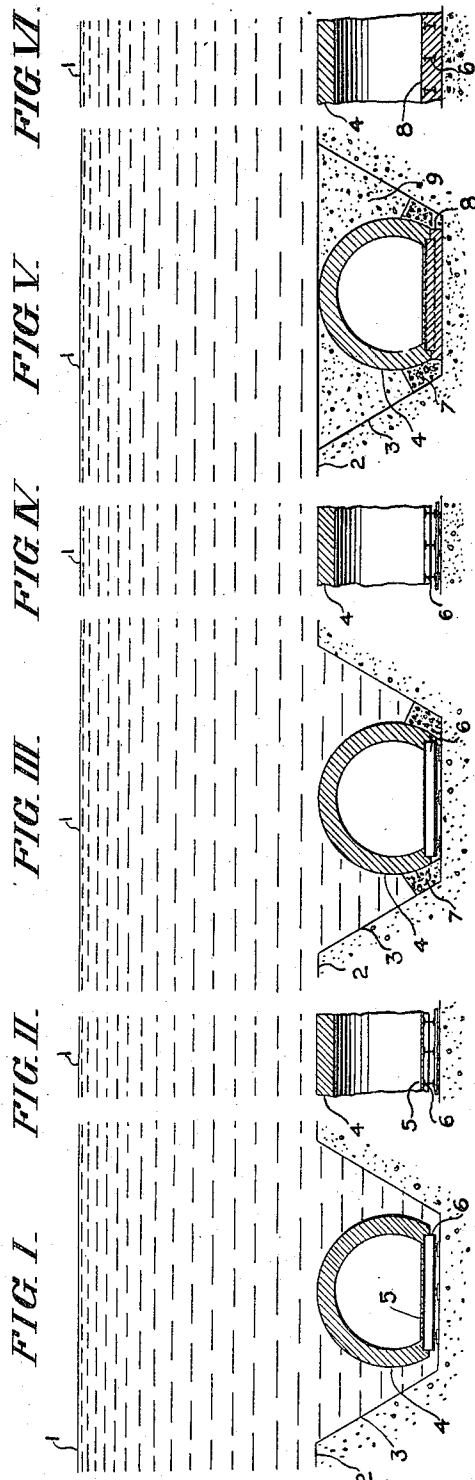


D. D. McBEAN & H. M. CHANCE.
METHOD OF BUILDING SUBAQUEOUS TUNNELS.
APPLICATION FILED NOV. 20, 1912.

1,060,271.

Patented Apr. 29, 1913.

3 SHEETS—SHEET 1.



Witnesses
Thomas M. Chance

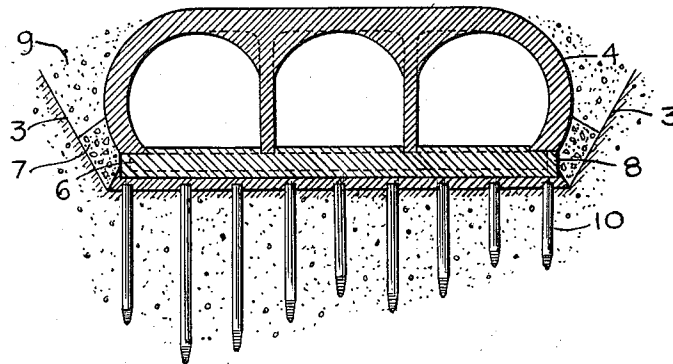
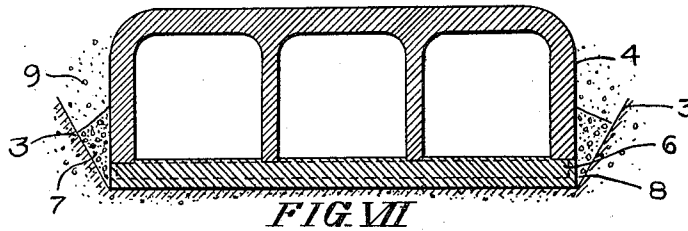
Inventors
Duncan D. McBean
Henry M. Chance

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Inventors
Duncan D. McBean
Harry M. Chance

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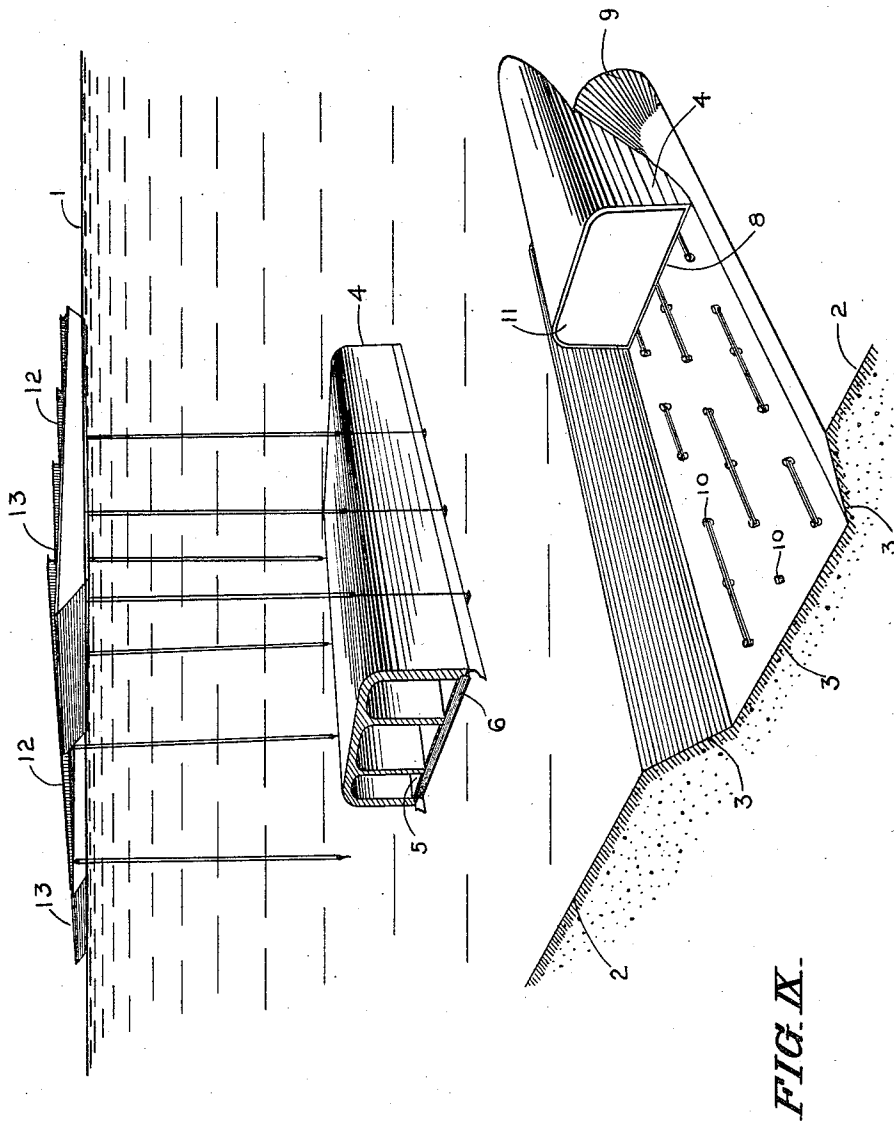


FIG. IX.

Witnesses
Thomas M. Chance
 Thomas M. Chance

Inventors
Duncan D. McBean
Henry M. Chance

UNITED STATES PATENT OFFICE.

DUNCAN D. McBEAN, OF NEW YORK, N. Y., AND HENRY M. CHANCE, OF PHILADELPHIA, PENNSYLVANIA.

METHOD OF BUILDING SUBAQUEOUS TUNNELS.

1,060,271.

Specification of Letters Patent.

Patented Apr. 29, 1913.

Application filed November 20, 1912. Serial No. 732,416.

To all whom it may concern:

Be it known that we, DUNCAN D. McBEAN, a citizen of the United States, residing at New York city, in the State of New York, and HENRY M. CHANCE, a citizen of the United States, residing at Philadelphia, in the county of Philadelphia and State of Pennsylvania, have invented a certain new and useful Method of Building Subaqueous Tunnels, whereof the following is a specification.

Our invention consists in an improved method of building subaqueous tunnels whereby the cost and time of construction are greatly reduced.

The methods heretofore used in constructing subaqueous tunnels may be divided into four classes, first, methods in which the site of the tunnel is unwatered by building a coffer dam around it, second, the shield method in which the tunnel is driven ahead by means of a protecting shield, third, methods in which the tunnel is built in place by lowering and depositing concrete directly in the water, and fourth, methods in which the tunnel, in whole or in part, is constructed at the surface and is floated and lowered into place.

Our present invention belongs to the fourth class, and involves the construction of the main body of the tunnel, in whole or in sections, of predetermined length, at the surface, the lowering of the structure into place, the building of a foundation beneath it and the completion of the structure, and of the connection between it and the foundation, after it has been placed in position; the latter operations being performed by using the main body of the tunnel, or a section thereof, supplied with air under pressure so that the foundation may be unwatered and construction work may be performed by men working within and protected by the main body of the tunnel or section thereof.

Tunnels have heretofore been built partly or wholly at the surface and lowered into place by several different methods, and the object of our invention is to overcome disadvantages which are inherent to all methods heretofore used or proposed. One of these methods consists in building the tunnel in sections at the surface, and constructing a pneumatic caisson under each section, the structure then being floated approximately into position, sunk to the bot-

tom of the river, and then sunk to the required depth by excavation made from within the caisson, after which the caisson is filled with masonry. Tunnels have also been built complete, in sections, at the surface and floated into position and sunk in a trench excavated to the entire depth by dredging, and a tunnel has been built by sinking a metal shell in a trench excavated by dredging and filling in around, below and above this shell with sand, after which the tunnel masonry was built inside the metal shell, and a tunnel was built under the Harlem River by Duncan D. McBean, under methods patented by him, in which the top half of the tunnel was built at the surface, floated into position and sunk into place upon a timbered inclosure previously constructed in a trench dredged in the bottom of the river, the said top of the tunnel and the timbered inclosure forming a working chamber in which he excavated material and built the foundation, bottom and side walls of the tunnel, compressed air being used to prevent leakage of water or silt into the inclosure, and to assist in supporting the timber walls of the inclosure during construction.

Our invention differs from any of these or other methods heretofore proposed or practised within our knowledge in that we use a working chamber which has for its boundaries the main body of the tunnel itself and the surface upon which the bottom of the tunnel is to be constructed, this working chamber is mobile and can be moved or shifted into exact place and is used to unwater the foundation, to enable us to excavate material required to be removed in order to prepare a proper foundation for the tunnel, for the construction of the foundation and for completing the bottom of the tunnel.

Figure I is a vertical transverse cross-section of a single tube tunnel showing our method of construction in its simplest form, with a temporary floor in place, the structure being in position (in a trench) for the preparation of the foundation and for doing the work of completing the bottom of the tunnel, and Fig. II is a longitudinal cross-section of the same. Fig. III is a section similar to that shown by Fig. I, with the temporary floor removed, so that the work of excavation and building of the bottom

may be done, and Fig. IV is a longitudinal cross-section of the same. Fig. V is a section similar to that shown by Figs. I and III, but shows the tunnel with the foundation and permanent floor completed, and Fig. VI is a longitudinal cross-section of the same. Fig. VII illustrates our method as applied to a three tube tunnel approaching a rectangle in general design. Fig. VIII illustrates our method as applied to building a three tube tunnel of an oval or circular type. Fig. IX is a diagrammatic perspective sketch illustrating how a section of the main body of the tunnel may be lowered into place from floats or scows.

Referring to the drawings of the several Figs. I to IX inclusive, like numbers refer to like parts; the line 1 being the surface of the water, 2 is the bottom of the river or other body of water, 3 shows the boundaries of a trench excavated in said bottom 2 to the required depth, 4 shows the main body of the tunnel which is built at the surface and floated or lowered into place in the trench 3. This tunnel body 4, is provided with a temporary floor 5 supported by transverse floor beams 6, as shown in Figs. I, II and IX.

Figs. III and IV show the same tunnel structure with the temporary floor 5 of Figs. I and II removed, so that access may be had to excavate material and deposit masonry below and surrounding the floor beams 6.

Fig. III also shows concrete or other fairly impervious material 7 placed in the lower part of the trench 3 to seal the opening between the sides of the trench and the body of the tunnel 4.

Figs. V and VI show the foundation and bottom masonry 8 completed and the trench space 9 back-filled with sand, earth or other material.

Fig. VIII illustrates our method as applied to an oval or circular type, and illustrates the use of piles 10, if necessary, below the floor of the tunnel, when the material is too soft and yielding to furnish a proper support for the structure. Such piles may be used under all or under a portion of the structure as conditions may require. When the material is of a character to furnish a good foundation, such as good sand or gravel, piles will not be necessary for supporting the structure.

While the drawings illustrate the construction of a single tube tunnel, and of two three tube tunnels, it will be understood that tunnels with two tubes or four tubes, or a large number of tubes, can be built by our method.

The materials of construction used in building tunnels by our method may be varied indefinitely, for any material suitable for tunnel construction can be used, such as

concrete, stone, brick, metal or other suitable substance or material, and these may be combined or used singly as desired. Concrete, brick or other masonry may be used in combination with metal shells, internal or external, or the masonry may be reinforced with metal rods, sheets, bars, plates or wires, as the reinforcement of masonry is at present practised in the building of engineering structures, or the whole body of the tunnel may be made of metal, or with a heavy metal frame incased in, or protected and reinforced by, concrete or other masonry.

The tunnel may be made waterproof by an outer covering or casing of suitable material impervious to water such as asphalt, or masonry laid in asphalt, tar or other suitable material, or by covering, or painting, with a protective coat of waterproof material, or by the use of waterproofing mixtures used in masonry construction.

The concrete or other fairly impervious material 7 of Figs. III, V, VII and VIII, deposited between the sides of the trench 3 and the body of the tunnel 4, may be lowered from scows (or by the use of a pipe) deposited in place in the water. In many cases this filling 7 will not be required, this space being filled with the back-filling 9; the deposition of this material 7, not being essential to the successful use of our method.

In proceeding to construct a tunnel by this method the trench is first excavated, preferably by dredging, to the desired width and depth, the bottom being carefully excavated to the desired grade, which can be done with a good approach to accuracy by modern dredging machinery, and is then prepared to receive the main body of the tunnel by the removal of any obstacles which might prevent it from being sunk in place. This latter work and the placing of temporary supports, such as beams or blocking in the bottom of the trench may be performed by divers. When the bottom of the trench is not sufficiently solid or level to permit of the tunnel body being lowered or sunk upon it even temporarily, supporting beams can be placed upon it, and blocked accurately to grade by divers, or concrete may be deposited in places, by lowering it from the surface, sufficient to form such temporary support as may be necessary to carry the weight of the structure prior to the building of the bottom of the tunnel. As will be explained herein, the weight of the structure which will thus require temporary support, will be quite small and can be adjusted to the conditions. When the material is too soft to be used for such temporary support, it will usually be too soft to be used as a foundation for the tunnel, and in such cases piles may be driven into the bed of the trench, being so driven that their tops are at the proper grade or cut off, after driving, to

a predetermined grade near the bottom of the trench, and used for the temporary support of the structure and also for the permanent support of the tunnel as shown by Fig. VIII.

It will be understood that our method of construction is not limited to the building of tunnels in trenches, as tunnels may be built by this method directly upon the floor or bottom of a river bed or lake bed, or even upon the top of a subaqueous embankment. While the drawings show the trench illustrated in Figs. I, III, V, VII and VIII, as excavated with the natural slope, or angle of repose, of the material excavated, it will be understood that the walls of this excavation or trench may, if desired, be supported by sheet piling as is commonly practised in excavating trenches in soft material.

The main body of the tunnel may be built at the surface, on shore, or in a dry dock, on pontoons, or in a floating box, and subsequently launched, or it may be built floating in the water, a temporary floor and the lower part of the sides of the structure being used to give the necessary buoyancy. If the structure is to be built in the water, the parallel transverse floor beams 6 shown in the drawings, which may subsequently form an integral part of the completed structure, may be connected in groups, a temporary floor 5 as shown by Figs. I, II and IX may be supported by these beams 6, and by closing the spaces between the ends of the beams, the air spaces between these beams and below the floor will furnish the buoyancy necessary to carry the weight of the lower portion of the walls of the tunnel structure as these are built. As the side walls are built and the structure sinks deeper into the water, the temporary floor of the tunnel 5, and the outer side-walls of the tunnel, together with temporary bulkheads 11, closing the ends of the structure, will convert it into a buoyant body which will float without the assistance of air trapped below the floor and this may then be allowed to escape. It will thus be seen that the main body of the tunnel is built above the surface, and in the open air, under normal working conditions, and in the case of masonry tunnels, this is a great advantage both as to the cost of construction and because it permits of thorough inspection of the work and insures the excavation of first class workmanship throughout. It is also evident that as the construction is carried on in the open air, it is possible to apply any kind of waterproofing that it may be desired to use, and to build or apply this outside the masonry, and in such a manner as to insure the absolute exclusion of water from the main body of the masonry or other material of which the tunnel is constructed.

The application of external waterproof-

ing, excluding hydrostatic pressure from the interior of the masonry or other material of which the tunnel is built, enables us to utilize the maximum strength of the whole thickness of the structure to sustain the pressure of the surrounding medium.

When the main body of the tunnel, or a section thereof, is completed, the ends of the structure being closed with removable bulkheads, one of which is shown by 11 in Fig. IX, it is then ready to be floated into position and sunk to its proper place upon the site of the completed structure. The position of the bulkheads and the position of the temporary floor will determine the buoyancy of the structure. If the total displacement of the structure is greater than its weight, it is evident that the structure will be buoyant, and that sufficient weight must be added to overcome this buoyancy. Any material may be used for this purpose, either inside or outside the structure. In practice, the displacement and weight of the structure will be calculated in advance with a close approach to accuracy, and the temporary floor and bulkheads may be so located as to make the displacement nearly equal to the weight, but if, owing to the design and dimension of the structure, a certain excess buoyancy exists, as will frequently be the case, the weight required to overcome it, and to sink and hold the structure in place, may be obtained by storing upon the temporary floor of the structure such material as will be used in the construction of the bottom of the tunnel, or by water ballast admitted to the interior of the structure, or by both.

The water ballast may, if desired, be carried in tanks inside the structure or in compartments occupying a portion or the whole of the interior of the structure.

Having floated the structure into place it may be controlled by derricks, cranes, or tackle from scows or vessels anchored or moored in position, or from cross-beams supported by such scows or vessels, as illustrated by Fig. IX, or from trusses or beams supported upon piles driven adjacent to the side lines of the tunnel, and the structure may thus be lowered accurately into place both as to line and grade. This operation is easily performed because the weight to be handled is comparatively small, being only that of the excess of weight of the structure over its buoyancy and as already described this may be made just as small as may be desired. In this respect this method has great advantages over those methods in which the completed tunnel is built at the surface and lowered into place, because in carrying out such methods the whole weight of the completed structure, (including that of the bottom masonry) must always be made very much greater than the displace-

ment, because such weight is necessary to secure the required stability and rigidity of the structure after it is placed in position.

Fig. IX, shows a section of the main body of the tunnel 4, suspended from cross-beams 12 carried on scows or floats 13 floating at the surface of the water 1, and in place to be lowered into the trench 3 excavated in the bed of the stream 2. It will be understood that both ends of this section are closed by bulkheads, although the drawing shows the forward bulkhead removed and a portion of the structure broken away to show the inner construction of the section of tunnel. One end of a completed section of tunnel is shown in this trench, the end of this completed portion being closed by the removable bulkhead 11. This sketch shows the back filling 9 completed to near the end of the completed section. In the floor of the trench 2, the projecting ends of piles 10 are shown supporting beams upon which the new section of tunnel is to rest during the preparation of the foundation and the building of masonry foundation. The scows 13 being anchored or moored in position, the section may now be lowered into place and guided and controlled by guy lines anchored at one end at the bottom in any desired position or by guiding piles driven at the sides of the trench in the proper position.

When the structure is floated into place, one end being in juxtaposition to any section of previously completed tunnel, it may be connected to such completed section by being bolted to it by divers, by the use of external flanges or connecting rings as has been practised in other methods of tunnel construction, or by means of telescopic joints or other devices such as are in common use for connecting the ends of pipes or tubes. It is evident that many different devices may be used for connecting the several sections of the tunnel, depending upon the materials used in construction and the design of the structure. A simple means of making this connection with bolts, is to make each section of the tunnel terminate in a flanged iron or steel ring, the flanges being provided with slotted (oblong) bolt holes to permit of adjustment in bringing the sections accurately together.

It will be understood that the structure must be placed accurately to line and grade, and supported in position by blocking or other means as already described, but if through any cause the proper position is not at first secured, it is perfectly feasible to raise the structure, or to shift it laterally, by the same means by which it was lowered, or by the use of lifting jacks, and to place it accurately in position upon blocking, beams or other temporary supports in the bottom of the trench.

In most cases, the part of the tunnel completed first will be one of the land ends, and in connecting with these land ends air-locks may be placed in the completed structure to give egress and ingress for men and materials to that portion of the tunnel in which work is being done in compressed air, just as air-locks are used in building tunnels by the shield method.

The bulkheads used in building the tunnel sections will be constructed with doors or removable plates, so that after a new length of tunnel is connected to a completed section, access may be had to the space between the bulkhead closing the end of the completed tunnel and the bulkhead of the newly connected section. The space between these bulkheads having been made wide enough to permit a man to enter and work between them, and a new section having been connected to a completed section, a workman now enters this space between the bulkheads and calks the joint between the two connecting flanges, thus shutting off all leakage of water through this joint, or the escape of air through it. The bulkhead of the new section is now opened, establishing communication between the completed tunnel and the newly placed section, and the air pressure being now made equal to that due to the hydrostatic head the men may now enter this section, take up portions of the floor, or get access to the space below the floor through doors placed in it for that purpose, and place blocking or other supports beneath the floor beams of the structure, so that it is accurately fixed in place upon these supports. As soon as this is done the sealing back-filling 7 of Figs. I, III, V, VII and VIII may be placed in position. At the same time masonry may be built in the small space between the two bulkheads to connect the masonry, (including the waterproofing,) of the completed tunnel with that of the newly placed section. The work of preparing the foundation is now commenced by unwatering the space below the temporary floor either by pumping out the water or by making the air pressure equal to the hydrostatic pressure at the foundation, and by then removing any mud or material which lies in the bottom of the trench, and upon which it would not be proper to build the tunnel. The foundation masonry and the masonry of the floor of the tunnel, including any waterproofing, is then built in place and connected with the masonry of the main body of the tunnel. Any system of construction for waterproofing the structure that was used in building the main body of the tunnel can be duplicated in building this masonry forming the bottom of the tunnel, so that the completed structure may be practically alike in all of its parts, those

parts built from within the tunnel structure in compressed air being exactly similar to those built at the surface.

If piles have been used either for temporary or permanent support, they may be cut off to any desired level during the construction of the foundation masonry, preferably being permitted to project slightly into this masonry, and any blocking, beams or other temporary supports, will of course be removed as the construction of this masonry progresses.

When it is desired to excavate for foundation or other purposes to an appreciably greater depth than the normal depth of the foundation, and it becomes necessary to increase the air pressure more than the excess of weight of the structure over its buoyancy, water ballast or other weight may be added to hold the structure in place, or it may be anchored by piles to the material of the bottom. When the bottom is underlaid by rock at moderate depth it may be fastened to bolts anchored in the rock floor.

The bottom masonry having been completed, the back filling 9 of Figs. V, VII, VIII and IX may be placed in position along the greater part of the completed section, another section may now be lowered in place and the above described operations repeated.

The foregoing description contemplates the use of air-locks in a land end of completed tunnel for access to the section under construction, but we do not limit ourselves to this method of gaining access to the tunnel during construction of the bottom, as it is also feasible to use vertical air-locks with shafts extending from the top of the tunnel up to above the surface of the water, the materials of construction being lowered from scows or from platforms built on piles, as was practised in the construction of the Harlem River Tunnel at New York city, as built by Duncan D. McBean in 1903.

It is evident that where rock occurs in certain parts of the bed of the stream, lake or other body of water that this can be excavated from within, the working chamber more cheaply than by the ordinary methods of excavating rock under water, and in such cases the conformation of the rock surface can be determined accurately by soundings and that portion of the main body of the tunnel for any section which includes projecting rock may be built to conform to such projections, so that the structure can be floated and sunk directly upon such rock surface, and that portion of the rock required to be removed can then be excavated from within the structure, thus affording a means of connecting sections of a tunnel built in rock with sections built by our method in soft materials. Stated broadly, our method provides a way in which any operation similar to those that have been car-

ried out in subaqueous working chambers may be performed when using our method, as we utilize the main body of the tunnel itself as a working chamber. One of the operations which may be performed when using our method is the driving of piling, round, square or sheet piling, from within the working chamber, at any angle from vertical to horizontal for strengthening or widening or deepening the foundation, etc., as has been similarly practised with subaqueous working chambers in repairing, reinforcing and building foundations of engineering structures.

In masonry tunnels built by our method, leakage of compressed air during construction due to porosity of the masonry, and damage to waterproofing from the excess of air pressure over the hydrostatic pressure on the upper parts of the structure may be obviated by using an internal metal shell, which may or may not remain as a permanent part of the tunnel structure. When such inner shell is used it will naturally take the place of centering during the construction of the top of the tunnel and may be so designed as to be capable of adjustment and use for this purpose.

It will be understood that when the temporary floor is placed high enough to give head room for men to work under it, this floor need not be removed until construction is completed and may be used as a convenient means of holding water or other ballast. This ballast can be shifted as desired to different locations in the structure, or from above or beneath this floor, as may be desired, and other floors or platforms may be built inside the structure in any position suitable for the purposes for which they are to be used.

As our method constitutes a radical departure from methods heretofore proposed or used, it seems desirable to state briefly some of the advantages which may be realized by its use. It enables us to build a thoroughly good tunnel in a trench excavated by dredging, which is the cheapest known method of excavating materials capable of being dredged. It permits us to build the structure of any materials which it may be desired to use, with or without inner or outer metal shells. As the main body of the tunnel is constructed in the open air, the cost of construction can be reduced to the minimum at which structures of any kind can possibly be built, and the very best workmanship can be secured throughout. As a relatively small part of the tunnel is built from within the tunnel, and as the masonry so constructed is built under conditions that will permit of thorough inspection and of the use of the same methods that are used in the open air, the quality of this work will be equal to that

constructed at the surface, and the cost kept within a relatively low figure. One of the chief advantages of the method is that it permits of externally waterproofing the whole structure. The possibility of reliable waterproofing will make it unnecessary to use the costly metal shell or lining with which subaqueous tunnels are generally built and upon which they depend for their strength and durability, for when the structure is waterproofed on the outside, the strength of the masonry of the whole structure is utilized to resist the pressure of the surrounding medium. Another important advantage is that by the use of this method a thoroughly stable and properly prepared foundation can be built beneath the tunnel, thus making the tunnel safe, and eliminating the danger of damage to, or the destruction of, the tunnel by settlement. The use of this method will secure a tunnel of maximum strength with any given quantity of structural material, because the designing engineer is not limited to any particular form or design, but may so distribute the structural materials as to produce a structure of the maximum strength and thus obtain a tunnel of maximum strength at the minimum cost for materials and labor. As it is evident that a number of tunnel sections may be under construction at the same time, and that by using vertical air-locks, work may be carried on simultaneously in different sections at several points along the line of the proposed tunnel, the time of construction can be greatly reduced, and even when the tunnel is extended only from its land ends, the relatively small quantity of work to be built in compressed air will insure the possibility of rapid progress. A very important advantage of this method is that by it we can build a tunnel exactly to the line and grade fixed in advance by the engineer, so that no allowance need be made for deviations from the plans.

We do not limit ourselves to the use of the particular means herein described for carrying out our method of subaqueous tunnel construction, for it is evident that the details may be widely varied without departing from the spirit of our invention; thus the temporary floor shown by the drawings, while performing a useful function, is not essential and may be omitted, for the structure may be floated and lowered in place without it, and the beams shown as floor supports and as remaining as a part of the completed structure are not essential, as the method of construction can be carried out without using either temporary or permanent floor beams. It is also evident that our method may be used in constructing tunnels in subaqueous trenches excavated in rock. It is also apparent that a portion of the floor of the tunnel may be constructed at

the same time and form a part of the structure built at the surface without departing from the spirit of our invention, provided always that such portions of said floor do not prevent free access to the foundation of the tunnel nor prevent us from free use of the structure as a working chamber in performing the necessary work in preparing the foundation for the structure and in constructing whatever foundation masonry, if any, that may be required.

In these specifications and the claims hereof, we have used the terms "body of the tunnel" or "main body of the tunnel" to include substantially all that portion of the tunnel structure above the floor and lower portion of the sides of the tunnel and such portions of the floor as it may be desired to construct at the surface; the term "floor of the tunnel" to mean that portion of the bottom of the tunnel necessary to insure sufficient strength to resist the stresses it will be required to sustain; the term "foundation of the tunnel" to mean the structures or material upon which the tunnel is built; the term "masonry foundation," "foundation masonry" or "masonry of the foundation" to mean masonry underlying the floor, and the term "bottom of the tunnel" to mean all of the masonry or other material comprising the lower part of the tunnel, including both the floor of the tunnel and the masonry of the foundation.

Having described our invention, we claim,

1. A method of constructing subaqueous tunnels which consists in building the main body of such tunnel, or the main body of a section thereof, at the surface; so constructing said structure as to permit of its use as a working chamber adapted to retain air under pressure; floating said structure into place and sinking it into the desired position upon the proposed site of the tunnel and maintaining air under pressure in said structure, whereby a working chamber is formed which is bounded by the inner surfaces of said structure and by the surface of the material upon which the tunnel is to be constructed, and completing the construction of said tunnel, or of said section thereof.

2. A method of constructing subaqueous tunnels which consists in building the main body of such tunnel, or the main body of a section thereof, at the surface; so constructing said structure as to permit of its use as a working chamber adapted to retain air under pressure; floating said structure into place and sinking it into the desired position upon the proposed site of the tunnel and maintaining air under pressure in said structure, whereby a working chamber is formed which is bounded by the inner surfaces of said structure and by the surface of the material upon which the tunnel is to be constructed, using said structure as a work-

ing chamber and completing the construction of the bottom of said tunnel, or of said section thereof.

3. A method of constructing subaqueous tunnels which consists in constructing the bottom of the tunnel in a working chamber produced by placing the main body of the tunnel, or the main body of a section thereof, upon the proposed site of the tunnel and maintaining air under pressure in said structure, whereby a working chamber is formed which is bounded by the main body of the tunnel or of said section, and by the surface upon which the bottom of the tunnel, or of said section, is to be constructed.

4. A method of constructing subaqueous tunnels which consists in building the bottom of the tunnel, or of a section thereof, in a working chamber produced by placing the main body of the tunnel, or a bulkheaded section thereof, previously constructed at the surface, upon the proposed site of the tunnel and maintaining air under pressure in said structure, whereby a working chamber is formed which is bounded by the inner surfaces of said structure and by the surface of the material upon which the tunnel, or said section thereof, is to be constructed, and in uniting said bottom with the said previously constructed structure.

5. A method of constructing subaqueous tunnels which consists in preparing a foundation by driving piles into the material upon which the tunnel is to be built, in lowering the main body of the tunnel, or the main body of a section thereof, previously constructed at the surface, into place above said piles, in maintaining air under pressure in said structure, whereby a working chamber is formed which is bounded by the inner surfaces of said structure and by the surface of the material upon which the tunnel is to be constructed, and in completing the bottom of said tunnel, or of said section, from within said chamber.

6. A method of constructing subaqueous tunnels which consists in building portions of the tunnel structure from within a subaqueous working chamber produced by lowering into place, immediately above the material upon which the tunnel is to be built, the main body of a tunnel, or the main body of a section thereof, provided with bulk-

heads closing the ends thereof, and adapted to retain air under pressure, whereby a working chamber is formed which is bounded by the inner surfaces of said structure and by the material on which said tunnel is to be built, and in uniting said portions with the previously constructed portion of said tunnel.

7. A method of constructing subaqueous tunnels which consists in building the main body of a tunnel, or of a bulkheaded section thereof, with sidewalls extending to such depth below the top of said tunnel as to adapt the structure to retain air under pressure substantially equal to the hydraulic head at the lower surface of the bottom masonry of said tunnel, in lowering said structure into place at the site of the tunnel and in maintaining air under pressure in said structure, whereby a working chamber is formed which is bounded by the inner surfaces of said structure and by the material on which the tunnel is to be built, in constructing the bottom of said tunnel and in uniting said bottom with said structure.

8. A method of constructing subaqueous tunnels which consists in building the main body of a tunnel, or the main body of a section thereof, with portions of the lower part of said structure constructed as a buoyant substructure able to float the structure during construction thereof and containing elements adapted to be retained as members of the permanent floor of said tunnel, in sinking said structure into place and in completing the bottom of said tunnel.

9. An externally waterproofed subaqueous tunnel structure consisting of a lower portion of said tunnel built upon the permanent site of said structure, and an upper portion of said tunnel subsequently united to said lower portion, the said waterproofing completely enveloping said tunnel structure.

In testimony whereof we have hereunto signed our names at Philadelphia, Pennsylvania, this 19th day of November 1912.

DUNCAN D. McBEAN.
HENRY M. CHANCE.

Witnesses:

CHAS. BUSH,
E. R. BARNES, Jr.