No. 620,101. Patented Feb. 28, 1899.

B. F. CARPENTER.

ART OF CONSTRUCTING TUNNELS.

(Application filed Dec. 16, 1897.)

(No Model.) 5 Sheets—Sheet 1.

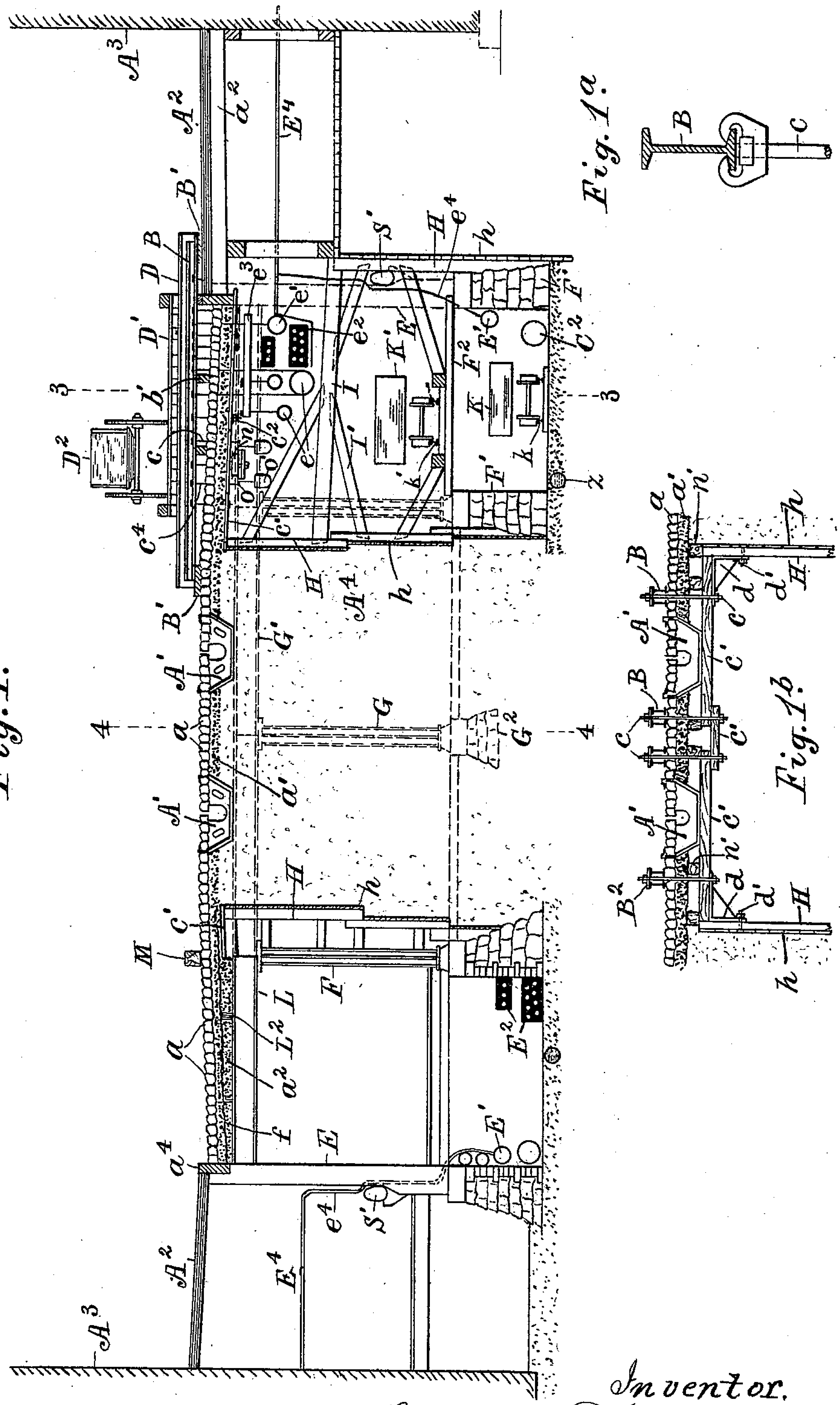

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Fig. 2.

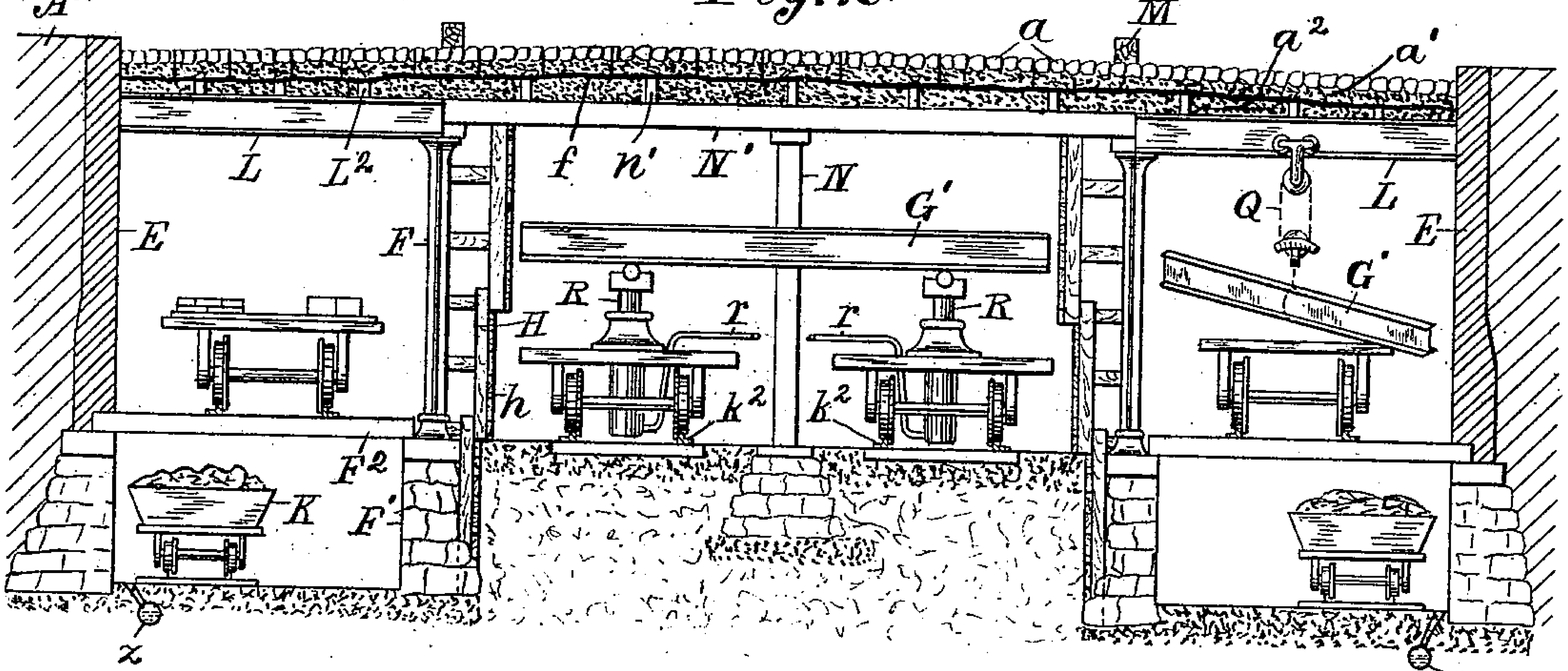


Fig. 3.

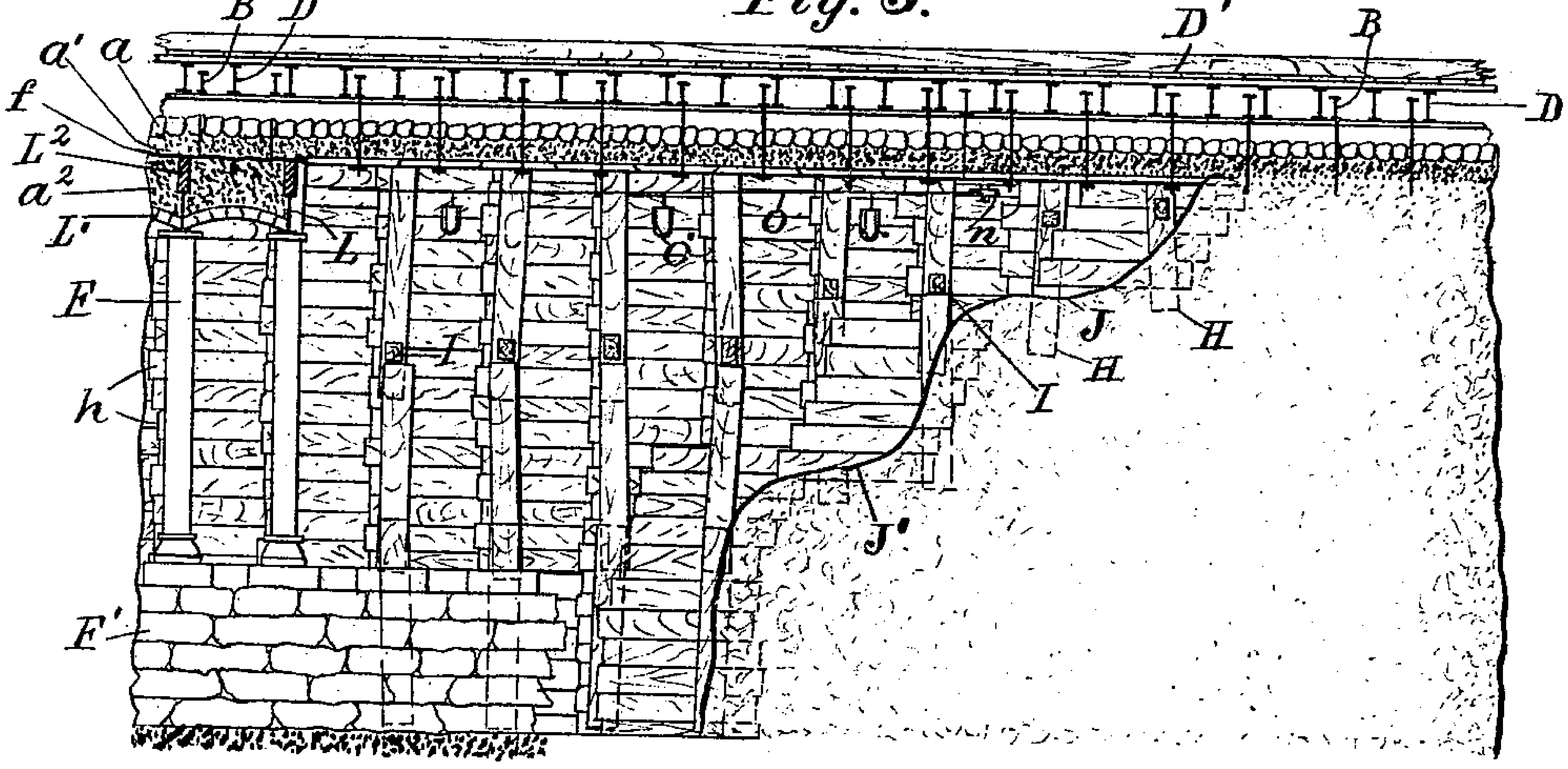
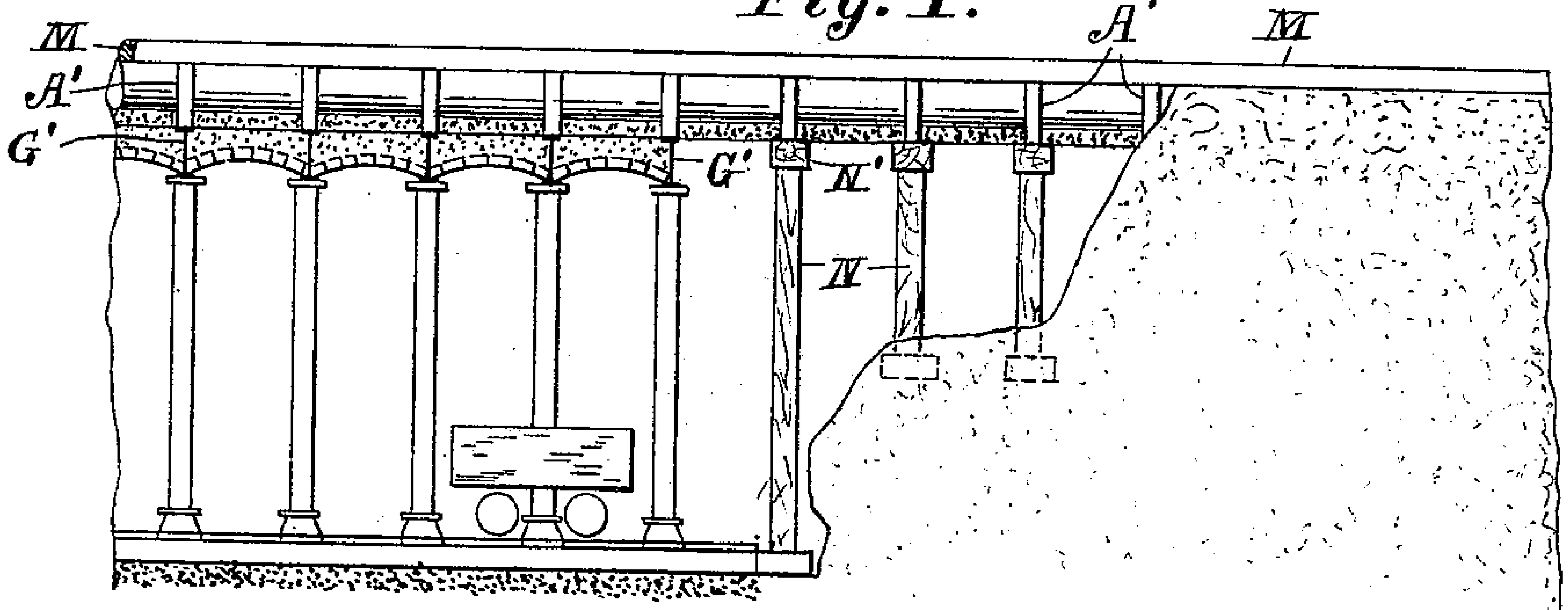


Fig. 4.



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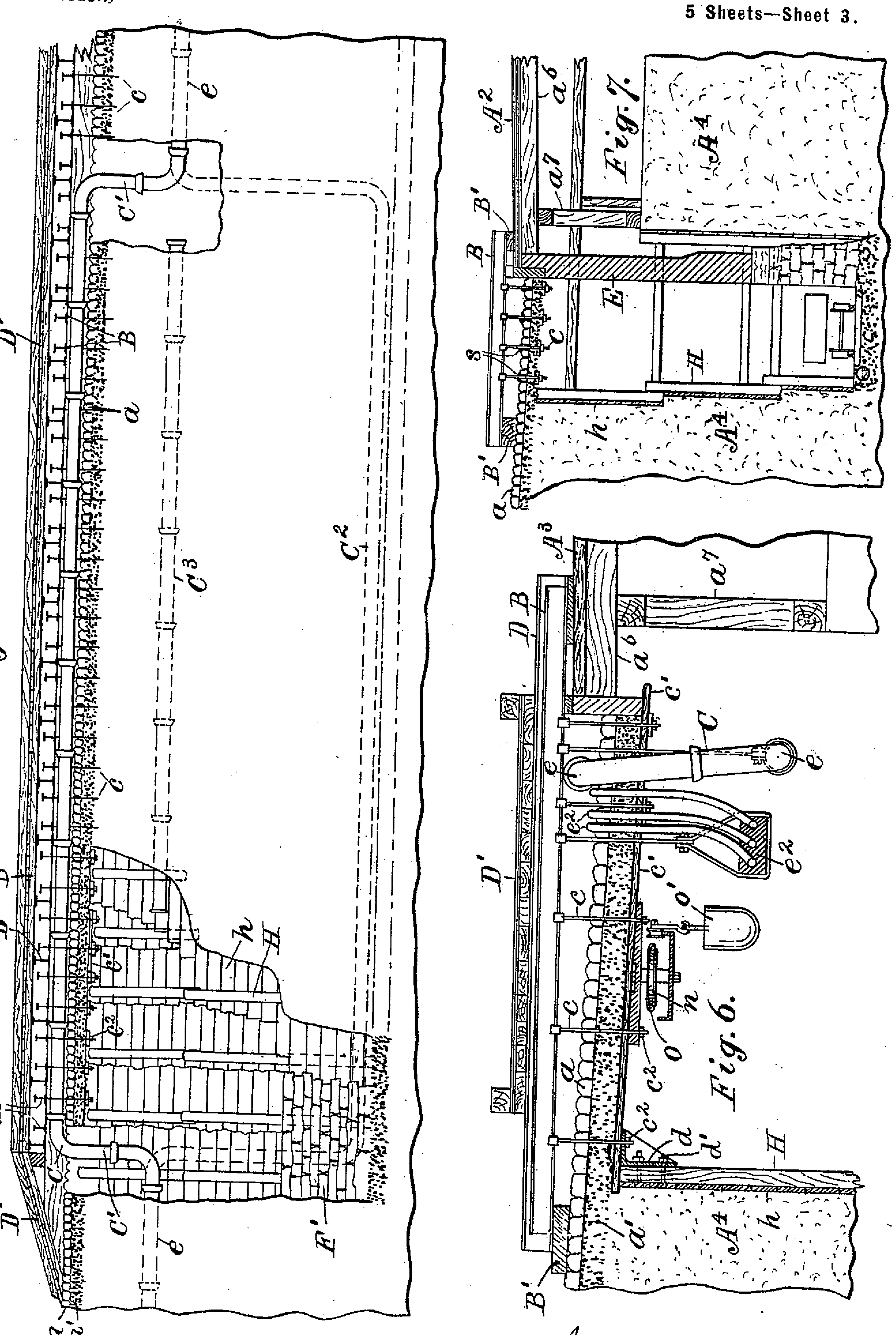

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Fig. 8.

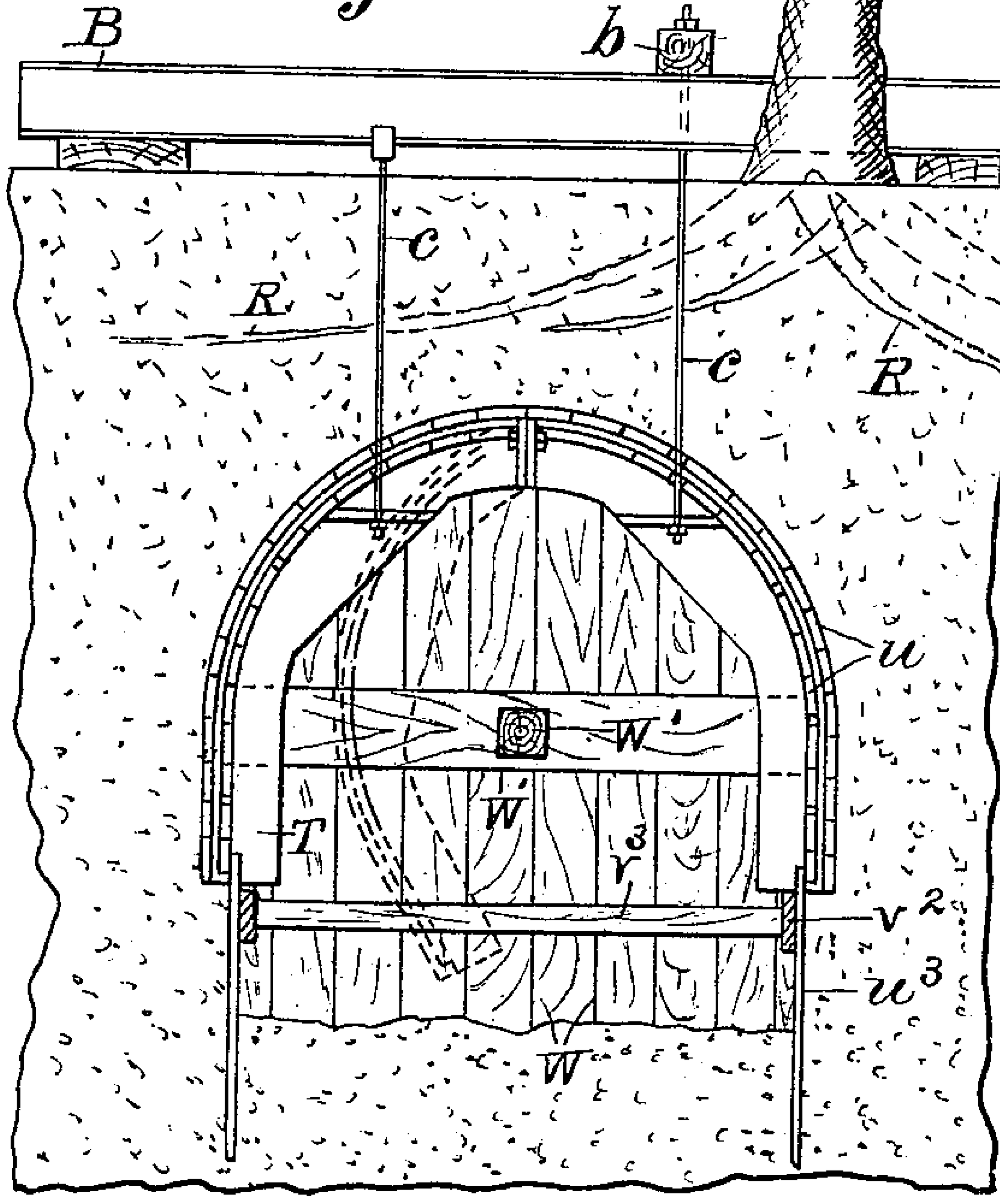


Fig. 10.

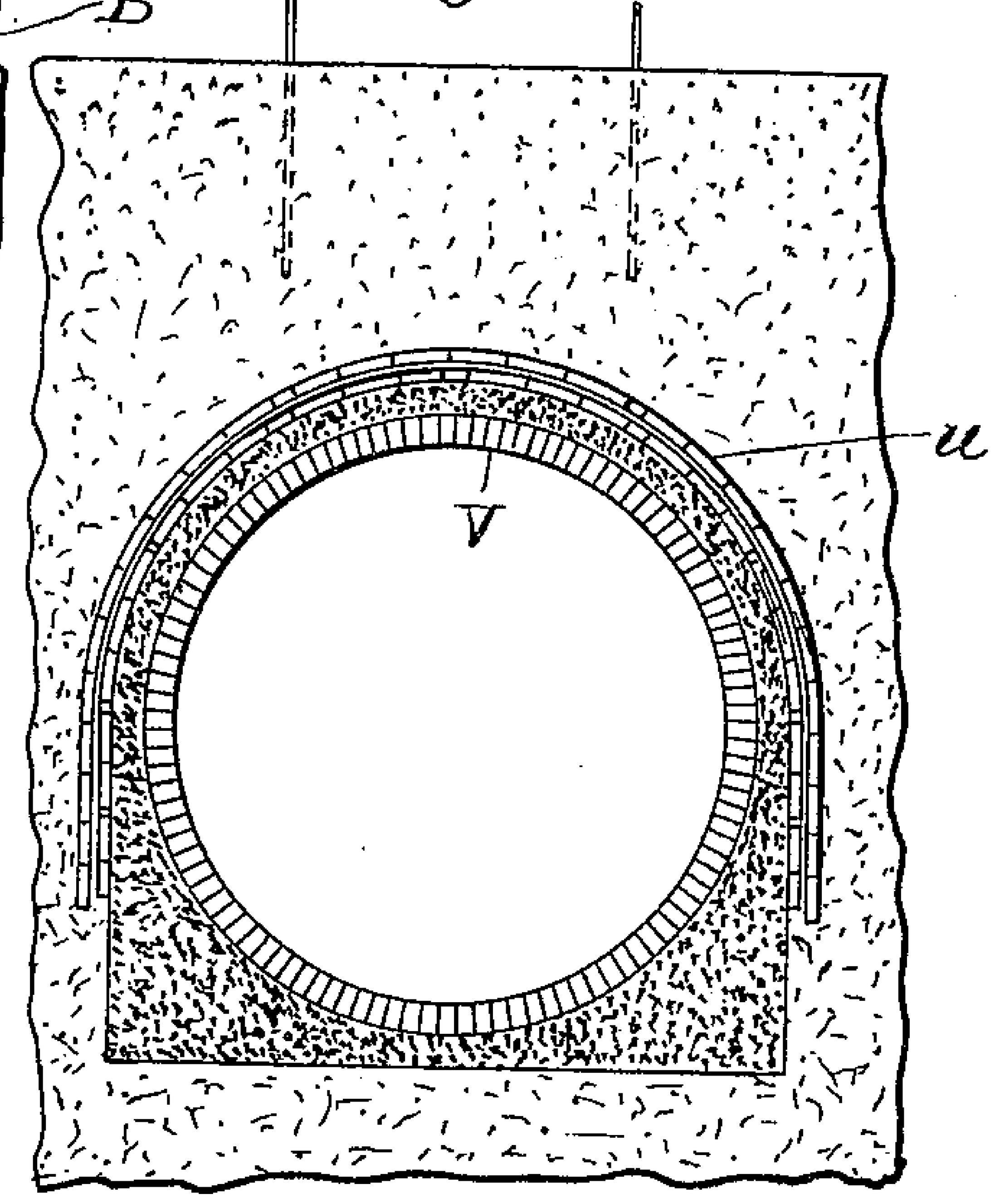


Fig. 9.

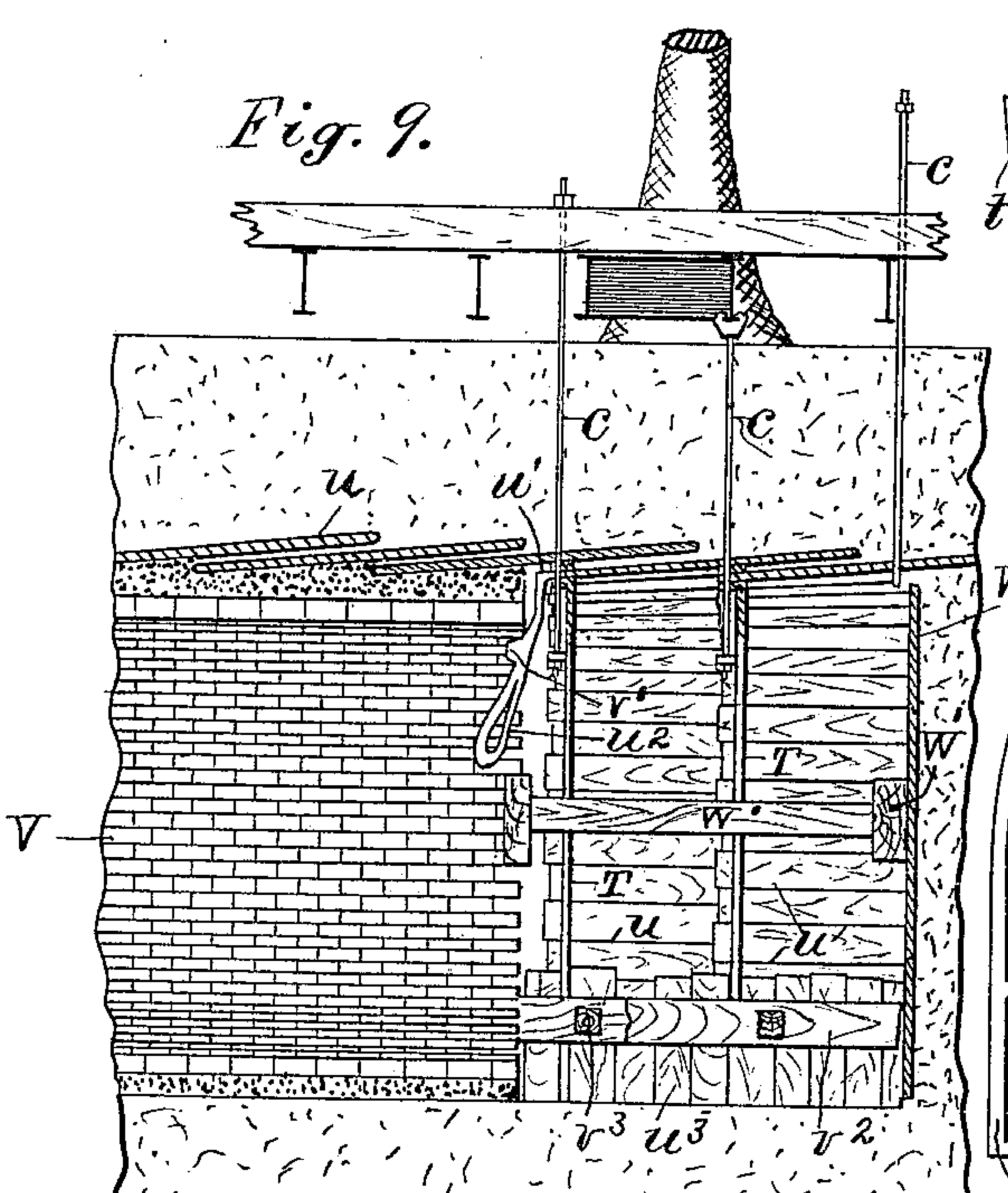


Fig. 12.

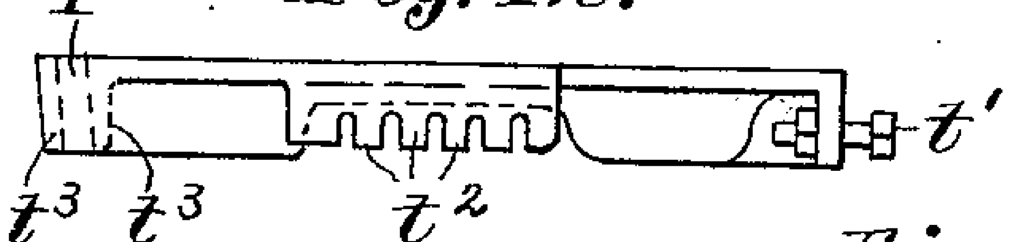
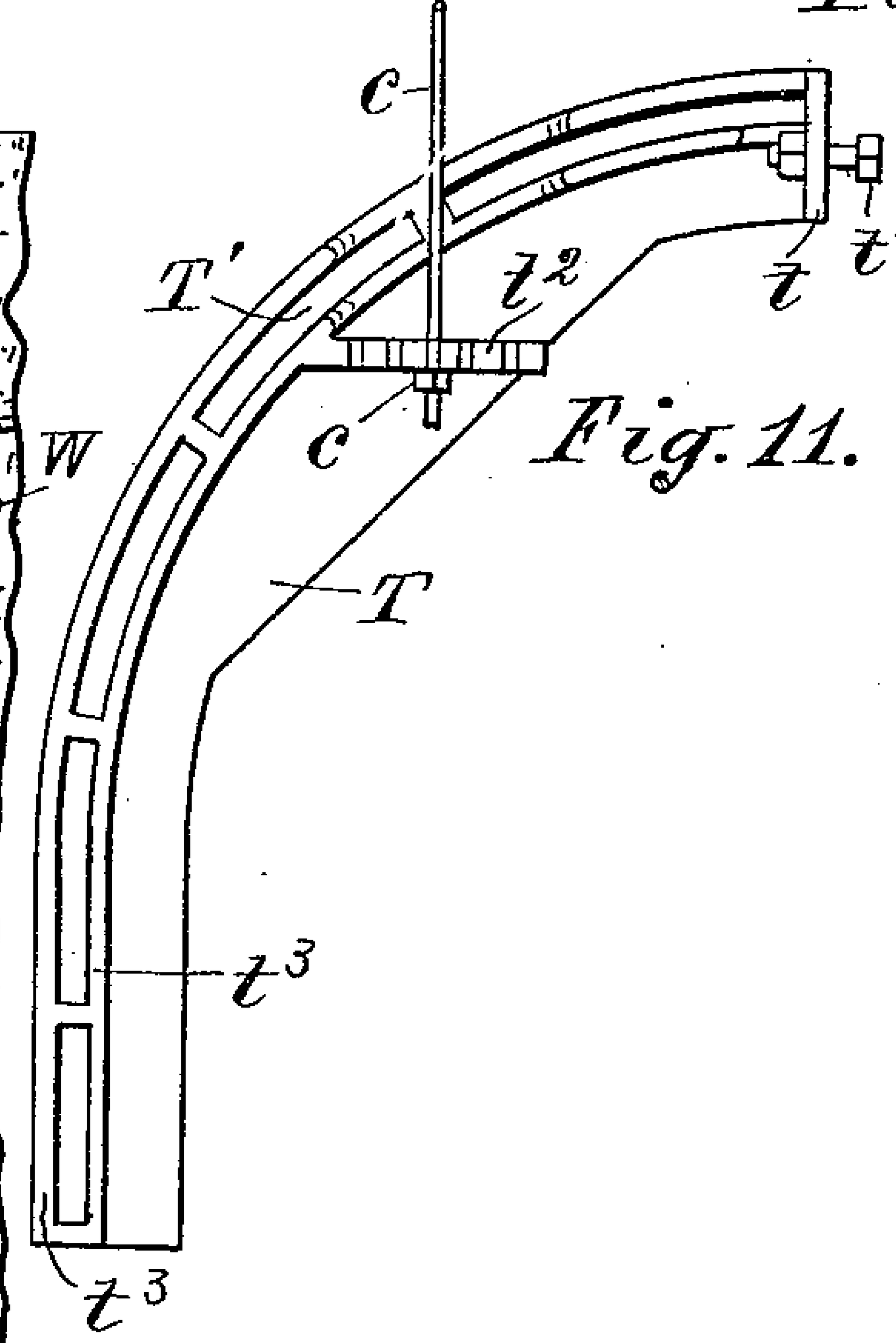


Fig. 13

Fig. 11.



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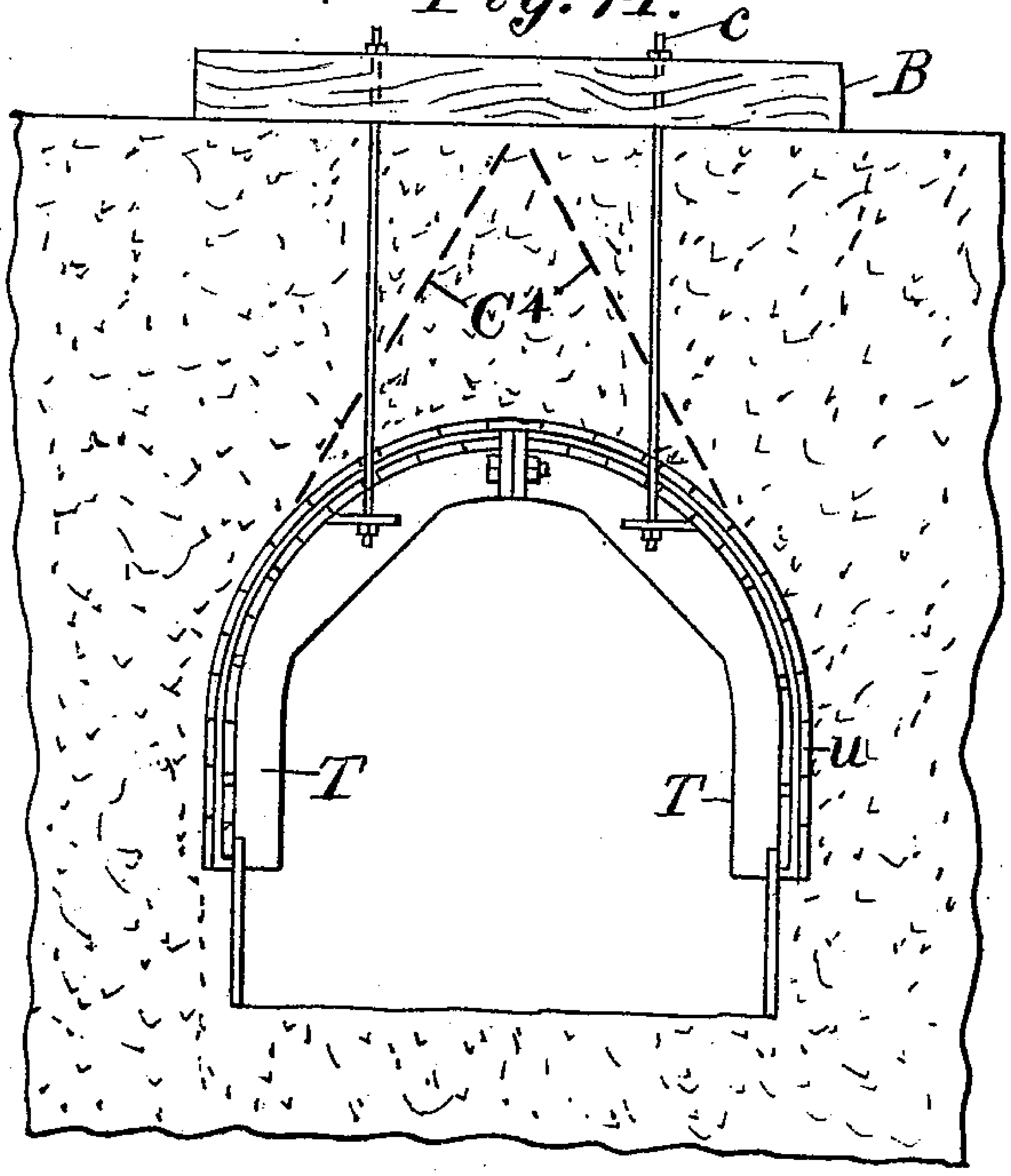
5 Sheets—Sheet 5.

Fig. 14.



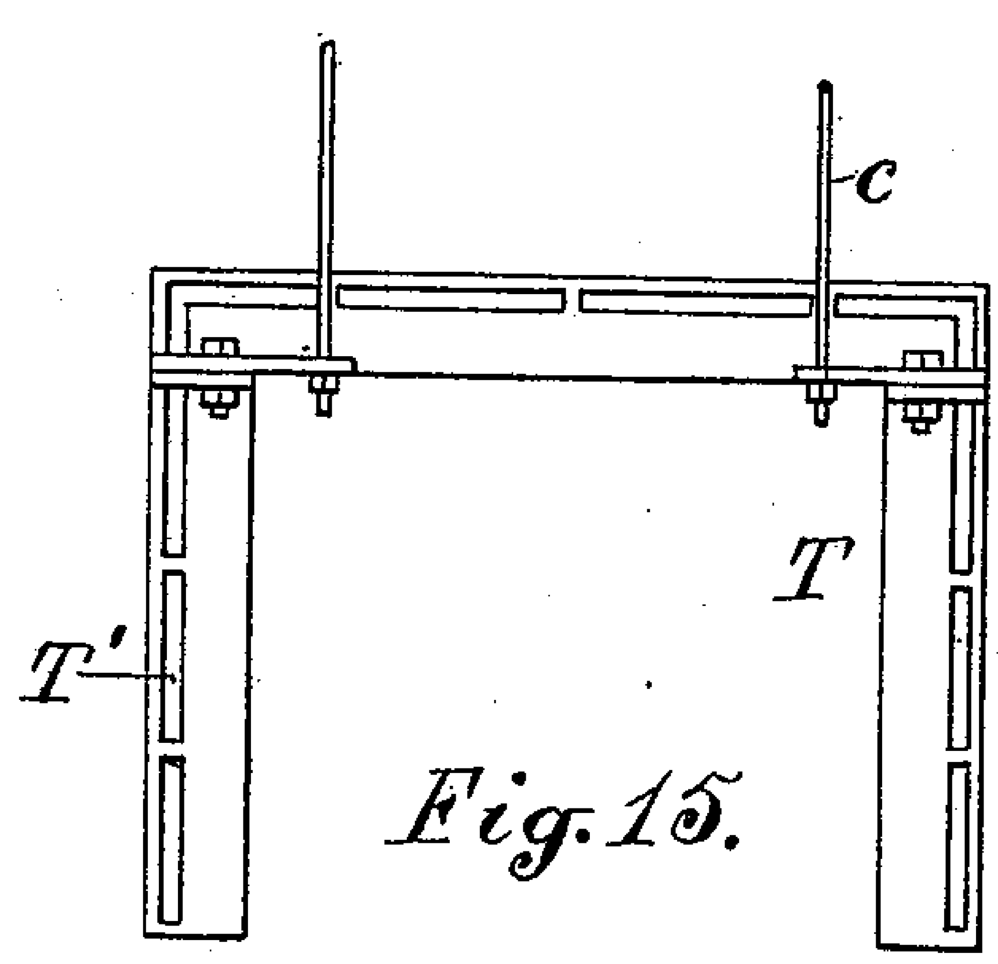


Fig. 15.

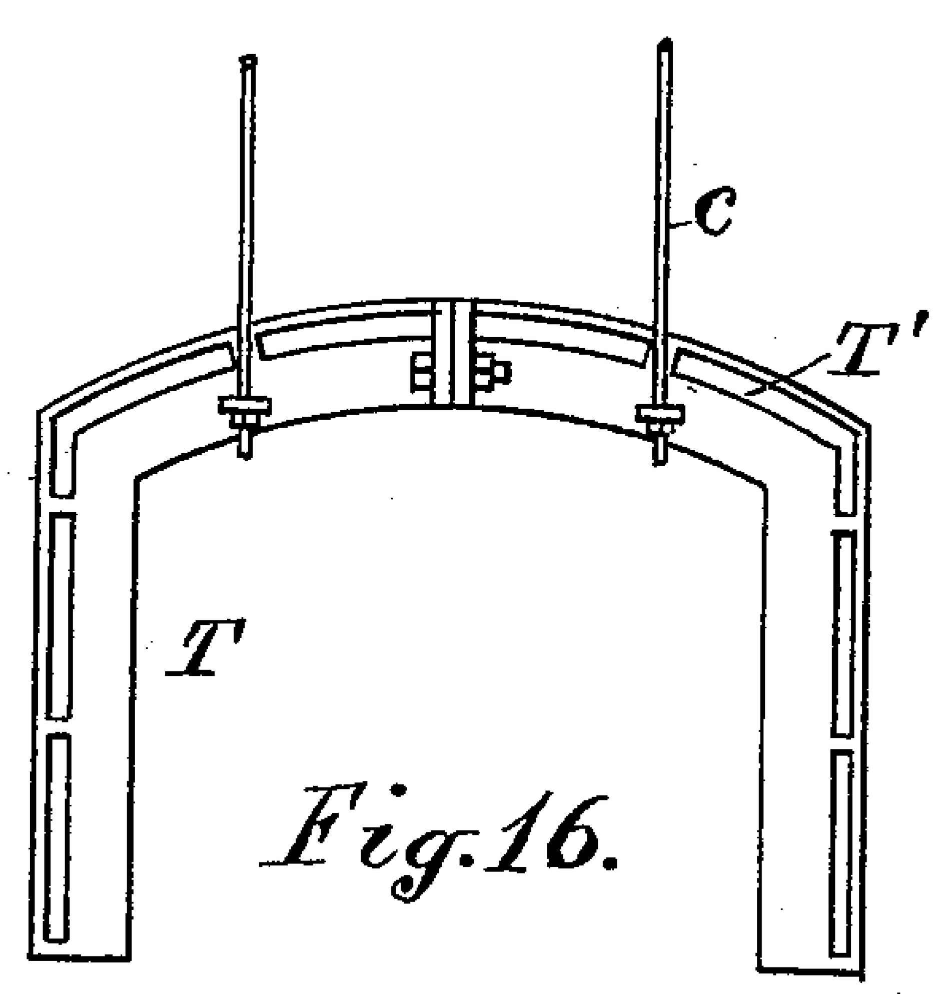


Fig. 16.

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UNITED STATES PATENT OFFICE.

BENJAMIN F. CARPENTER, OF ROSELLE, NEW JERSEY.

ART OF CONSTRUCTING TUNNELS.

SPECIFICATION forming part of Letters Patent No. 620,101, dated February 28, 1899.

Application filed December 16, 1897. Serial No. 662,164. (No model.)

To all whom it may concern:

Be it known that I, BENJAMIN F. CARPENTER, a citizen of the United States, residing at Roselle, county of Union, State of New Jersey, have invented certain new and useful Improvements in the Art of Constructing Tunnels, fully described and represented in the following specification and the accompanying drawings, forming a part of the same.

The object of the invention is to construct required works beneath the surface with as little obstruction or disturbance of the surface as possible and to interfere in the smallest degree with the traffic which finds movement over the excavation during such construction.

The object is also to preserve substantially unbroken and uninjured the pavement of the street and its substratum foundation when the excavation is under streets or to preserve the trees, shrubs, and surface structures and ornaments if under parks and public squares. Such preservation is sometimes a determining factor as to whether such subsurface work shall be executed, and sometimes the cost of removing and again restoring such surface improvements would prove prohibitive. The protection of such subterranean work from injury by water is secured in my invention by maintaining the surface water-tight during excavation and construction, thereby preventing flooding and consequent liability to damage, which is in some instances of vast importance, especially when contiguous or adjacent structures and their foundations are endangered. The unhealthy vapors emanating from open-trench tunneling, such as from sewers in city streets, as well as the storage of excavated earth, with all its attendant nuisance, can be avoided by the method I have devised. Instead of a system of props and frames which carry the weight of the soil over the excavation by supporting it from below my method holds it in suspension from above by means of suspension-rods connected to surface supports or temporary bridging, which distributes the weight on and into the adjacent embankments. By such means of supporting the surface material the tunnel is largely freed from timbering and obstructions, so that suitable railways or suspended tramways can be operated for removing the excavated earth and introducing the constructive materials, thus greatly facilitating the work.

The surface properly suspended by my method becomes itself a brace or support to hold the embankment in place, thereby preventing any yielding of adjacent foundations or the sliding of the earth in the embankments, which is their natural movement toward an excavation.

Underground passages or arcades are frequently required in the construction of underground railways and have sometimes been formed by means of open trenches, which necessitated the destruction of the street-pavement and the necessity of subsequently relaying the same at great cost.

In the present invention the beams or surface-supports are arranged in place and the rods extended downward through the soil or pavement to the required depth before the excavation of the tunnel is commenced. An opening being made at any point in the line of the tunnel, it is obvious that a heading may be readily extended in the direction of the rods and roof boards or plates secured by such rods as the heading is driven forward. The surface material is thus supported temporarily until the permanent structure is erected in the tunnel, concrete or earth being packed between such structure and the surface material to permanently support the same.

Where the street-pavement, as is common in many cities, is laid upon a bed of concrete, the concrete forms a rigid mass which possesses sufficient strength to support the weight of the pavement across a narrow span; but the insertion of suspension-rods through the pavement and the application of plates and nuts to their lower ends serves to support such a rigid pavement effectively over a span of any required width, as the entire weight of the pavement is transferred to such rods.

Where the rigidity of the pavement is preserved during the driving of a tunnel, it may be used most effectively to sustain the adjacent buildings by inserting braces between the curbstones and the foundations of such buildings.

To avoid the interruption of the traffic over a pavement where the beams are laid to carry the suspension-rods, a temporary bridge may be constructed by supporting at their ends upon the surface other beams of greater depth, with their ends extended beyond the sides of the proposed excavation, and laying a floor upon such beams at a little distance above the beams which support the pavement. The traffic may then be carried upon such bridge without imposing any strain whatever upon the suspended portion of the pavement and without inducing any jars or vibrations in the beams which carry the suspension-rods. With the pavement thus suspended and provision made for sustaining the traffic without loading or jarring such pavement the tunnel is readily excavated by any ordinary means, the soil at the sides of the tunnel being sustained by timber frames and poling-boards, where necessary, until the permanent structure is erected.

The excavation of the tunnel is greatly facilitated by the suspension of the roof, as such suspension obviates the necessity of using any braces or supports for such purpose, and the floor of the tunnel may therefore be occupied by a track and cars run to and fro thereon to remove the earth and bring in building materials.

Where the tunnel is driven adjacent to the lower surface of such a rigid pavement, the rods and plates which support the pavement are removed in succession as the permanent structure is erected and the weight is transferred from the rods to such permanent structure. Where the roof of the tunnel is driven in proximity to soft material—as ordinary earth, sand, or gravel—the suspension-rods may be employed to sustain plates and boards which support temporarily the entire roof of the excavation, or the rods may be used to suspend iron frames, around which poling-boards may be driven, as is common with the timber frames heretofore used in tunneling.

It has been discovered that the roots of the trees which are found in ordinary parks do not penetrate the soil many feet in depth, and by the means just described it is obvious that a tunnel can be built four or five feet beneath the surface supporting such growing trees and a sewer constructed or a tunnel for a railway built without injury to the trees or any serious interference with their growth.

The cardinal feature of the present invention is the introduction of suspension-rods through the surface to the top of the intended excavation to support the roof of the excavation while the permanent structure is inserted, and similar suspension-rods may be inserted through the surface material without disturbing the same to support sewers, gas and water mains, or electrical conduits which may be found in the line of the excavation. Temporary pipes may be laid in a pipe-gallery as the excavation progresses, and at suitable intervals, as from six to ten hundred feet, the mains would be connected with such temporary pipes and the dead pipes then removed from the ceiling of the tunnel preparatory to erecting the roof of the tunnel. In such case the temporary pipes would be first suitably connected with the service-pipes taken from the corresponding mains, and the destruction of such mains would not therefore interrupt the use of such service-pipes. Where the number and kind of mains which are to be removed from the tunnel are fully known in advance, a section of eight or ten hundred feet of corresponding mains may, before the tunnel is excavated, be laid upon the surface beneath the temporary bridge and connected with the existing service-pipes. By connecting such temporary section of mains at opposite ends with the mains in the ground the intervening portions of the mains in the ground become dead pipes and may be removed in succession when excavating the tunnel. The labor of suspending such pipes within the tunnel is thus wholly avoided, and the permanent mains may be located within the substructure when it is finished or in any other permanent place and be suitably connected with the service-pipes.

The various details of the invention will be understood by reference to the annexed drawings, in which—

Figure 1 is a transverse section of a wide street with a tunnel in process of construction under the right-hand portion of the pavement, a tunnel completed under the left-hand portion, and a structure to be erected between the two tunnels indicated by dotted lines in the remaining earth. Fig. 1^a is a section of a suspension-beam with stirrup for the suspension-rod. Fig. 1^b shows a modification of Fig. 1. Fig. 2 is a similar cross-section showing the lateral tunnels completed and the middle tunnel under process of construction. Fig. 3 is a longitudinal section through the side tunnel on line 3 3 in Fig. 1, showing the heading of the tunnel and a part of the completed structure. Fig. 4 is a similar view, in longitudinal section, through the center tunnel on line 4 4 in Fig. 1. Fig. 5 is a longitudinal section of the tunnel-heading with the adjacent soil, showing the temporary mains for supplying service-pipes during the driving of the tunnel. Fig. 6 is a cross-section of such heading, showing the gooseneck connections of the mains either above or below the surface. Fig. 7 is a cross-section of a trench for constructing a single wall or row of piers without breaking the surface. Fig. 8 is a cross-section of a sewer-tunnel with the surface soil supported adjacent to the roots of a tree. Fig. 9 is a longitudinal section of the same at the center line. Fig. 10 is a cross-section showing the completed tunnel. Fig. 11 is an elevation of one of the metal frames shown in Fig. 8. Fig. 12 shows the bottom end of such frame, and Fig. 13 the joint-flange upon the top of such frame. Figs. 14, 15, and 16 show modifications of the tunneling-frames.

A designates the surface, *a* the pavingblocks, if such surface be paved, and a' a concrete bed or layer supporting such blocks.

In Fig. 1, A' designates cable-conduit frames, A^2 the sidewalks at the edges of the pavement, and A^3 the front lines of the adjacent buildings.

B represents metal suspension-beams supported above the pavement across the intended tunnel by stringers or blocks B', which transfer the load to solid supports at the sides of the tunnel.

c designates the suspension-rods, carried by the beams B, c' boards or plates applied to their lower ends to support the roof of the tunnel, and c^2 the nuts screwed upon the rods.

b' are blocks inserted between pavement and beams B to prevent fracture of the pavement by the nuts.

D designates the bridge-beams, (shown in Fig. 1,) supported upon the blocks or stringers B' and carrying the temporary bridge structure D', upon which a wagon D^2 is shown.

E designates walls at the outer sides of the lateral tunnels, F the permanent posts at the inner sides of such tunnels, and L' the permanent girder-beams supported by such walls and posts. Foundations F' are shown beneath the posts F, and foundations G^2 beneath posts G, which are represented between the posts F to support, with such posts, the beams G' beneath the middle of the street. When such structure is completed, it forms a quadruple tunnel for a four-track railway, which would be excavated as follows: The route of the tunnel being surveyed, rows of holes for the rods c are drilled at suitable intervals, as two to five feet, according to the nature of the surface, in lines across the proposed tunnel at a suitable depth to penetrate the top of the same. The rods are then inserted and the blocks B' and beams B arranged to connect such rods with the bottom flange of the beams by suitable stirrups or hangers, as in Fig. 1^a, or by cross-pieces above the beams, as shown at b in Figs. 8 and 9. If provision be required for the traffic, the beams D, of greater depth than the beams B, are arranged between the same and the platform or bridge D' built thereon, with inclines at the ends to lead the vehicles thereon, as shown in Fig. 5. The excavation being commenced, the lower ends of the rods serve as a guide for the top of the excavation, and the material above the same is supported by the boards or plates c', which are made of suitable dimensions to properly sustain the material and held in place by the nuts c^2. Timbers H and poling-boards h are shown at the sides of the excavation, with cross-bars I and braces I' to hold such timbers in place, the timber framing being put up as the excavation advances and the poling-boards h driven in slightly ahead of the excavation, as shown in Fig. 3. Where pipes e e' or electrical conduits e^2 are encountered and it is desired to retain them in position, they may be suspended by rods directly to the beams B, as with the largest of the pipes e, (shown in Fig. 1,) or a bar e^3 may be hung to the beam B by suitable rods and the pipes suspended therefrom, as shown in the pipes e' and conduit e^2.

The process of excavating the heading is shown in Figs. 3 and 5, where the pavement a and concrete a' are shown suspended over a certain section of the tunnel by the suspension-rods, and other rods in advance of the heading are shown extended through the pavement to be used when reached by the excavator.

In Fig. 3 short timbers H are shown at the end of the upper bench J, with the poling-boards h driven partly into place, and similar timbers and partly-driven poling-boards are shown adjacent to the lower bench J'. As the tunnel is extended a track k is laid upon the floor and cars K used to remove the earth and bring in the material for the masonry F, which is advanced as fast as the excavation is extended, the mason-work being built around the beams H where they intersect the same.

The drawings show in Figs. 1 to 5, inclusive, side tunnels having large subways for pipe-galleries, and when the walls F' are built at the sides of such galleries beams F^2 may be placed across the same and a track k' laid thereon and cars K' operated above the cars K.

In practice a section of several hundred feet in length would be completed with the foundation-walls F', and the cars would then furnish full provision for bringing in the materials for the permanent structure, represented in Fig. 3 as consisting of the iron posts F and girder-beams L, carrying the jack-arches L'. At the left side of Figs. 1 and 3 the posts and girder-beams are shown in place, with the jack-arches and masonry above the same. Blocks L^2 of suitable material are shown in these figures inserted between the beams L and the under side of the concrete a' to support the latter temporarily when the suspension-rods are removed and during the filling in of the intervening space with earth or concrete a^2. Such concrete may be filled up to the plates or boards c', leaving a space when the boards and rods are successively removed into which asphaltum or liquid cement f may be poured through the holes in the pavement through which the rods are withdrawn.

By using blocks L^2 made of asphaltum concrete the liquid asphaltum unites perfectly with the same and forms an unbroken waterproof covering to the structure beneath the pavement. At the right side of Fig. 1 the foundation-walls F' only are shown finished, and the location of the posts F and girders L are indicated in dotted lines. Prior to the erection of such girders a cable-carrier may be sustained by rods c^4, Fig. 1, and an endless cable carried over a pulley n to transport buckets o' for removing the earth, and the head-pulley of such cable-carrier may be advanced from time to time as the heading is pushed forward, so as to take the earth from the bench nearest the ceiling. The space between the completed work at the left of Fig. 3 and the heading may represent eight or ten hundred feet, and in such space a cable-carrier could be conveniently operated to carry the earth from the heading backward to a car or to a shaft, where an elevator would take it to the surface. The pulley *n* for such carrier is shown in Fig. 3 with the rope and buckets extended partly toward the finished work; but the driving apparatus for the rope is omitted, as it forms no part of the present invention and is already well known.

In Fig. 1, M designates a stringer extended along the pavement at the inner side of the finished tunnel to confine the heavier traffic to the space over such tunnel while the intervening earth is excavated. Such earth is shown in Fig. 2 temporarily sustained by the timbers H and poling-boards *h*, braced against the posts F, and Fig. 4 shows the means for removing such earth. Beneath this portion of the street no suspension-rods are required, as falsework can be supported upon the posts F to carry the body of the pavement and to sustain the cable-conduits, if such there be in the street, as shown in Fig. 1. The falsework consists of posts N and girders N′, which may be, as shown in Fig. 4, inserted gradually below the surface as the heading is advanced, such falsework being fitted to the under sides of the cable-conduit frames and blocks *n*′ (shown in Fig. 2) being fitted between the girders N′ and the pavement to support it upon such girders until the permanent structure can be erected. In removing the earth under the cable-conduits the permanent structure would be built, as shown in Fig. 4, as close as possible to the heading where the earth is removed, car-tracks k^2 being laid and extended toward the heading as fast as the foundation for it can be completed, as shown in Fig. 4. By this method of construction the double tunnel required under the middle portion of the street for a four-track road can be constructed without breaking the surface of the pavement or interfering with the passage of cars upon the car-tracks thereon. The movement of wagons and other loads over the pavement by the car-tracks is, however, preferably diverted to the sides of the street by stringers M during such period, as shown in Fig. 2.

It is obvious that the use of falsework to support the pavement during the excavation of the central tunnels is secured by the presence of the posts F, which have been previously erected in constructing the lateral tunnels, and it is the previous construction of such tunnels which obviates the necessity of suspending the pavement over the central tunnel in excavating the latter.

Fig. 2 shows the great facilities for operating with rapidity which are secured by this method of construction, as six tracks may be operated in the four tunnels and pipe-galleries to take away the earth and bring in the materials for construction. A movable hoisting-tackle Q is shown in the right-hand tunnel in Fig. 2 lifting one of the girders G′ upon a car to transfer it to cars upon two tracks in the central tunnel. Such cars are shown provided with pneumatic hoists R, having air-supply pipes *r*, and the beam when transferred to such cars is hoisted to the tops of the posts F and swung around to rest upon the same. The poling-boards and supporting-beams are taken down as fast as the earth is removed, thus leaving free space for the insertion of the posts G and girders G′ in place of the temporary falsework N N′. In Fig. 1 the main *e*′ is shown connected with the house A^3 by service-pipe E^4, and a permanent main E′ is shown in the pipe-gallery below connected also by pipe e^4 with the same service-pipe, so that when the tunnel is finished, with the mains in the pipe-gallery connected to the main supplies, the pipes, which are suspended in the tunnel, may be removed, while the service-pipes E^4 remain connected with the permanent main E′, as shown at the left side of Fig. 1. Where it is admissible, I prefer to lay a section of temporary mains—as water, gas, and other conduits—upon the surface of the street and connect such section at its ends with the mains in the ground, so that the pipes in the ground between such connections become dead pipes and may be promptly removed when they are encountered in digging the tunnel. The sewer S′ is shown bracketed on the wall E, being suspended until the wall is built. In such case a section of eight or ten hundred feet of temporary mains may be laid and connected with service-pipes, so as to furnish a temporary supply when the service-pipes from the ground are cut off. When the tunnel is completed, the permanent mains may be located within the substructure or in any new placement outside the tunnel, and when such permanent mains are connected with the service-pipes the temporary mains would be removed. The temporary pipes are preferably covered by a bridge or platform when laid upon the pavement, so as to protect them from accidental injury, the bridge being supported at a suitable distance above the surface for this purpose. The bridge may also serve to protect the pipes from frost by packing suitable non-conducting material around the pipes beneath the platform of the bridge. Such construction is shown in Figs. 5 and 6, where the bridge-beams D are shown supported by stringers B′ at a suitable distance above the pavement A to introduce a water-pipe C, a long section of which is shown laid upon the pavement and connected at the opposite ends (by goosenecks C′) with mains *e* in the ground. The portions of the mains remaining in the ground (designated C^3) thus become dead pipes, and may be readily removed as the excavation progresses, a heading being shown at the left end of the figure with one of the dead pipes projecting into the same.

In Fig. 6 the water-pipe e and also electrical conduits e^2 are shown between the pavement and the bridge, and the cable-carrier for the buckets o' is also shown upon a larger scale than is possible in Fig. 1.

Dotted lines C^2 are shown in Fig. 5, illustrating the possible location of a permanent pipe in the bottom of the tunnel, as is shown at C^2 in Fig. 1, the same being connected by goosenecks at opposite ends with the mains in the ground, as would be proper when the section of tunnel is finished and it is necessary to remove the pipes laid upon the pavement, the main C^2 being connected with the service-pipes before the temporary pipe was disconnected therefrom. By such method of construction the suspension of the pipes within the tunnel, as illustrated in Fig. 1, is wholly avoided and the tunnel may be constructed with much greater rapidity.

Fig. 7 shows the means of constructing a single wall at the side of a street, where it is deemed preferable to erect such wall before the remainder of the tunnel is driven, so that it may serve to support the foundations of buildings before the tunnel is excavated. In such case the pavement or superincumbent earth would be supported by suspension-rods, as shown in the figure, and in order to excavate and build the wall without breaking the surface of the street along the entire line of the wall a space is excavated at the side of the wall of sufficient width to lay a track and operate cars, as shown.

The method of construction shown in Figs. 1 to 6 is especially applicable to cases where a rigid pavement is already laid above the line of the tunnel; but Figs. 8 to 13 show means for excavating the tunnel by the use of suspension-rods in parks and squares where there is no pavement. In such cases the bridge-beams which carry the suspension-rods may rest directly upon the soil over the tunnel or may be supported upon blocks or piers which relieve the earth wholly from pressure across the line of the tunnel.

Fig. 10 shows a completed sewer-pipe with the suspension-beams B resting directly upon the earth and the rods drawn from the earth, as would be admissible when the masonry is finished, while Fig. 8 shows blocks B' beneath the ends of the suspension-beams B to relieve the earth over the excavation from the load upon the rods, and the method of arranging the suspension-beams may be thus varied to suit the particular requirements of such case.

Figs. 8 and 9 show the means for excavating a tunnel and building the required masonry where there is no pavement and where the soil requires poling-boards at the top as well as at the sides of the excavation to support it until the masonry is built. Such means consists of metallic frames provided with slots in the edge adapted to receive the poling-boards, which are thus driven through the frames instead of outside the frames, as is common when "timber frames" are used. Such frames can be erected with much greater rapidity than timber frames. In Fig. 8 a frame T in two parts, forming each one side of an arch, are united at the center by flanges t and bolt t'. Notched lugs t^2 are provided upon the frames to engage the lower ends of the suspension-rods c, which thus serve to wholly sustain each pair of frames. Each frame is provided with slots T' in its margin, through which poling-boards u may be driven, as shown in Figs. 8 and 9. The suspension-rods c are inserted in the earth in advance by surveying the route of the tunnel upon the surface and properly arranging cross-beams and rods to intersect the roof of the tunnel. During the excavation of the tunnel a pair of the frame parts T is introduced when each pair of rods is encountered and the frame parts are then set in the position shown in Fig. 8 and securely bolted together at the center. Footing-boards u^3 are driven down at the sides of the excavation and supported by cleats v^2 and braces v^3, and the floor of the excavation is then covered with concrete X, as shown in Fig. 8, upon which the masonry of a sewer or tunnel is built. The masonry is carried forward as close to the heading as is practicable to permit the driving of the necessary poling-boards through two or three of the frames T. Fig. 9 shows the facing-boards W at the end of the heading, one of the frames T in which the poling-boards are last driven, and another of the frames T in readiness to be removed when the poling-boards are pushed past the edge of the same.

In Fig. 9 the masonry V of the sewer is shown partly completed and the face-boards W are supported against the end of the sewer by bars and brace W'. The masonry of the sewer V is shown built close to the nearest frame T, which may be done when the preceding frame is removed. The ends of the poling-boards u project a short distance beyond the frame T, and it is necessary in order to remove such frame and continue the building of the mason-work to drive the boards through the slots T' in the frame. A bent drift u', which is provided with a handle u^2, is held against each of the poling-boards in succession, while a hammer is applied to a seat v' upon the handle to force each board through the slot in the frame. When the boards are all driven through the slots, the frame parts may be disconnected at the center by removing the bolt t' and the foot of each frame then swung inwardly, as shown in dotted lines in Fig. 8, after which it may be set in front of the facing-boards W and engage with the rods c, which are shown in Fig. 9 pushed up to insert the frame, and would then be drawn down into engagement with one of the notches of the lugs t^2 to apply the supporting-nut c^2. The poling-boards are driven at such an inclination through the slots T' that they pass outside of the frame in advance, and when a frame is set before the face-boards W other boards may be driven through the slots T in like manner to support the earth, while the face-boards are removed and set forward sufficient to introduce another frame.

In Fig. 10 the sewer is shown formed with an inner course of bricks and an outer course of concrete and is built, as shown in Fig. 9, in close contact with the poling-boards, which remain in place when the sewer is completed. By this method of construction the tunnel may be driven and the mason-work completed without disturbing the surface soil or injuriously affecting the roots of growing trees and shrubs, and the injury is thus wholly avoided which is inflicted upon the ground adjacent to a trench when a tunnel or sewer is built in an open trench and the earth is thrown upon the surface at the top of the same. The same freedom from damage to the contiguous surface is secured by suspending a street-pavement, as hereinbefore described, and constructing a tunnel beneath the same without breaking the surface, as the expense of removing and relaying the pavement is not only saved, but the obstruction to the traffic which would be thereby caused and the damage to surrounding objects by the piling of earthen stones thereon.

From the above description it will be seen that the means may be materially varied to carry out my invention, and that its essential feature is the use of suspension-rods to support the surface material while excavating beneath the same, and that the means used for sustaining the rods upon or above the surface is immaterial, as well as the kind of supports at the lower ends of the rods, which carry the suspended material.

Where iron frames are used to support poling-boards, it is obvious that the shape and proportions of such frame may be varied to suit the conditions—as, for instance, the character of the soil, the depth of the tunnel below the surface, and the lines of pressure at such depth, as well as the shape of the substructure.

Fig. 14 shows that the frame and poling-boards are not compelled to support the entire weight of the superincumbent earth, as the material in most cases has a certain degree of cohesion, which is preserved if the tunnel is driven without breaking or disturbing the material. The dotted lines C^4, which inclose a triangular mass of the material immediately above the top of the frame, represent the material which, in the case of cohesive earth, would rest upon the frame, while the material outside of such lines would be supported by its own cohesion. It is owing to such cohesion of the earth that it partly supports its own weight above the tunnel and that the bridge-beams or surface supports may operate satisfactorily when placed directly upon the ground, as shown in Fig. 14. The bridge-frames thus placed may serve effectively to support the frames and portion of earth within the lines C^4, as the material outside of such lines maintains its stability and is capable of supporting the load.

Figs. 15 and 16 show, respectively, a frame with horizontal top and a frame having a flat arch at the top, the joint between the two parts of the frame being placed upon the center line in Fig. 16, the same as in Fig. 8, while the frame in Fig. 15 is shown in three pieces, which embrace, respectively, the top arch and the side legs. The flanges and bolts which connect the parts of the frame make the frame practically a unit and substantially of the same strength as if made in one piece, and the sides are thus enabled to resist the pressure to which they are subjected. The suspension-rods are preferably attached to the frames at such points as to equalize the pressure at each side of the rod upon the top and sides of the frame. The metallic frames possess a great advantage over the ordinary timber frames in respect to the rigid connection of the top and sides, which enables the pressure upon the top to balance the pressure upon the sides when the rods are connected to the frames intermediate to the middle and sides, as shown in Fig. 8. Such frames also facilitate the introduction of the poling-boards by the provision of the slots in the margins of the frames, the flange outside of which slots supports the forward ends of the poling-boards and prevents them from crowding inward against the new boards when inserted in the slots.

In the application of poling-boards to the exterior of timber frames it is necessary to wedge up the forward ends of poling-boards to introduce fresh boards inside the same; but with the construction shown and described herein such wedging is wholly avoided, and the heading may thus be carried forward with much greater rapidity. The suspension-rods are preferably inserted in the earth or pavement above a considerable section of the proposed tunnel before the latter is driven, and such construction offers the advantage of permitting the survey for the route of the tunnel to be made above the surface, where it may be performed with much greater rapidity, accuracy, and cheapness than underground, as the position of the rods in the earth as the operators push the heading forward furnishes a guide in the driving of the tunnel and in the erection of the masonry therein.

It will be understood that where the suspended material is of rigid character, like a bed of concrete, the rods require only washers or small plates applied above the nuts c^2 to adequately support the load.

The blocks b' (shown in Figs. 1, 6, and 7) permit the operators in the tunnel to tighten the nuts upon the suspension-rods without breaking the bed of concrete, as the blocks by their contact with the under side of the suspension-beams prevent the concrete from being bent upwardly.

Where the beams rest directly upon the surface, the tension of the nut serves merely to clamp the material against the under side of such beam. The beams are termed "surface supports" herein, because in any case they operate on or above the surface and sustain the material between the surface and the tunnel-roof, which material I have termed herein the "surface" material.

Where the supported material is of loose earth, sand, or gravel, boards would be applied to the entire lower surface of such material as the heading is advanced and bars or plates applied to the rods to support the whole of such boards.

An important feature of my invention is the facility afforded for both vertical and transverse alinement of the permanent structure. Proper surveys being established on the surface when the suspension-beams are placed, the lower ends of the suspension-rods will indicate with exactness a datum line for the erection of the permanent structure and all temporary timbering, false work, &c. They will also furnish an approximate alinement for construction sufficient for all temporary work.

Where adjacent foundations or embankments require support, the thrust of the earth A^4, Figs. 1 and 6, may be balanced against the foundations by securing brackets d to the pavement at the sides of the heading to bear against the poling-boards which support the earth A^4 and bracing the outer edge of the pavement or adjacent curbstone against the walls or foundations of such buildings. Where vaults occur along the sidewalk, roof-stringers a^6 and posts a^7 are put in them to brace the buildings against the concrete of the pavement, and thus prevent all tendency to cave toward the tunnel. The outer walls of vaults may then be safely removed, as the pavement itself serves as a brace to the embankments or buildings at both sides of the tunnel.

To leave a suitable space for the waterproof layer, a board of suitable thickness, as one inch, would be placed beneath the suspended material (as the concrete a') as the masonry was built up to the same, the board being drawn forward as the masonry progressed, thus leaving a continuous space between the top of such masonry and the lower side of the suspended material, into which space the asphalt would be introduced.

The blocks L^2 or n' are inserted between the construction in the tunnel and the suspended material, as shown in Figs. 2 and 3, to support such material when the suspension-rods are removed or the earth is excavated between the false girders N' and the superincumbent pavement, and the waterproof layer when introduced then encircles such blocks and can be made to form a waterproof joint therewith by making the blocks of the same material as the fluid which is used for flushing the interspace.

Where asphaltum is used the blocks would be made of asphaltum composition or concrete, and where hydraulic cement is used the blocks would be made of such cement.

Where the suspension-rods are used, as over the side tunnels shown in Fig. 2, the holes left by the withdrawal of the rods serve to introduce such fluid, which is preferably forced in by a suitable pump, so that the waterproof layer may fill every interstice and effectually prevent the penetration of moisture. A continuous waterproof layer f is shown in Fig. 2 extended over the roof of the four tunnels, and as no suspension-rods are required where false work is used holes would be drilled from the surface to introduce the waterproof liquid in the space above such false work.

Where the tunnel is excavated by suspending the pavement and thus wholly avoiding the fracture of its surface, the water is most effectually prevented from running into the tunnel during its construction, and the damage is thus avoided which is often caused to such works by storms and floods. By preserving the pavement with its natural grade the provision which usually exists for carrying off the surface water is maintained in full operation during the construction of the tunnel, and the storm-water is thus prevented from interfering with the progress of the work.

A drain-pipe z is shown at the bottoms of the lateral tunnels in Figs. 1 and 2, and such drain may be provided during the process of construction to receive any water which flows from the earth, so that it may be pumped to the surface.

To wholly exclude water from the excavation, melted asphaltum s may be poured into the holes after the rods are inserted therein, as shown in Fig. 7, to make a tight joint around each rod, such asphaltum not preventing the rods from being driven upward when their removal is necessary. Fig. 2 of the drawings shows pneumatic lifts used for raising the permanent girders G' to the tops of the posts F, and similar means may be employed for setting the girders L in place over the lateral tunnels, and great facility for riveting the girders or any parts of the structures is also secured by the employment of pneumatic hammers and riveting devices. By such means the work may be done with great thoroughness and rapidity, as well as with uniformity of operation and convenience of handling the tools.

By supporting the pavement and its substratum concrete in the manner described and preventing water from penetrating the same the pavement not only forms a most perfect covering to exclude water from the excavation, but forms a perfect brace between the embankments or foundations at the sides of the tunnel, thus diminishing in a very great degree the tendency of the foundations to yield and rendering possible the excavation of a tunnel which could not be otherwise driven.

Where an underground road is constructed close to foundations by means of an open trench, sheet-piling is required at an enormous expense to sustain such foundations during the construction of the tunnel, while my construction provides an efficient means of sustaining such foundations by the braces a^6, (shown in Figs. 1, 6, and 7,) which brace the buildings against the pavement, which is held in a rigid position at the outer ends of such braces. By applying such braces at the opposite edges of the pavement to the buildings at opposite sides of the street the strain upon the pavement is balanced and it is enabled to form a perfect support for the structures upon both sides. It should be understood that it is not material how the surface supports are disposed which carry the suspension-rods C, as they may be extended longitudinally of the street instead of transversely, especially where it is impossible to arrest the traffic. The construction suited for such a case is illustrated in Fig. 1^b on Sheet 1 of the drawings, where the suspension-beams b are shown extended lengthwise near the tracks upon the cable-conduit frames A′.

Fig. 1^b illustrates a construction suitable for excavating a tunnel under the middle of a street only, where there would be no side structures to carry false work beneath the pavement, and the pavement should therefore be sustained by suspension. In such a case the permanent structure would be built as close as possible to the heading, and the longitudinal suspension-beams B would be made of suitable strength to span the excavation, the front ends of such beams resting over the solid earth, and the rear ends of the same resting above the permanent structure, so that the intermediate pavement and car traffic would be efficiently supported by the suspension-rods.

Fig. 1^b shows the side embankments sustained by timbers H and poling-boards h', which would be introduced as the heading is advanced, and the roof-supports c would be placed beneath the conduit-frames A′ as they were reached in excavating and the concrete bed supported by blocks n', resting upon the plates or bars c'. The thrusts of the side embankments are shown balanced against one another by brackets d, attached to the bars c' and timbers H, such brackets also being secured by the suspension-rods c. With such construction it is evident that a tunnel may be driven beneath the car-tracks and the permanent structure erected therein without disturbing the traffic.

By attaching the brackets d to the bars or plates c', as shown in Fig. 6, the surface material may be utilized (if of rigid character like concrete) to form a strut or brace between the side embankments, and the latter thus sustained in great measure without the use of cross bars or timbers to effect such bracing, and the supporting of the surface material thus not only obviates the necessity for posts to hold up such material, but also of cross-braces, which greatly obstruct the operation of the workmen.

The longitudinal suspension-beams B, which transfer the load of the surface material to the embankment in advance of the heading and to the finished substructure in the rear of the heading, may be used in other cases than that just described, as my invention is not limited to any particular form or disposition of the surface supports.

The beams B and D (see Fig. 5) form a single continuous series of transverse beams arranged across the line of the proposed tunnel, with the beams D of greater height or supported with their upper surfaces above the tops of the suspension-beams B to sustain the traffic independent of such suspension-beams. The stringers or supports B′ for such beams are arranged in advance beyond the sides of the tunnel to transfer the load of the suspended material and of such traffic to the embankments or other supports, as shown in Figs. 6 and 7, at the sides of the tunnel. I have therefore claimed such a continuous series of beams of divers heights in the combinations described herein.

Where temporary conduits are laid upon the surface of the pavement which is to be suspended, a platform may be built over the same to protect such conduits and the weight of such platform removed from the surface by the series of beams of different heights, with the suspension-rods hung from the lower beams and the platform sustained upon the higher beams, as just described.

It will be understood that my invention is adapted not only for tunneling under paved streets or those which have a rigid pavement of concrete, but in any soil or earth of such character as can be excavated without blasting where the surface of the soil is exposed or uncovered sufficiently to arrange the supports or beams to sustain the suspension-rods.

The term "surface material" is used herein as including all the material between the top of the excavation and the uncovered surface of the ground and which in my invention is sustained by suspension from surface supports until the underground supports are provided, when the weight of the surface material is successively transferred to such underground supports.

It should also be understood that the plates or bars c' may be made of any dimensions or material adapted to support the suspended load, and such plates may consist of narrow bars, which sustain the load at intervals only, where the surface material is rigid like concrete, as shown in Figs. 7 and 1^b, or the plates may be formed of longitudinal boards adapted to cover the whole surface of the material, as shown at c' in Fig. 5, and upheld by transverse bars or cleats, through which the suspension-rods c are extended. By this latter construction each particle of the surface material may be supported without excessively multiplying the number of suspension-rods. I have used the term "plates" c' in the claims to include these various forms of boards and bars.

Having thus set forth the nature of the invention, what I claim herein is—

1. The herein-described method of constructing a tunnel beneath a street, park or other uncovered body of earth without disturbing the surface of such earth, which consists in supporting the unbroken surface material by suspension, during the excavating of the tunnel and the erecting of the underground supports, substantially as herein set forth.

2. The herein-described method of constructing a tunnel beneath a street, park, or other uncovered body of earth without disturbing the surface of such earth, which consists in supporting the unbroken surface material by suspension progressively during the excavating of the tunnel, and thereafter transferring the weight of such material to the underground supports, as set forth.

3. The herein-described method of constructing a tunnel beneath a street, park, or other uncovered body of earth without disturbing the surface of such earth, which consists in supporting the unbroken surface material by suspension during the excavating of the tunnel, and independently supporting the street traffic above the surface material, to relieve the latter from jar and strain, substantially as set forth.

4. The herein-described method of constructing a tunnel beneath a paved street without disturbing the pavement, which consists in supporting the said pavement by suspension, during the excavating of the tunnel, and bracing the lateral embankments of the tunnel by such pavement during the erection of the underground support, substantially as herein set forth.

5. The herein-described method of constructing a triple tunnel beneath a paved street, which consists in first suppporting the pavement along the sides of the street by suspension during the excavating of the lateral tunnels, and utilizing such pavement to brace the embankments of such lateral tunnels, and excavating the central tunnel after the underground supports of the lateral tunnels are completed, substantially as herein set forth.

6. The herein-described method of constructing a tunnel through a street or uncovered body of earth containing mains for water, gas or other purposes, and without disturbing the surface of such street, which consists in supporting the unbroken surface material by suspension, and also the said mains, during the excavation of the tunnel, substantially as herein set forth.

7. The herein-described method of constructing a tunnel beneath a street having a rigid pavement without disturbing the pavement, which consists in supporting the unbroken surface material by suspension during the excavating of the tunnel and the erection of underground supports with a roof for the tunnel, and flushing the top of such roof with waterproof material, as hydraulic cement or asphaltum.

8. In the construction of tunnels, the means for supporting the surface material during the excavation of the tunnel, consisting of a suitable support above such material, suspension-rods extended downward therefrom to intersect the top of the tunnel, and a plate or bar c' sustained by such rods to support the surface material substantially as herein set forth.

9. In the construction of tunnels, the means for supporting the surface material, consisting of a beam extended across the line of the proposed tunnel above the surface, suspension-rods extended downward therefrom to intersect the top of the tunnel, and plates or bars of suitable dimensions to carry the material sustained by such rods, and in contact with its lower side, substantially as herein set forth.

10. In the construction of tunnels, the means for supporting the surface material, consisting of a series of beams extended across the line of the proposed tunnel above the surface, suspension-rods carried by such beams and extended down to intersect the top of the tunnel, the rods serving to guide or direct the excavating of the tunnel, and having the plates c' secured successively to the rods to sustain the surface material, as the excavation progresses, substantially as herein set forth.

11. In the construction of tunnels, the means for supporting the surface material, consisting of a series of blocks or stringers upon the surface beyond the sides of the proposed tunnel, a series of beams supported transversely across the line of the tunnel upon such blocks or stringers, suspension-rods carried by such beams and extended down to intersect the top of the tunnel, and suitable plates attached to the lower ends of the rods to sustain the surface material.

12. In the construction of tunnels beneath a rigid street-pavement, the combination, with such pavement, having holes drilled through the same, of the tunnel having a permanent structure erected therein with a space between the top of the same and the bottom of such pavement, and a filling of waterproof material, as hydraulic cement or asphaltum, applied to such space and to the holes in the pavement.

13. In the construction of tunnels beneath a rigid street-pavement, the combination, with means for supporting the unbroken surface material by suspension, of a permanent structure within the tunnel having a space between the top of the same and the bottom

of the suspended pavement, and blocks L^2 fitted in such space to transfer the weight of the pavement to the permanent structure, substantially as set forth.

14. In the construction of tunnels, the combination and arrangement of suspension-rods extended downward from the surface to intersect the roof of the tunnel, plates c' attached thereto below the surface material, and a series of transverse beams of divers depths extended across the line of the tunnel above the surface, the shallower beams having the suspension-rods secured thereto, and the deeper beams having a platform laid thereon above such shallower beams, to carry the street traffic independently of the surface material, substantially as set forth.

15. In the construction of tunnels, the means for supporting the surface material during the excavating of the tunnel and simultaneously supporting a load above such surface material, consisting of the blocks or stringers B' arranged upon the surface beyond the sides of the proposed tunnel, a series of suspension-beams B carried upon such stringers across the line of the tunnel, with suspension-rods and plates for supporting the surface material, and bridge-beams D arranged upon the same stringers between the beams B, with a platform sustained upon such bridge-beams above the top of the suspension-beams, as and for the purpose set forth.

16. In the construction of tunnels beneath the surfaces of streets having a pavement with rigid substratum and bordered by buildings, the means to support the pavement and buildings during the excavating of the tunnel, consisting of a series of beams upon the surface of the street, rods extended from such beams through the pavement and substratum to intersect the top of the tunnel, with plates to support the surface material, and braces between the edge of such pavement and the adjacent buildings or foundations, as and for the purpose set forth.

17. In the construction of tunnels having a rigid pavement, the combination with beams supported upon the surface, of suspension-rods extended downward from the beams through holes drilled in the pavement to intersect the top of the tunnel, plates c' sustained by such rods to carry the surface material, and waterproof material, as hydraulic cement or asphaltum, filled in the holes around such rods to exclude the surface water from the tunnel excavation; substantially as herein set forth.

18. The means for constructing a tunnel and subgallery for pipes and conduits in earth without disturbing the surface of the earth, consisting of beams upon the surface, suspension-rods extended therefrom to intersect the top of the tunnel, plates supplied successively to the rods to support the surface material while excavating a heading, piers constructed along the bottom of the tunnel at the sides to form a subgallery and beams upon the piers across such gallery with rails and cars thereon, to bring the materials into the tunnel and to remove the earth therefrom, substantially as herein set forth.

19. In the construction of tunnels, the means for supporting the surface material and sustaining a cable-carrier upon the roof of the tunnel, consisting of suitable supports above the surface, suspension-rods extended downward therefrom to intersect the top of the tunnel, plates to support the surface material upon such rods, and connections from such rods to the mechanism of the cable-carrier, for sustaining the same upon the roof, substantially as herein set forth.

20. In the construction of tunnels in which sewer, water pipes, and other conduits are encountered, the combination, with supporting-beams above the surface along the line of the tunnel, of suspension-rods extended downward therefrom to intersect the top of the tunnel, plates to support the surface material upon such rods, and connections between such suspension-rods and the sewer, water pipes or other conduits, to sustain the same upon the supporting-beams, substantially as herein set forth.

21. In the construction of tunnels in which sewer, water pipes, and other conduits are encountered, the combination, with supporting-beams above the surface along the line of the tunnel, of suspension-rods extended downward therefrom to intersect the top of the tunnel, plates to support the surface material upon such rods, a beam sustained within the tunnel by such suspension-rods, and connections from the sewer and other conduits to such beam, whereby the surface beams carry the weight of such conduits.

22. In the construction of tunnels through a street containing mains for conveying water, gas, or for other purposes without disturbing the surface of such street, the combination with such main conduits in the earth, of temporary conduits laid upon the surface of the earth over a proposed section of the tunnel and connected by goosenecks at their opposite ends with the mains in the earth, suitable beams or supports upon the surface adjacent to such temporary conduits, rods extended downward from such beams or supports to intersect the top of the tunnel, and plates c' secured successively to the rods to sustain the surface material as the excavation progresses; whereby a heading may be driven with the surface material suspended from the rods, and the dead mains removed when encountered in the earth, substantially as herein set forth.

In testimony whereof I have hereunto set my hand in the presence of two subscribing witnesses.

BENJAMIN F. CARPENTER.

Witnesses:
THOMAS S. CRANE,
EDWARD F. KINSEY.