each of a lower or base member *f*, lying beneath, and a shorter member *g*, lying upon, the tunnel-tubes and united by the upwardly and inwardly inclined side members *h* and intermediate braces *i*, all of said truss members being not only riveted together, but secured to the shell *a* and external angle-rings *b* by bolts or rivets *u*, where their contact with such parts permits. Said trusses are also tied together by longitudinal channel-beams *j*, extending parallel with the sections *E*.

A line of piling *F*, which may be spaced correspondingly with the trusses above described, is driven into the water-bed preferably immediately beneath the center line or axis of each tunnel-tube, so as to support the weight of the latter securely, and thereby insure it against injury by settling when traffic is established within the tunnel.

Each tubular section *E* is provided near both ends with temporary standing-pipes *k*, each having a flange at the lower end bolted to a similar flange of the curb *l*, surrounding an inlet-aperture in the tunnel-tube, having a trap-door *m* normally closed, but adapted to be opened outwardly upon its hinge against a stop-lug *n*, so arranged that when released the door will drop by its own weight to its seat and automatically close said aperture from the inflow of water in case the tube *k* should be accidentally wrenched off the tunnel-tube by collision therewith of boats or floating matter of any kind upon the surface of the water. Each tube *k* is provided with a vertical series of horizontal bars *o*, constituting a ladder for the use of workmen employed in building the tunnel.

The central tunnel-sections are also provided each with a larger inlet or working tube or shaft *p*, applied and held in place thereon similarly to the end pipes *k* and through which the necessary apparatus, supplies, and ballast for carrying on the construction of the tunnel may be lowered into the tunnel-tube beneath by means of a derrick *q*, arranged upon the platform *r*, surmounting said shafts *p* and carrying in addition the

hoisting-engine *s*, boiler *t*, and motor-driven dynamo *u*, deriving its motive power from the boiler *t*, such apparatus, with other devices necessary or useful in connection with the building operation, being designed more particularly for assisting in the work of uniting the several sections, as well as performing other operations required in completing the tunnel. The working tubes *p* may be provided with trap-doors and ladders similar to those of the leveling-tubes *k*, and all of such standing tubes are preferably provided with the usual guys *v* for staying them.

Each tunnel-section is provided with the usual road-ballast 2, in which are embedded the sleepers 3, supporting the railway-tracks 4, and which contains also a central drainage trough or gutter 5. Arranged above and at the edges of this roadway are the side conduits 6, adapted to house gas or water mains, signal pipes or wires, &c., such conduits being surmounted by longitudinal platforms or sidewalks 7 for such uses as may be necessary or desirable.

In addition to the one or more freight-cars 8 with which the central tunnel-tubes are initially provided for carrying supplies for the building operation each such tube has a work car 9, containing an electric motor 10 and connected pump 11, the motor 10 deriving its electric current through a trolley-pole 12, making electrical contact with a conductor-wire 13, supplied with current from the dynamo or generator *u* upon the working platform *r*.

Each tunnel-section is provided initially with a water-tight bulkhead 14, having flanges detachably secured by suitable bolts to the webs of the end angle-rings *c* and provided near the lower edge with apertures having valves 15. The ends of two sections having been arranged in telescopic relation upon the water-bed, the flexible inlet-pipe 16 of the pump 11 is connected with one of the valves 15 and the flexible discharge-pipe 17 is similarly connected with an outlet-valve 18 in the tunnel-tube *E*, when, the said valves being opened and the pump put in operation, the water confined between the opposed bulkheads and the end portions of their respective tunnel-tubes is forced out, the external pressure upon the exposed outer end of the last-installed section thereby being permitted to force such adjacent tunnel-tubes together and close the space between the flared portion *a'* of the one and the channel-ring *a*² of the other, into which latter, after the opposed bulkheads have been removed and the adjacent angle-rings *c* secured together by the bolts 19, the plastic cement or artificial-stone filling is injected through the valve 20, Fig. 6, by means of a suitable pump, as 11.

To convey a better understanding of the method of procedure employed in placing in position the several tunnel-sections and in establishing communication between them, I

will now describe the various steps involved in the construction of the tunnel in their preferred order.

The intermediate tube or tubes (forming a simple or compound section, as the case may be) are first built upon the shore of a suitable waterway in a convenient position for launching, including in their component parts not only the shell *a* and its internal and external strengthening rings or ribs *c* and *b*, respectively, the attached series of transverse trusses and the non-metallic filling intermediate said rings, but having also the internal parts—as the road-bed, railway-tracks, conduits, electrical conducting-wires, &c.—and the necessary freight and working cars and other requisite apparatus and supplies employed in making and sealing the joints between the adjacent sections. The standing tubes *k* and *p* may be added in the course of this stage of the operation. Simultaneously with such work upon the land a section of the trench may be dredged in the water-bed intermediate and preferably equidistant from the opposite shores suitable for receiving such tunnel-section, and one or more lines of piles properly driven in such trench, spaced at short intervals, and having their upper ends removed at substantially the level of the bottom of the trench and thus adapted to rigidly sustain the said intermediate section in its permanent position in the trench. This section having been temporarily closed at both ends by means of the detachable bulkheads 14, it is now launched by means of suitable ways and towed to a position directly above the trench previously prepared for it, where it is moored by means of lines or cables 21, connected with winches 22, each mounted upon one of four floats or working boats *F*^x, which are anchored by cables 23 in pairs upon opposite sides of the tunnel-line and substantially equidistant therefrom. This initial section is now so ballasted by the introduction through the working shafts *p* or *k* of pig-iron or other suitable ballasting material sufficient to barely destroy its buoyancy when it sinks into the trench, the lines 21 serving to guide it substantially into alignment with the proposed tunnel and to effect its final lateral adjustment by proper manipulation of the winches 22, the tops of the tubes *k* and *p* projecting sufficiently above the surface of the water to enable the transit men to determine the proper position of the section by sighting across them to given objects upon the shores. The dredgings from this initial trench or cut having been removed to some suitable dumping-ground, the excavation of the adjacent cuts for the adjoining tunnel-sections is next effected, the dredgings therefrom being employed to fill in the excavation first made and partially occupied by the intermediate tunnel-section, so as to completely cover the latter, whereby a secure anchorage is provided for the laterally-projecting lower portions of the frames or trusses surrounding the tunnel-tubes as well as for

their connecting longitudinal channel-beams. The adjacent tunnel-sections, having in the meantime been built similarly to the initial section and then launched and floated to the vicinity of their respective excavations, in which are continued the lines of piling begun in the central portion of the trench, such additional tunnel-sections are similarly sunk into their respective positions and properly aligned with the first-installed section, also by the use of their standing-pipes *k*, and are brought into telescopic relation with the extremities of the central sections to which they are fitted. As the tunnel-sections adjoining the initial section are arranged in such relation by means of the mooring-lines 21, the joints between their adjacent ends are further closed by the use of a hauling-tackle comprising the pulley-blocks 24, which may be attached to heavy rings or bands 25, slipped over the adjacent working tubes *k* of the adjoining sections, connected together by a hauling-line 26, which may be attached at one end to the hoisting-engine *s*, upon the working platform *r* or to a suitable winch upon one of the boats *F*^x. By actuating the hoisting-engine or winch to exert a pull upon the line 26 the opposed sections may be brought together with sufficient force to close the joint between their extremities from the free entrance of water through the same. The work-car is now moved to one end of the central section and the water confined between the bulkheads 14 is pumped out and the bulkheads, which are constructed of several independent sections, removed, each from the interior of its respective tube, after which the end angle-rings *c* of the adjoining tubes are bolted together, either temporarily or permanently, and the filling of non-metallic material is injected into the annular space between the flared portion *a'* of one tube and the angle-ring *a''* of the adjoining tube, after the setting or hardening of which filling the valve 20 may be removed and the aperture in the shell *a* closed in any suitable or convenient manner preparatory to applying the inner coating of cement intermediate the rings *c*, which was temporarily interrupted around such valve in constructing the tube. The joint at the opposite end of this initial tunnel-tube may be similarly formed and sealed, each of the adjacent tubes or sections being finally forced home to effect the metallic closure of the joint by means of the external water-pressure upon the bulkhead at the farther end of the tube from the central tube or section.

It will be observed that while the mere opening of one of the valves 15 in the bulkheads 14 will permit such portion of the confined water to escape into the interior of the tunnel-tube, as will remove the resistance opposed to the pressure upon the extreme end bulkheads by means of which the adjoining sections are telescoped for closing the joint between them, it is desirable to pump out all of such water in order to form a vacuum between such op-

posed bulkheads, and thereby add the atmospheric pressure upon such inner bulkheads to the external water-pressure upon the outer end bulkheads for closing the joint. The succeeding sections are similarly added to the composite tunnel-section thus formed shoreward in each direction from the central or intermediate section, a part of the dredgings from the excavation for each section being utilized for filling the trench-section inclosing and for covering over the previously-laid tunnel-section, while the road-bed and the tracks of each tunnel-section are successively connected with those of the adjoining sections as soon as internal communication is established between them by the removal of the temporary bulkheads, so that the single working car of each of the initial tubes of the compound intermediate section may be used in the formation and sealing of each joint as the several sections are added. When the final section at each shore of the waterway is placed in position, the detachable bulkhead at its shore end is retained in place until the confining-wall C is built around its exterior, as indicated in Fig. 1, after which such bulkhead may be removed and the section connected with the land portion of the tunnel in any convenient or suitable manner.

The leveling-pipes *k* of each tube E may, if desired, be removed immediately after each has performed its function, as before described, in readiness for use in connection with the succeeding section to be installed, or each section may be built with its individual leveling-pipes, all of which may be retained in position until the completion of the tunnel, as indicated in Fig. 5. In like manner the removable bulkheads 14 may be used successively in different tunnel-sections, as their employment is limited to the closing of the ends of the tunnel-tubes during the launching and floating of such members to their respective positions and their adjustment in respect of and union with the adjacent tubes of the tunnel.

From the foregoing description it will be seen that the present improvement offers, among others, the following important advantages over other methods of tunnel construction, first, it enables the constructors not only to work in the actual building of the tunnel simultaneously at four different points—viz, from the center shoreward in both directions and from each land terminal in the direction of the sea-wall—but permits of the construction of the individual tunnel-sections upon land at the same time as the trench is being dredged and otherwise prepared for the reception of such sections, and, second, it admits of the carrying on of every part of the work of construction either above the surface of the water or within the tunnel-tubes, and therefore wholly obviates the necessity of employing divers for doing certain portions of the work, as has been required in the construction of subaqueous tunnels pre-

viously devised, and hence it eliminates a hitherto-constant danger to the workmen and liability to disaster in the work encountered in the building of tunnels by other methods.

Although I have described herein the order preferably followed in the construction of the tunnel, it is to be understood that the present improvement is not limited thereto—as, for instance, the building of all of the tunnel-sections of the series may, if preferred, be effected simultaneously instead of successively, and the trench for such sections may be dredged and the piles driven therein continuously and without awaiting the installation of the successive tunnel-sections. It is also evident that under certain circumstances the construction of the tunnel may proceed from one shore of the waterway to the other instead of by the preparatory placing of an initial intermediate section from which the tunnel is extended shoreward in both directions by adding the remaining sections.

In reference to the driving of piles and cutting them off at the required levels within the trenches, I may say that this also may be effected by the use of the apparatus described and claimed in my pending application, Serial No. 64,219, filed June 12, 1901, suitably fitted for the purpose in accordance with my designs.

Having thus set forth the invention, what I claim herein, and desire to secure by Letters Patent, is—

1. The method of building subaqueous tunnels which consists in constructing an initial intermediate section with temporarily-closed ends and placing it in position intermediate the shores of the waterway, adding successively thereto shoreward in both directions adjoining sections having similarly-closed ends and connecting the latter with the ends of said intermediate section, establishing communication between the adjacent ends of the sections thus joined, and continuing to add sections to the composite section so formed until a connection is effected between the shores of said waterway.

2. The method of building subaqueous tunnels which consists in constructing a series of tunnel-sections having the ends temporarily closed by detachable water-tight bulkheads and placing said sections in position end to end upon the water-bed to form closed water-chambers intermediate the opposed bulkheads of each pair of adjoining sections, withdrawing the water from said intermediate chambers, and permitting the external water-pressure acting longitudinally to force said sections together, and then removing said opposed bulkheads to establish communication between said adjoining tunnel-sections.

3. The method of building subaqueous tunnels which consists in constructing a series of tunnel-sections the ends of each of which are adapted to fit the adjacent ends of the other section or sections, inserting in both ends of each said tunnel-section detachable bulk-

heads adapted to close the same to exclude water therefrom, placing said sections successively in position upon the water-bed with their adjacent ends fitted together, expelling the water intermediate each pair of opposed bulkheads of the adjoining sections as they are placed in position and thereby permitting the external water-pressure upon the opposite ends of the composite section thus formed to

force said sections into normal connected relation, and then removing said detachable bulkheads to establish communication between said adjoining sections.

4. The method of building subaqueous tunnels which consists in constructing upon the shore of a waterway a series of temporarily-closed tunnel-sections having ends adapted to be connected in telescopic relation when placed end to end, launching said sections and floating them to the site of the tunnel, mooring said sections successively between suitable floats or working boats anchored upon opposite sides of the tunnel-site and connecting them to said boats by suitable lines or cables by which they are held directly over the line of the proposed tunnel, sinking said sections into position upon the water-bed, connecting the adjacent sections thus located by suitable hauling-tackle, drawing the same into telescopic relation, sealing the intermediate joint thus formed, and establishing communication between the sections thus joined.

5. The method of building subaqueous tunnels which consists in successively forming in the bed of the waterway the adjoining portions of a sectional trench, and laying successively in their respective sections of said trench the members of a series of tunnel-sections, and covering each said tunnel-section with dredgings from the succeeding trench-section.

6. The method of building subaqueous tunnels which consists in constructing a series of tunnel-sections, forming in the bed of the waterway a section of a trench corresponding in length with one of said tunnel-sections and permanently removing the dredgings therefrom, laying the initial tunnel-section in said trench-section, forming an adjacent trench-section and simultaneously filling in the first said trench-section with a portion of the dredgings therefrom, laying an adjoining tunnel-section in the second-named trench-section and connecting it with the first-named tunnel-section, and continuing the operation of dredging successive trench-sections and laying therein the successive tunnel-sections until the tunnel is completed.

In testimony whereof I have signed my name to this specification in the presence of two subscribing witnesses.

SIMON LAKE.

Witnesses:

H. E. BISHOP,
A. J. MILLER.