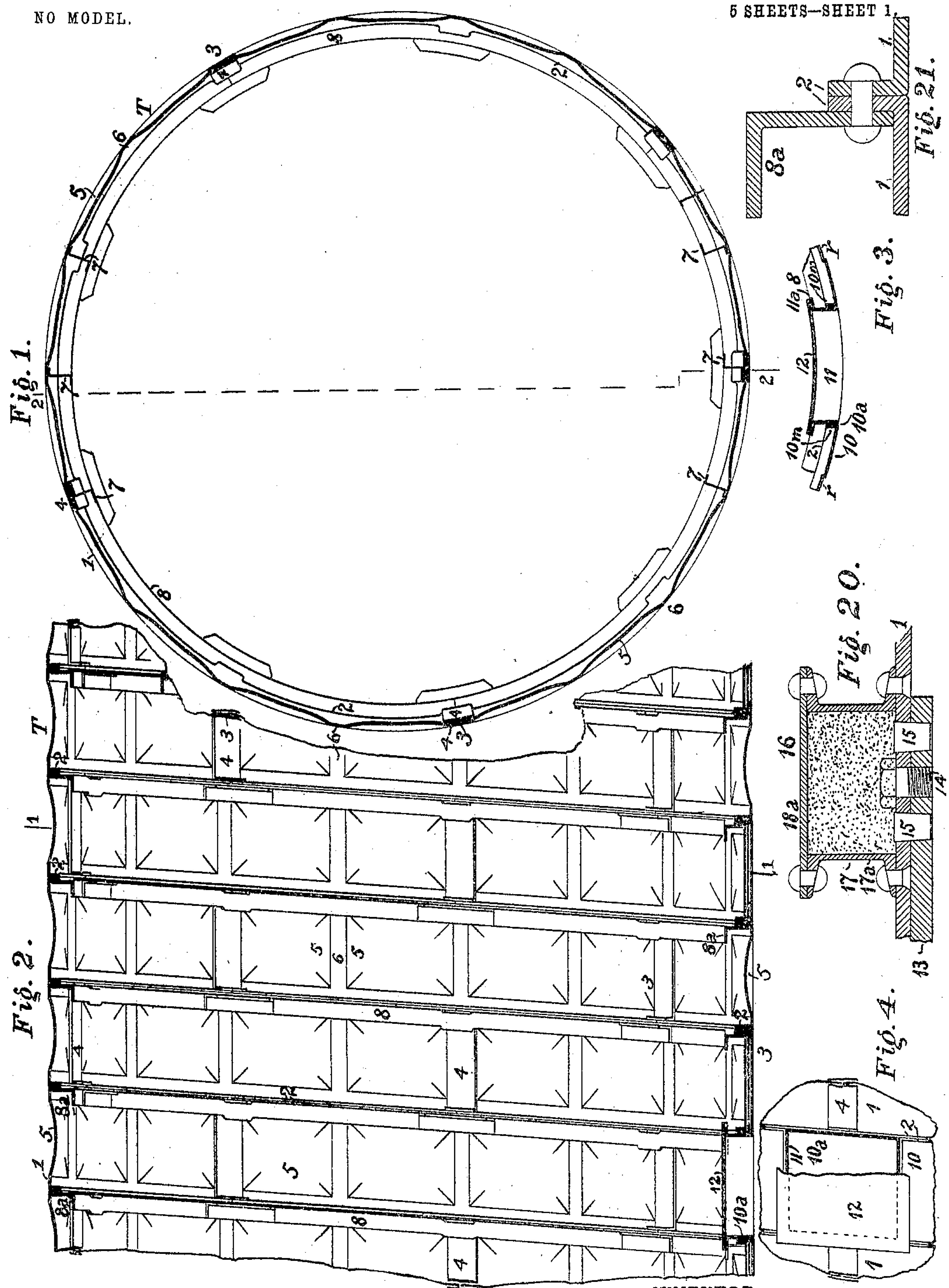
No. 770,894. PATENTED SEPT. 27, 1904.

C. N. DUTTON.

CASING OR LINING FOR TUNNELS.

APPLICATION FILED FEB. 2, 1904.

NO MODEL. 5 SHEETS—SHEET 1.



WITNESSES:

Edwin L. Yewell

J. H. Burgess Jr.

INVENTOR.

Chauncey N. Dutton

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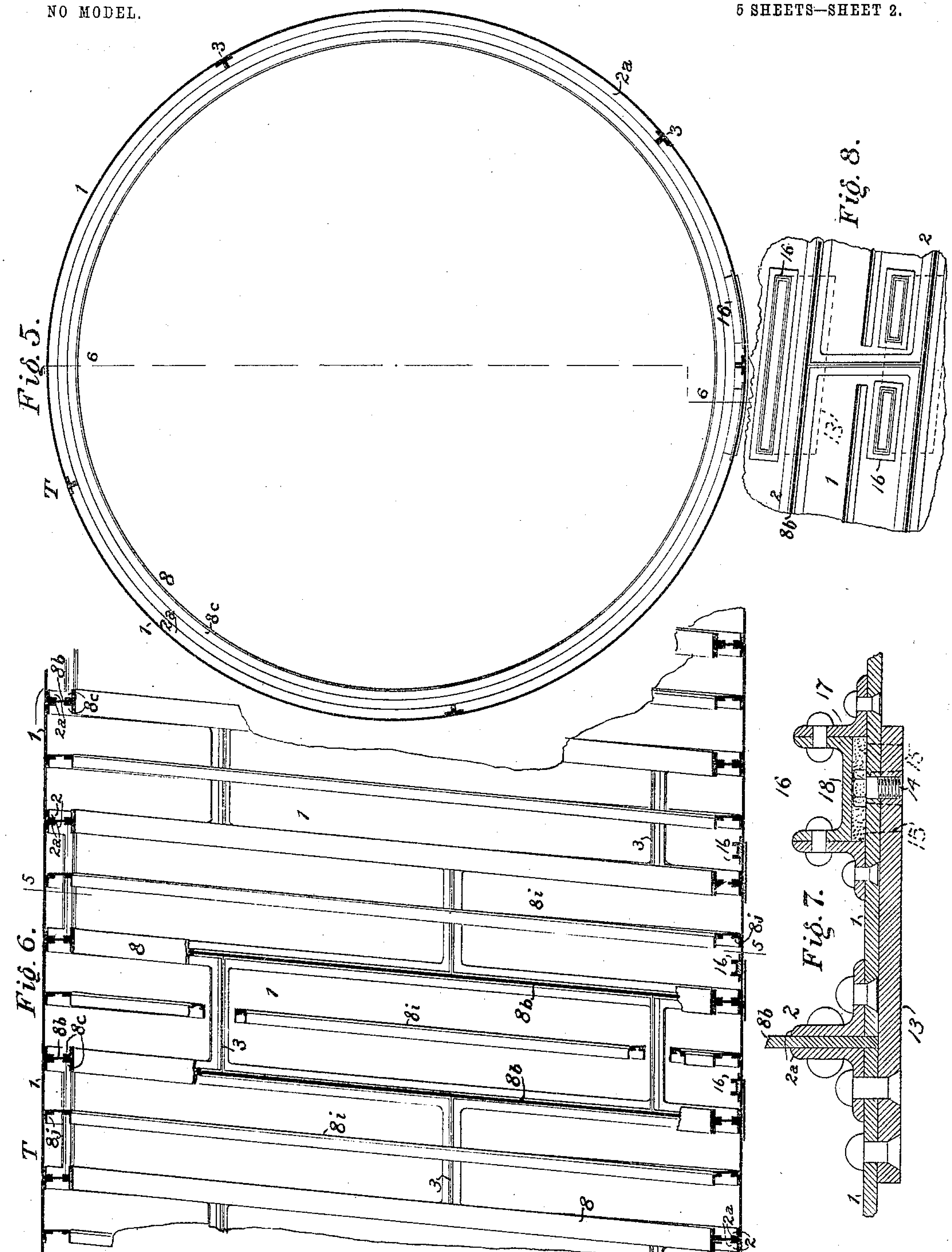

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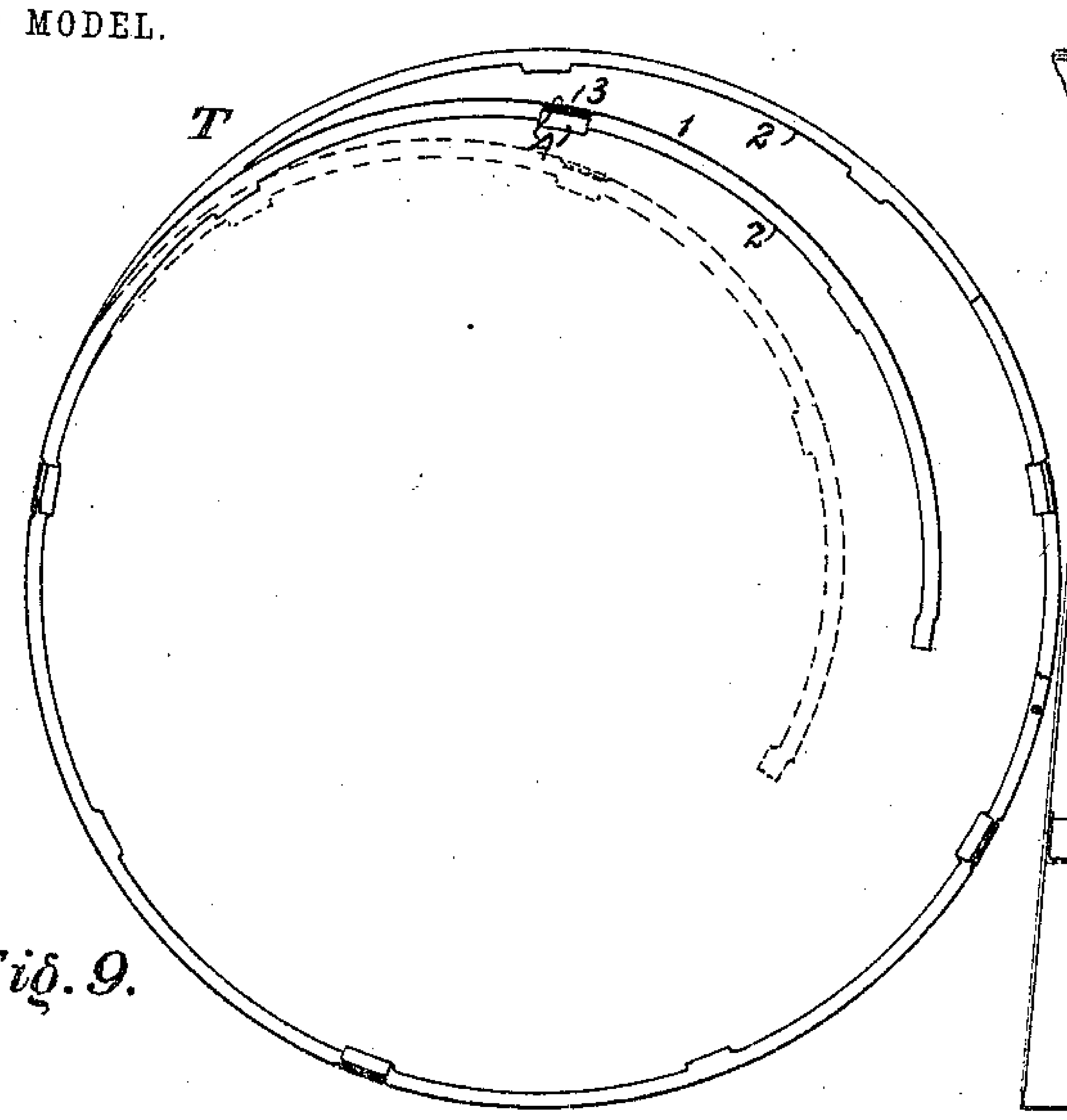


Fig. 9.

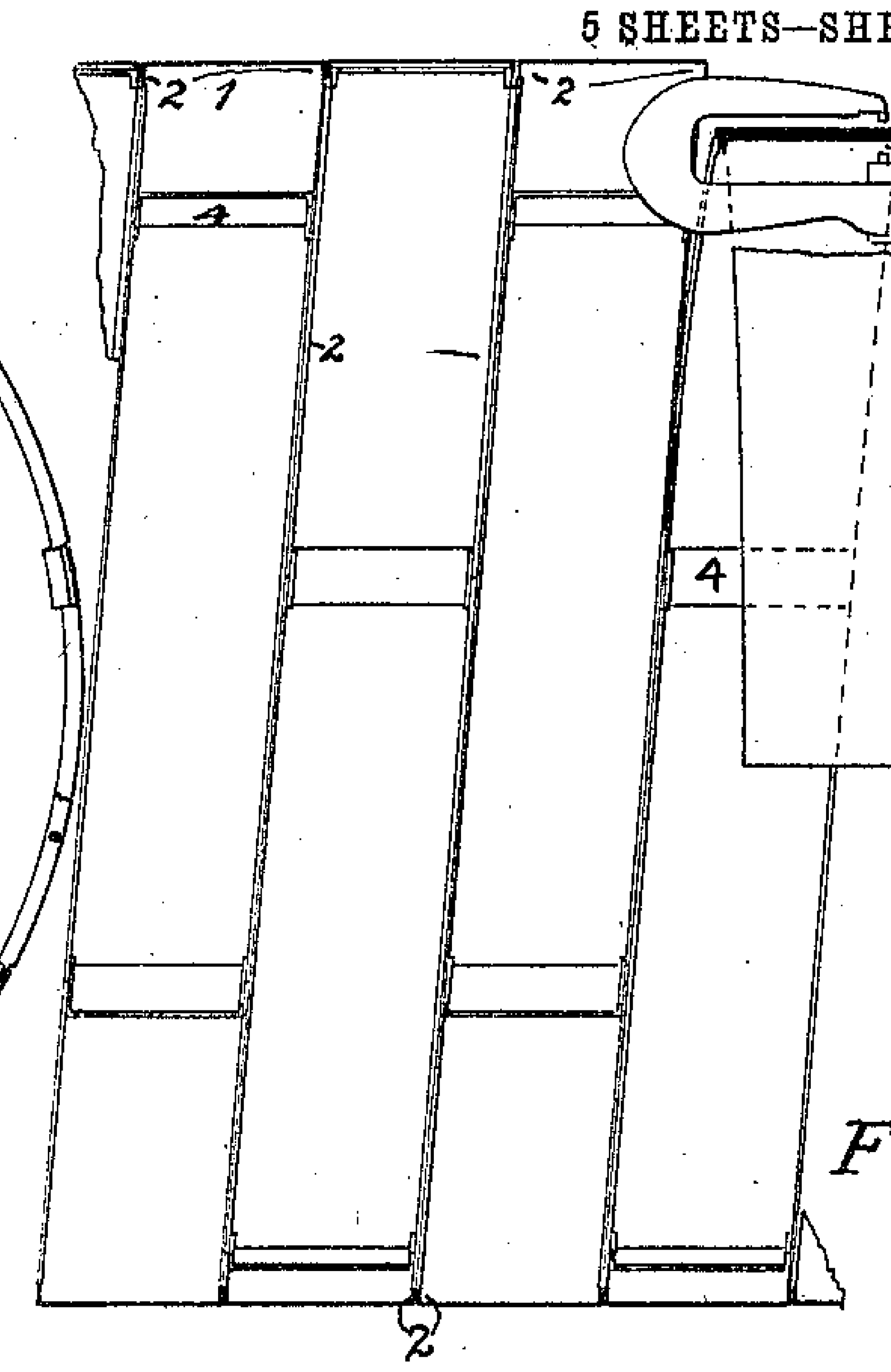


Fig. 10.

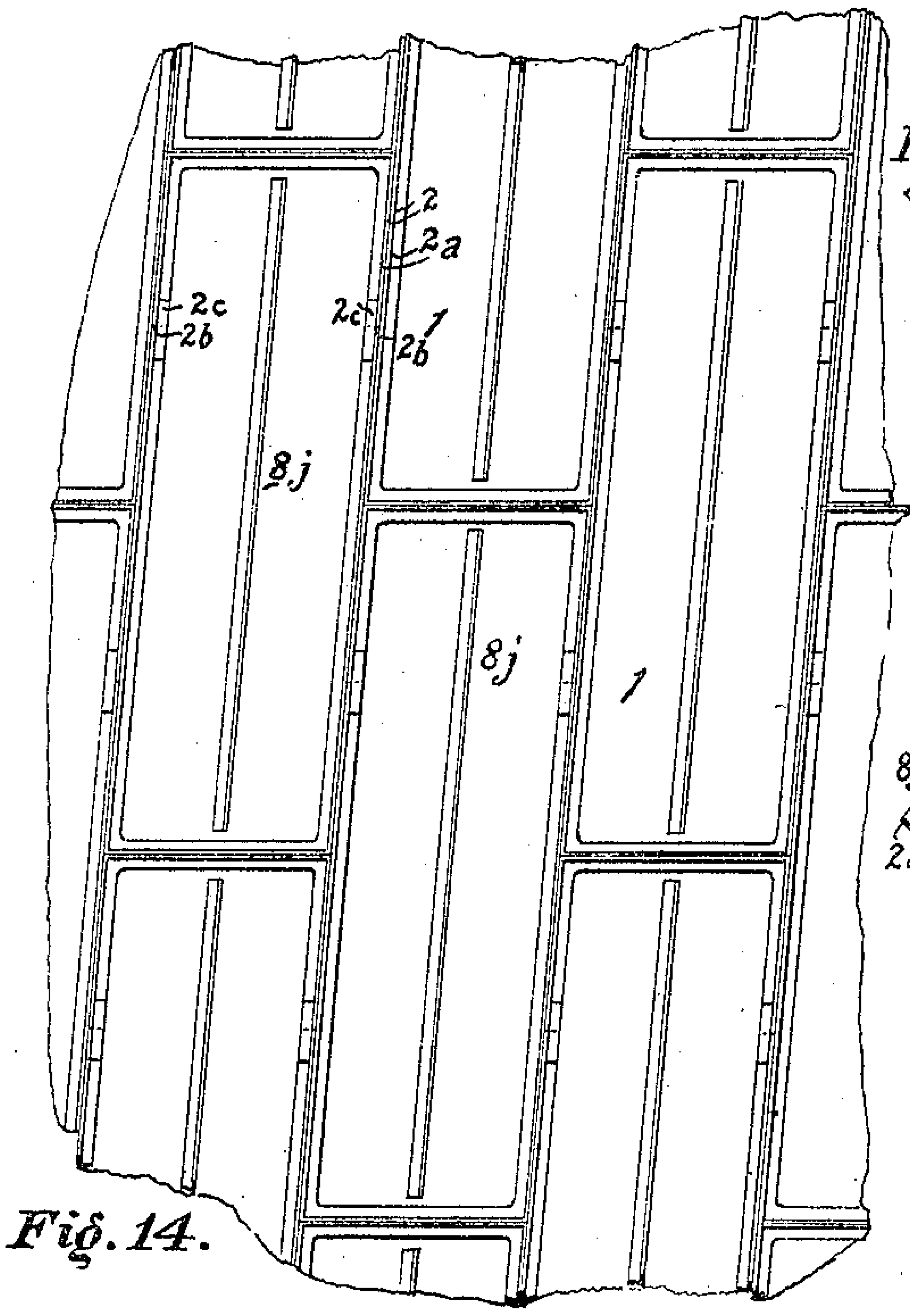


Fig. 14.

Fig. 16.

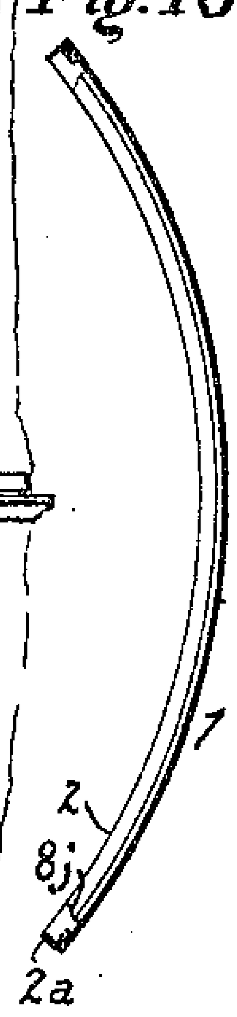
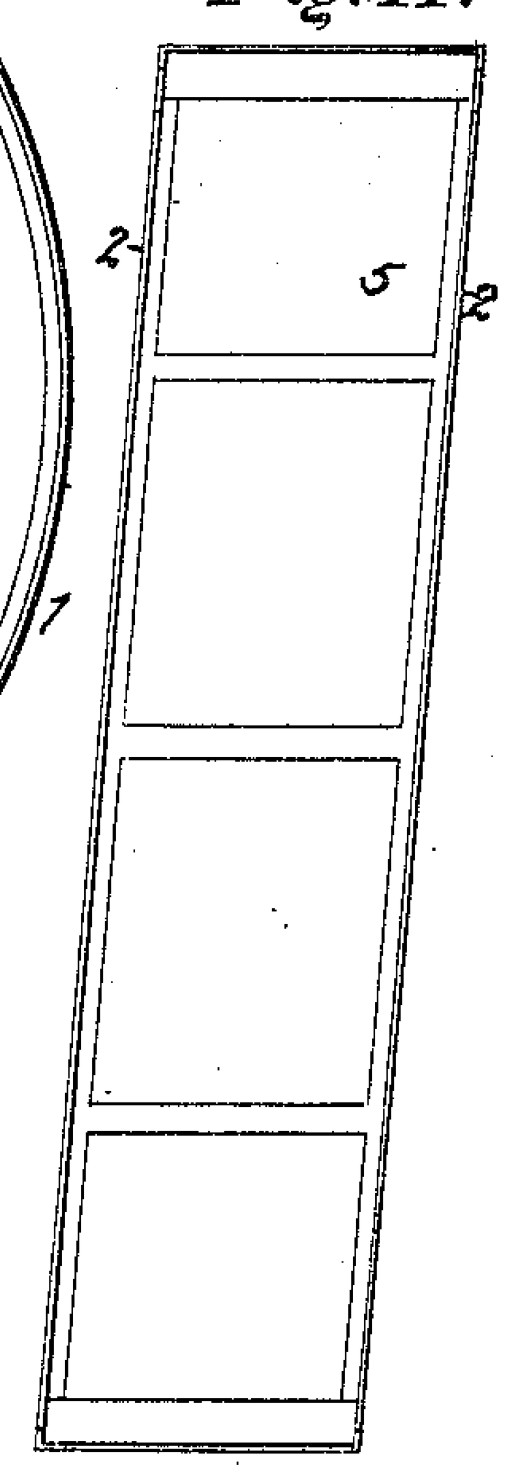


Fig. 11.



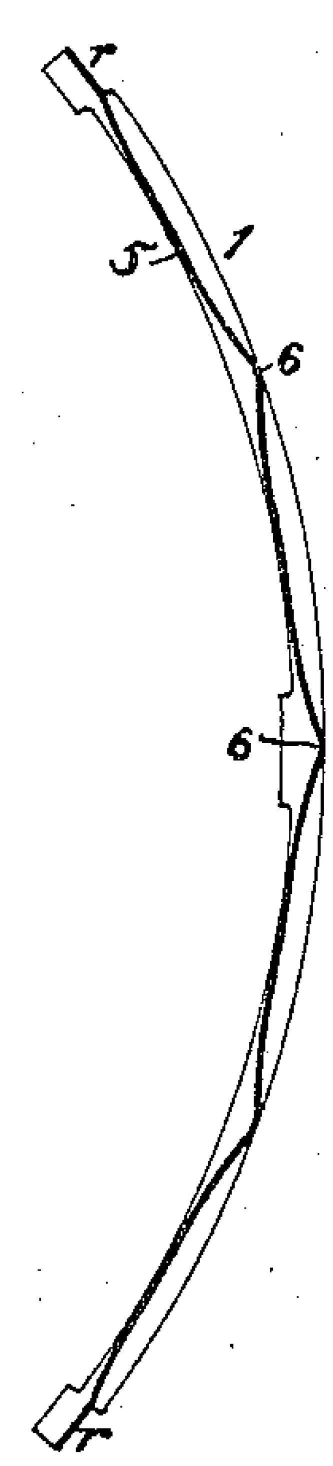


Fig. 12.

Fig. 15.

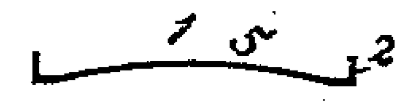


Fig. 13.

WITNESSES:

Edwin L. Yewell

J. H. Burgess Jr.

INVENTOR.

Chauncey N. Dutton

by W. E. Schoenborn

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NO MODEL.

5 SHEETS—SHEET 4.

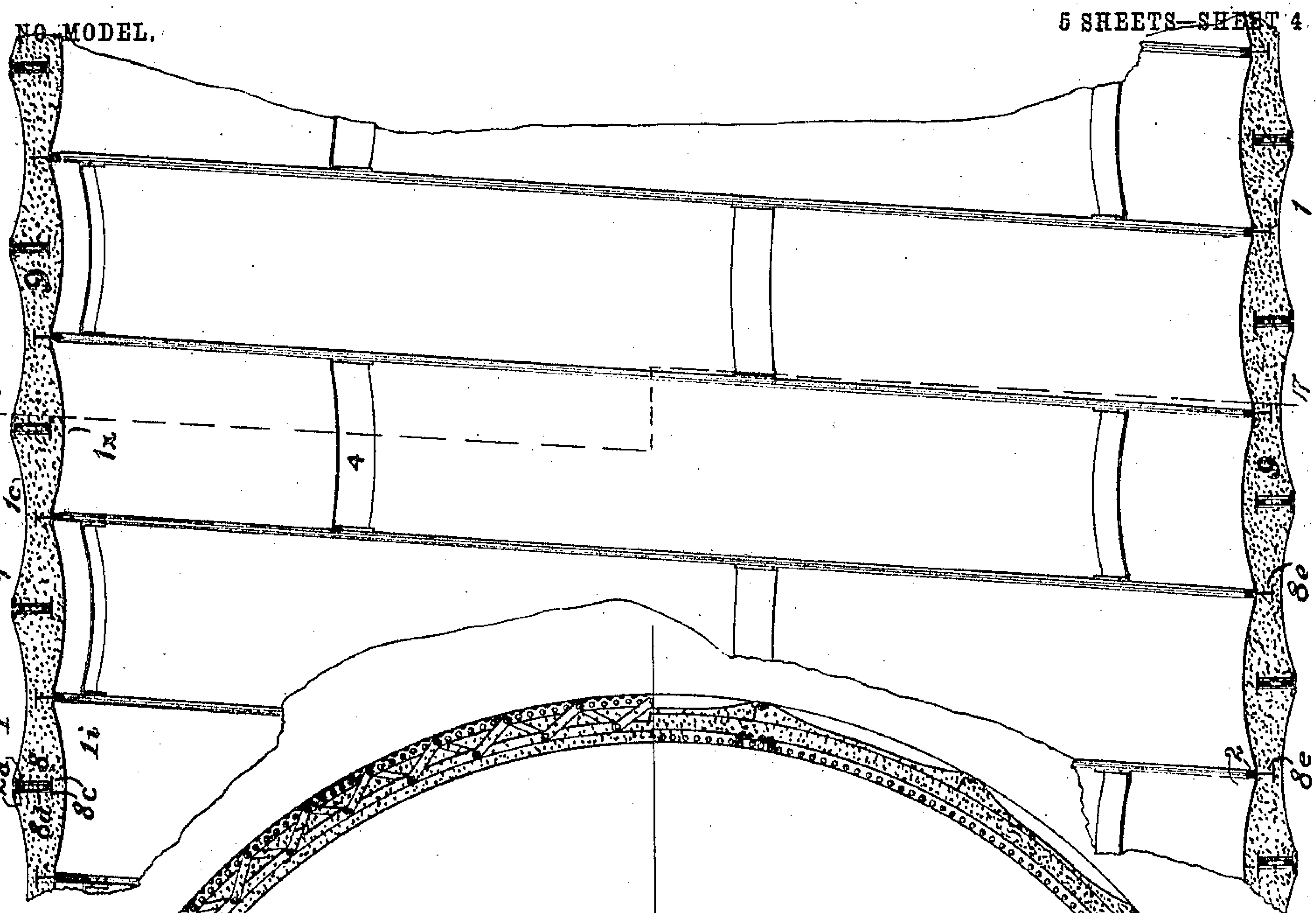

Fig. 18.

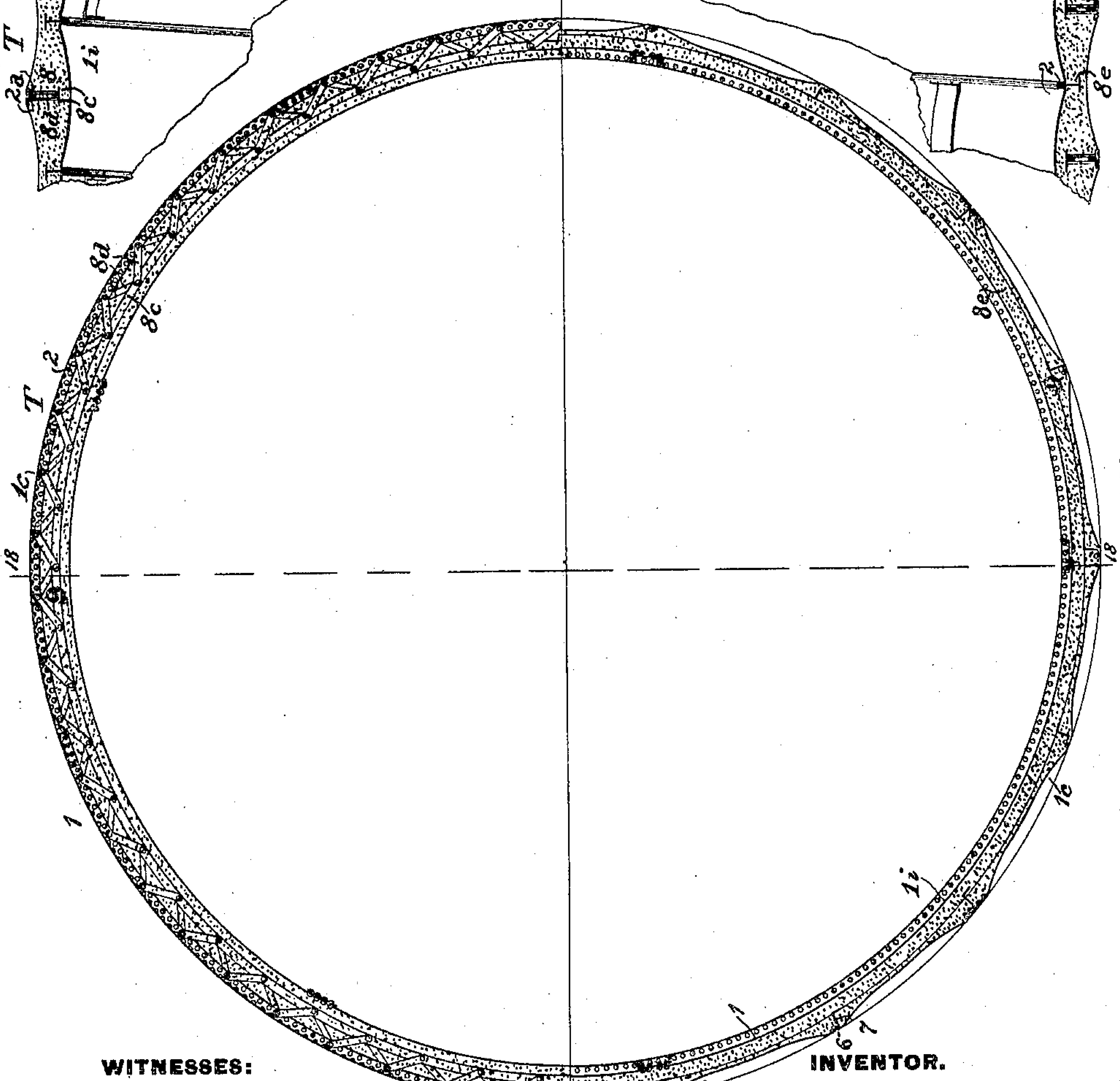

Fig. 17.

WITNESSES:

Edwin L. Yewell

J. H. Burgess Jr.

INVENTOR.

Chauncey N. Dutton

by W. E. Schoenborn

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NO MODEL. 5 SHEETS—SHEET 5.

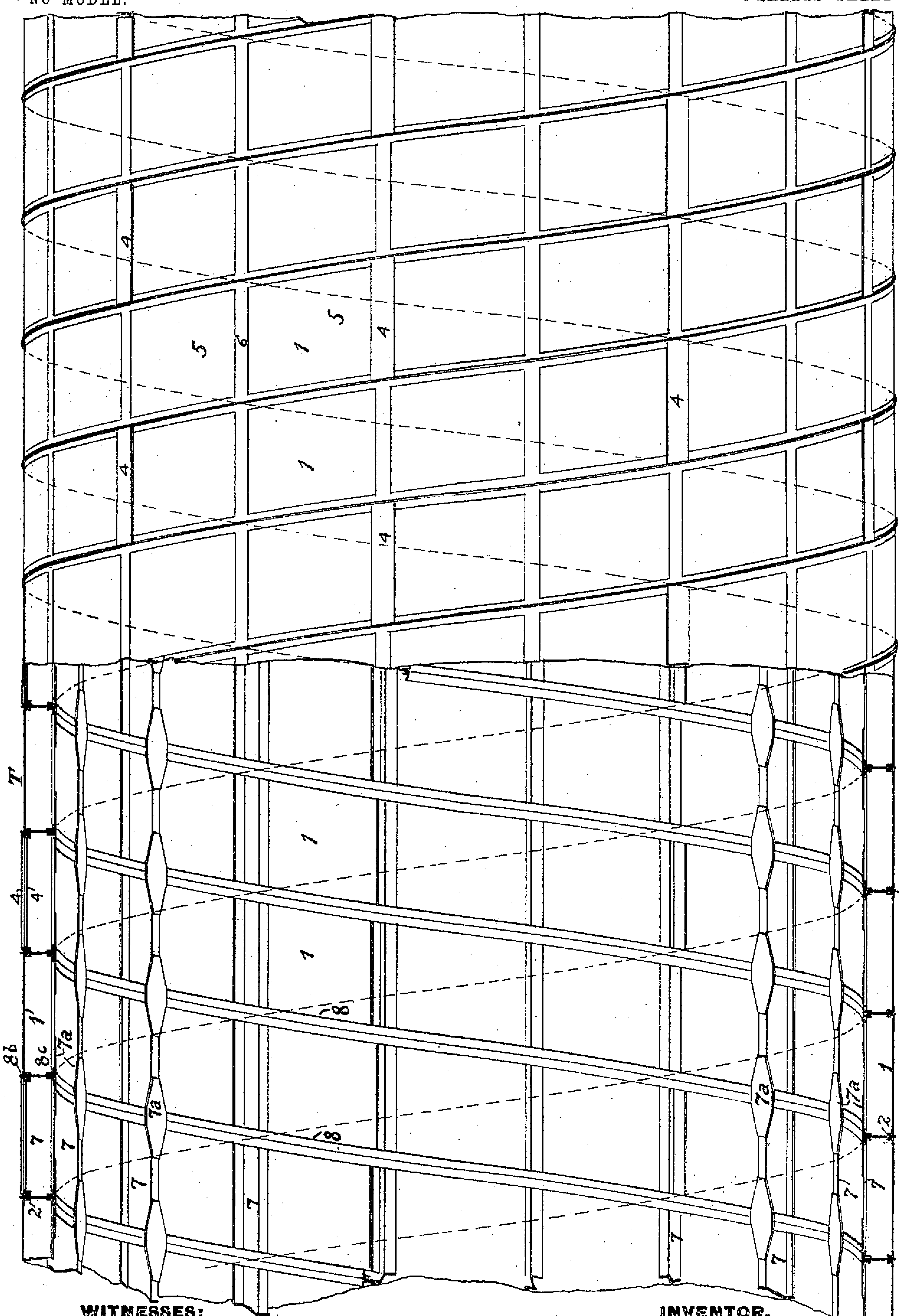

Fig. 19.

WITNESSES:

Edwin L. Yewell

J. H. Burgess Jr.

INVENTOR.

Chauncey N. Dutton

by W. E. Schoenborn

Att'y.

No. 770,894. Patented September 27, 1904.

UNITED STATES PATENT OFFICE.

CHAUNCEY N. DUTTON, OF NEW YORK, N. Y.

CASING OR LINING FOR TUNNELS.

SPECIFICATION forming part of Letters Patent No. 770,894, dated September 27, 1904.

Application filed February 2, 1904. Serial No. 191,742. (No model.)

To all whom it may concern:

Be it known that I, CHAUNCEY N. DUTTON, of the city of New York, county and State of New York, have invented certain Improvements in the Casings or Linings for Tunnels, designed to make their construction cheaper, safer, and quicker and to make them safer, more durable, drier, and more comfortable in after use, of which the following is a specification.

My improved tunnel-lining constitutes, substantially, a spiral riveted calked wrought-metal plate structure, the plates being spirally internally flanged, riveted through the said flanges with rivets normal to the spirals or substantially parallel with the axis of the tunnel, the longitudinal joints being preferably riveted with butt-joints, their riveting being made possible by springing the forward end of the lining already in place inwardly, so that the arm of a power-riveter can be introduced between the back of the longitudinal joint to be riveted and the inside of the lining already set, the riveting of the spiral joints being held back, say, one-sixth to one-third of a circumference to that end. The edges of the internal spiral flanges and of the inside butt-plates of the longitudinal butt-joints are calked with a calking-tool, making an absolutely tight job as against either internal or external fluid-pressure.

My lining will be made of wrought metal—say of wrought-iron or mild or soft steel. Wide thin plates may advantageously be buckled or corrugated. Wrought iron or steel can be so fabricated as to make a tunnel-lining which will be absolutely impervious to the entrance of water from without or the escape of air from within—desirable ends practically unattainable with tunnel-linings of any other material.

Heretofore attempts to line tunnels with wrought metal have been unsatisfactory, owing to faulty design, and metallic tunnel-linings have been made of cast-iron in the form of rings, generally in segments with both circumferential and longitudinal joints flanged and bolted and packed with fibrous material or soft metal, according to the fancy of the designer. Because the ring segments are voussoirs and, moreover, because it is impossible to make them accurately to dimensions without machining them it is usual to key or wedge up one segment of each ring and to give the bolts considerable play in their holes; but a bolt "is a vain thing for safety" in a structure subject to shocks, jars, and vibration, as is a tunnel for railroad or vehicle service, and such a construction is obviously wholly unfit to sustain the torsional strains found in a double-track tunnel in soft material. Further, during construction, as frequently happens, when a tunnel runs out of firm material into silt and it becomes necessary to change from atmospheric to compressed air the stress in the tunnel-lining may change from compression to tension and the poorly-designed joints of the cast-iron lining open, greatly increasing both the cost and the danger of operations.

My improved spiral riveted calked steel casing or lining will make an absolutely perfect lining, air and water tight, and adapted to safely and permanently sustain any stress or strain or alteration thereof to which it may be subjected, either during construction or in after use.

Cast-iron is not well adapted for use in spiral tunnel-linings. It has small coefficients of distortion and flexure, and therefore cast-iron flanges cannot be successfully riveted and calked, and for the same reasons cast-iron spirals cannot be successfully assembled unless their contact-surfaces are turned to true helices in a screw-lathe. Wrought iron or steel, on the contrary, has a very large coefficient of distortion, and therefore the spiral edges of my spiral segmental steel tunnel-lining plates can be flanged to approximate the theoretical helix, and they can be successfully assembled and riveted with safety and celerity, because the pressure required to rivet them will press the flanges into sufficiently close contact for subsequent calking.

The term "steel" where used herein means wrought-steel or wrought-iron or equivalent material. The term "calked" may be interpreted in its broadest sense; but generally it means the closure of riveted joints by upsetting the metal of the members thereof by concussion applied at their edges, as with a calking-tool and hammer or pneumatic calking-tool—that is to say, it has the significance usual in good plate-metal work.

Such a lining is described in the following specification and shown in the accompanying drawings, in which—

Figures 1 to 4, 11 to 13, and 17 to 19, inclusive, and 21 show a spiral flanged steel buckled plate-lining with flanged and riveted and calked spiral joints and double-butt-riveted and calked longitudinal joints, Fig. 1 being a transverse section on the line 1 1 of Fig. 2, Fig. 2 a longitudinal section on the line 2 2 of Fig. 1, Fig. 3 a transverse section showing a section or segment with a manhole-opening and manhole, and Fig. 4 a plan thereof. Figs. 5 to 8, inclusive, and Figs. 14, 15, and 16 show a spiral sheared rolled plate-lining with angles riveted to the plates to make both the spiral and longitudinal flanged joints, Fig. 5 being a transverse section on the line 5 5 of Fig. 6, Fig. 6 a longitudinal section on the line 6 6 of Fig. 5, Fig. 7 an enlarged partial longitudinal section showing a mode of reinforcing a spiral joint, and Fig. 8 a plan thereof. Figs. 9 and 10 are respectively a transverse and longitudinal section showing the mode of riveting longitudinal butt or lap joints. Figs. 11, 12, and 13 are respectively an inside view, side view, and end view or section of a spiral segmental flanged steel buckled plate adapted for double-butt longitudinal joints; and Figs. 14, 15, and 16 are respectively a developed plane view, transverse section, and longitudinal section of a spiral segmental flanged sheared rolled-steel tunnel-lining plate. Figs. 17 and 18 show a composite tunnel-lining of spirally-riveted and calked steel plates with ribs or frames and concrete filling, Fig. 17 being a transverse section on the line 17 17 of Fig. 18, and Fig. 18 a longitudinal section on the line 18 18 of Fig. 17. Fig. 19 shows, partly in elevation and partly in section, a tunnel-lining with a plurality of spirals. Fig. 20 shows a modified form of dam for inclosing the inside ends of members which pierce the tunnel-lining and which cannot themselves be calked, and Fig. 21 is an enlarged partial longitudinal section showing the riveting of a spiral flanged joint.

My improved tunnel construction is most advantageously applied by the so-called "shield system" of tunnel-driving, although it may be used in connection with any method of driving. In the shield system the work of excavation and the placing of a temporary or permanent lining are sought to be facilitated by the use of a movable tunnel-head called a "shield" because it shields the workmen from accidents. The best-designed tunneling-shields are generally cylindrical structures divided by transverse bulkheads into three longitudinal divisions—namely, a cutting or driving face, a working chamber, and a hood. The function of the driving-face is to extrude or cut the material through which the tunnel is driven and to compress it and deliver it in sufficiently compact condition and conveniently to the working chambers and the operators. The function of the working chambers is to facilitate and render safe the removal of such material, and to this end the working division is frequently subdivided by vertical and horizontal longitudinal partitions into cells. The function of the hood is to provide a chamber in which sections of the lining can be erected with safety and celerity. Hydraulic power and compressed air are piped to the shield, the chief office of the hydraulic power being to actuate hydraulic jacks, by which it is driven forward, and in my system to rivet the joints of the lining. Whether the tunnel be driven by the shield system or by some other it is obvious that the lining, whether temporary or permanent, should be put in position with the greatest possible celerity and in the closest possible proximity, if possible in contact with the material it is to support and exclude. My spiral steel lining accomplishes these ends perfectly.

Referring to the drawings, T is a tunnel-bore, and 1 1 spiral steel casing or lining plates. The drawings generally show the lining as formed of convolutions of a single spiral; but it is obvious that two, three, or any desired number of spirals can be used with equal facility, and in some cases with great advantage, as in large tunnels, where there is plenty of room, and as many gangs of men can be worked at lining as there are spirals. Therefore in such cases a plurality of spirals renders the speed of driving entirely independent of the work of lining and dependent solely on the speed of excavation. Such a plurality of spirals is shown in Fig. 19. It is obvious that the members of a tunnel-lining and their joints and fastenings must be so designed as to assemble and be fastened by workmen inside the tunnel, and in case a fastening projected outwardly or was of such design as to necessitate work on the outside of the lining after it was assembled it would be necessary to do wasteful and difficult excavation for the mere purpose of getting at the fastening. To facilitate joining the spiral plates 1 1 and to render it practicable to rivet them and to rivet them with power-riveters working inside the tunnel, inwardly-projecting flanges 2 2 are formed along their spiral edges. The plates are riveted through these flanges with rivets normal to the spirals or substantially parallel with the axis of the tunnels, as shown on an enlarged scale in Figs. 7 and 21, and are calked on the inner edges of said flanges. The flanges 2 2 may be formed by flanging the plates 1 1, or they may be formed by riveting on angles, the flanging method being shown in Figs. 1 to 4, 11 to 13, and 17 to 19, inclusive, and 21, and riveted on flanges in Figs. 5 to 8 and 14 to 16, inclusive. Where it is desired to resist heavy external or internal pressure and to that end to develop and utilize approximately the full strength of the lining-plates, the longitudinal joints are best made butt-joints, single or double butts, as may be desirable, as shown in Figs. 1 to 5 and 11 to 13, inclusive, in which 3 3 are the longitudinal joints, and 4 4 butt-plates. When double butts are used, as shown in the drawings, the ends of the spiral plates 1 1 are pressed inwardly, as shown, to form exterior recesses or rabbets *r r* to accommodate the outer butt-plates 4 4, so that they will be fair with the outside of the lining. One great advantage of the butt-joint for tunnel-linings is the facility it affords for justifying the rivet-holes in the spiral flanges. So far as I am aware, no attempt has heretofore been made to provide a satisfactory and convenient method for making such justification, the necessity for which will be obvious when it is considered that the bolt or rivet circle in a circular single-track railroad-tunnel lining may approximate seventy-two feet in circumference and may be lengthened or shortened nearly an inch by strain within the elastic strength of the metal. It has been usual to elongate the bolt-holes, and thereby get the work together at the total sacrifice of its ability to sustain torsion. In my lining the rivet-holes of the spiral joints are justified at the longitudinal joints by making said joints wider or narrower, as may be desirable. I make the lining-plates standard and provide butt-plates of different widths or with differently-spaced lines of rivet-holes for the longitudinal joints, so that the spiral rivet-holes can be instantly justified by the use of butt-plates having rivet-holes of the proper spacing. Where there is no necessity of developing great strength or for justifying the rivet-holes of the spiral joints, the longitudinal joints may be flanged, as shown in Figs. 5 to 8 and 14 to 16, inclusive. To find the angular length of a spiral segmental lining-plate where only one spiral is used, divide three hundred and sixty, the degrees in a circle, by an odd number and take two such parts for the angular length of the segments. Such plates "break joints" perfectly when assembled. When more than one spiral is used, the segments may be of any convenient length.

Where it is desired to use very light plates of considerable width, the plates may be buckled, as shown in Figs. 1 to 5, 11 to 13, and 17 to 19, inclusive, in which 5 5 are buckles, and 6 6 flats, or rather cylindrical surfaces, parts of the generating-cylinders. The object of these flats 6 6 is to facilitate the riveting on of longitudinal stiffeners 7 7, which are desirable to make the lining rigid and facilitate the driving of the shield by the hydraulic jacks. The best form for such stiffeners is the **Z**-bar, because of the ease with which other members may be riveted to it. Where buckled plates of light weight are used, it is obvious that the strength necessary to prevent the tunnel from collapsing must be provided in the spiral ribs 8 8. Such stiffening-ribs can be readily assembled with my spiral steel lining-plates and riveted to the spiral flanges thereof and will act with the same to develop the maximum strength with the minimum weight, because the members will act together, can sustain tension as well as compression, and will resist distortion as an arched beam, whereas cast-iron linings cannot sustain tension and function merely as block structures or simple arches and require very much larger and heavier members to develop an equal strength. Where thick plates are specified or where it is desired to use a cheaper material, rolled sheared steel plates may be used, as shown in Figs. 5 to 8 and 14 to 16, inclusive, and the flanges 2 2 may be formed of angles 2^a 2^a, riveted to the plates. It is obvious that any plates may be so flanged. Where it is desired to use flanged connections for the longitudinal joints, as shown on the same figures, calking is facilitated by making the flange-angles 2^a 2^a continuous along the sides and across the ends, the corners being pressed hot with sharp exterior arrises, the angles 2^a being spliced conveniently with splice or covering angles, as shown in Fig. 14, in which 2^b 2^b are the splices, and 2^c 2^c the splicing-angles. The splices should always come at the same end of the plates and about one-fourth of its length, as shown, so that no splice will coincide with a longitudinal joint or with another splice.

The spiral stiffening-ribs 8 8, which stiffen the lining, are riveted to the flanges 2 2 and spliced to the longitudinal ribs 7 7 where they meet. In Figs. 1, 2, and 21 the ribs are shown as formed of angles 8^a 8^a, riveted to one side of the spiral flanged joints. In Figs. 5 to 8 and 17 to 19, inclusive, the ribs are shown as built-up members, those in Figs. 5 to 8 having a web-plate 8^b riveted to or into the spiral joint and having angles 8^c 8^c riveted to the web-plates at their intrados. In Figs. 17 and 18 the ribs of the outer or temporary lining or casing are shown as formed with open-web members, either lacing or lattice bars 8^d 8^d uniting the flanges 2 2 of the plates 1 with the inner angles 8^c 8^c. This open web facilitates bedding the ribs in concrete. In the same figures the ribs of the inner lining are shown as **T**-bars, the lead and web bedded in the concrete filling, and the plates of the inner lining riveted by their flanges 2 2 at the intrados of said **T**-bars.

All connections are power-riveted, preferably hydraulic-riveted. Obviously the rivets can be readily set and gripped in the spiral flanges 2 2 of the lining-plates 1 1 and in the flanged longitudinal joints. Longitudinal butt-joints may be power-riveted from inside the tunnel with almost equal facility by the method illustrated in Figs. 9 and 10. This method is assuming a portion of the lining to be in place and riveted up. The riveting of the forward end of the spiral joint between the completed lining and the plate or plates last assembled therewith is held back, say, one-sixth to one-third of a circumference, so that such a length of lining-spiral is free along its spiral edge. Said free end of said plate is sprung inwardly sufficiently to admit the arm of a power-riveter between the back of said plate and the inside of the finished lining, a butt-plate or butt-plates and a segment of lining are assembled with the free end of the plate aforesaid, and the longitudinal joint is riveted up, (the spacing of the lines of rivet-holes in the butt plate or plates being such as to justify the rivet-holes in the spiral flanges of the added segment and the finished lining,) the riveter is removed, the plate first referred to is sprung or drifted to its final position, and the riveting of the spiral joint is progressed a length equal to that of the added segment, leaving the forward end thereof free in order that another segment may be joined to it in manner aforesaid, and this process is continued throughout the tunnel. The elasticity of steel is such that the lining-plates of a twenty-three-foot tunnel if flanged for three-fourth-inch rivets and rolled to be of exact tunnel diameter, with all the fibers free from strain, can be sprung to a diameter of about twenty-one feet without exceeding the elastic limit of strain in the fibers most strained, which allows a maximum working clearance of about twenty-one inches for riveting said longitudinal joints. The middle spiral (drawn in full lines in Figs. 9 and 10) shows this proportionately. If more clearance be wanted, or if the plates have less elastic movement, as in case the rivets are relatively larger and the flanges deeper, or the flanges be formed of angles riveted to the plates, or the metal be poor, the lining-plates 1 1 may be rolled to a diameter so much smaller than that of the tunnel that when they are sprung out to their final position their inner fibers of the flanges will be stretched to a point just inside their elastic limit. As such a plate can be sprung inwardly (putting said fibers in compression) about as far as it can be sprung outwardly, this method gives nearly twice the elastic movement and clearance for riveting longitudinal joints that the first-described method does. The middle spiral before referred to in said figures shows the plate, as above described, with its fibers free from strain, and the inner spiral (shown in dotted lines) shows proportionately the inmost limit of the elastic movement of the lining-plates and the maximum clearance possible without overstraining the fibers of the flanges. In a twenty-three-foot tunnel the clearance can be thirty to forty inches in plates not buckled. Buckled plates have about half greater elastic movement than plates not buckled. The flanges are of such small sectional area relatively to that of the plates that they have correspondingly little effect on the position of the center of gravity and the neutral axis with respect to this bending. On the contrary, buckles, because they occupy nearly the entire surface of the plate, do have a very marked effect and cause the center of gravity and the neutral axis to move inwardly about one-third the depth of the buckles and so much nearer the inner edges of the flanges, thereby reducing the strain on their inmost fibers for a determined elastic movement or flexure, which is directly proportional to their distance from said neutral axis and increasing the total possible elastic movement which is inversely proportional thereto. If the buckles are as deep as the flanges, the elastic movement is about one-half greater than in plates not buckled. Greater force is necessary to bend the buckled plates, but they bend a half farther.

The torsional elasticity of the plates 1 1 is such that the spiraling can be forcibly reversed and one, two, or more complete spirals can be longitudinally riveted inside the tunnel, so that stock, as it were, of plates with longitudinal joints riveted can be assembled in readiness for an unusually rapid forward movement of the shield or tunnel-head, and the plates so longitudinally riveted and held in readiness can be sprung into position in a few seconds and their spiral joints temporarily secured by bolts in a very brief time—say four or five minutes to a spiral. If the plates were four and one-half feet wide, this would give a speed of driving for a few minutes approximating a foot a minute. The best time on record for setting a cast-iron ring of tunnel-lining is forty-five minutes. While a cast-iron ring is being set the shield must stand still. The celerity with which spiral steel lining can be placed is hereby forcibly illustrated and also the fact that with my lining the speed of driving a tunnel depends not at all on the speed with which the lining can be placed, but solely on the speed at which the shield or heading can be driven. In soft material this facility of placing and securing the lining is of the highest importance, because the shield should be driven forward with the greatest possible force and rapidity, the operation being much safer and cheaper under such conditions. These advantages inhere in a properly-designed spiral lining of steel or wrought-iron, because such linings can sustain both tension and compression and are capable of great elastic movement or flexure. They are not possible with cast-iron linings or with ring linings of any material.

The usual width of cast-iron ring segments is eighteen inches. My spiral riveted steel lining-plates can be advantageously used of much greater width, the number of joints being correspondingly reduced. The limiting factor as to width is the most advantageous width and height of air-lock doors through which the plates must frequently be passed.

Very wide plates may have a spiral stiffening-rib 8^1 or a plurality of such ribs intermediate between the spiral flanges 2 2. Such intermediate ribs are shown in Figs. 5 to 8 and 14 to 16, inclusive. In order that such plates may be flexible until they are in final position, the flange-angles 8^j 8^j only of the intermediate ribs are shop-riveted, and the other members of said ribs—that is to say, the web members 8^b and inner angles 8^c and cover-plates, if such there be—are riveted on after the plates are in place. After the spiral joints are riveted the spiral and longitudinal joints are calked, the term "calked" meaning made tight, preferably by upsetting the metal in the joined members. Inspection of the drawings shows that both the spiral and longitudinal joints have the edges of their members perfectly accessible for calking.

In driving tunnels by the shield system it is usual to let the hydraulic jacks of the shield bear against the lining already in place for driving the shield forward by hydraulic power. Thus the lining already in place serves to a greater or less extent as a guide for keeping the shield approximately in true line. Such guiding of the shield is better accomplished by the use of a plurality of spirals in the lining, as shown in Fig. 19, and by machining the extrados of the web-plates 8^b of the stiffening-ribs 8 to a true cylindrical surface and riveting such rib-plates into the flanged spiral joints with their extrados slightly projecting beyond that of the lining-plates 1 1, as shown in Fig. 19, so that the hood of the tunneling-shield may be guided on such machined surfaces. This also facilitates curving a tunnel, as in such cases the ribs may be made eccentric with the lining—that is to say, they may be machined and drilled for the rivets—so that when assembled they will project and hold off the hood of the shield to one side of the lining already in place, and thereby tend to steer the shield in the desired direction.

In cases where it is desired to build foundations under a tunnel or do work beneath it a manhole-section 10, containing a manhole-opening 10^a, as shown in Figs. 1 to 4, inclusive, or a number of such sections may be interpolated and riveted into the spiral lining. Such a manhole-section is made of standard lining-plate width and pitch and has inwardly-projecting flanges 2 2 for making the spiral joints, longitudinal flanges 3^a for making standard butt-joints or flanged longitudinal joints, as may be used in the rest of the tunnel-lining, and inwardly-projecting parallel flanges 10^m about the manhole-opening 10^a for riveting in a manhole-casing 11, made to fit the opening 10^a and having a laterally-projecting flange 11^a, to which a manhole-cover 12 or an air-lock can be riveted and calked. All the joints of the manhole-section, manhole, and manhole-cover can be power-riveted and calked, their design being similar to that of similarly-joined parts of the lining.

Where a tunnel is supported at intervals on foundations or piles or where a tunnel runs out of firm ground into silt, a tunnel-lining acts as a beam and is subject to beam strains, and an unsupported tunnel through silt or other yielding material and used for railroad or vehicle service acts as a beam in distributing the rolling load over a considerable length of the yielding material. In double-track tunnels a train passing on one track causes a torsion on the lining in addition to the beam strains above referred to. The spiral flanged joints and the longitudinal butt-joints of my tunnel-lining are preferably adapted to resist shearing and compressive stresses and the spiral joints will resist a definite amount of tensile stress; but in cases where the beam strains are very heavy and it is desired to develop approximately the full strength of the lining-plates to resist them it is desirable to reinforce those spiral joints which are liable to severe tension. Such places are the tops of the spiral joints above supports and their bottoms midway between supports. This reinforcing may be done inside the lining by longitudinal members—as, for example, by sufficiently splicing the longitudinal ribs 7 7 with splice-plates 7^a 7^a, as shown in Fig. 19. It may also be done by the method shown in Figs. 5 to 8, inclusive, in which 13 13 are tension splice-plates shop-riveted to the back of a lining-plate 1 1 near and projecting beyond its forward edge, so that said splice-plate 13 will extend over the next forward lining-plate 1 sufficiently to be bolted and pinned thereto with bolts 14, which hold the plates together, and tapered pins 15, the holes for which are reamed while the plates are in final position and held together by the bolts 14, the pins being driven hard. This joint will carry tension as well as it would if riveted. To make it water and air tight, a dam 16 is riveted and calked about the inner ends of the pins and bolts 14 and 15, consisting in a box 17 made of angles and shop-riveted to the plate 1 and inclosing the bolts and pins, and a cover 18 of channel section riveted into the box, the inner space being filled with concrete or lead, so that the pins cannot back out. In lieu of making the box of angles it may be made of channel section 17^a, with the back of the web inside the box and the flanges projecting outwardly, one flange being shop-riveted to the plate 1 and a cover-plate 18^a being riveted to the other flange, as shown in Fig. 20. Either of these details admits of power-riveting all the joints and perfect calking and will be safely and permanently water and air tight.

My spiral riveted tunnel-linings may be classified relatively to their modes of carrying the loads into direct-acting and indirect-acting. The direct-acting linings (shown in Figs. 5 to 8 and 14 to 16, inclusive) have heavy cylindrical rolled sheared plates, which form elements in the arch structure and sustain circumferential compression. The buckled plate-linings, on the contrary, act indirectly, the arch functions being practically localized in the spiral ribs 8, the buckled plates acting as covers and conveying the pressures to the nearest perimetrical spiral and longitudinal ribs 8 and 7.

My tunnel-linings will be subject to widely different conditions and must function differently, according to the conditions existing in the localities where they are built. In tunnels through hard material for passenger service they will sustain but little stress, and their chief function will be to absolutely exclude water and make the tunnel dry; but in tunnels through soft stuff and under water they will not only exclude water and earth, but also sustain great collapsing and other stresses. Where the ground-water is fresh and pure, it has little corrosive action, and steel linings placed in direct contact with the earth will have a very long life. Where the ground-water has great corrosive action, because of its saltness or acidity, steel linings are supposed to be less durable than where the water is fresh and pure. The drawings show different types of linings adapted to such varying conditions. Figs. 1 to 16, inclusive, show linings in direct contact with the material they exclude and having thick plates 1 1. Where the tunnel is driven through soft stuff and the ground-water is very corrosive, I prefer to use the type of lining shown in Figs. 17 and 18, which exhibit a composite lining consisting in a very light outer spiral riveted calked steel buckled plate-casing 1^c, a concrete filling 9, and a moderately heavy inner spiral riveted calked steel plate-lining 1^1, the stiffening-ribs 8 of both the steel casings or linings being bedded in the concrete 9, thus forming a very light, strong, durable, and air and water tight steel-and-concrete structure. The outer spiral flanged steel buckled plates are just heavy enough to be safe against perforation by ordinary accidents—say one-eighth inch thick. Their inwardly-projecting flanges 2 2 are formed of angles 2^a 2^a riveted to them, and their spiral stiffening-ribs 8 8 have open webs 8^d, the better to facilitate bedding them in the concrete filling. This outer casing 1^c is put in with the shield, and its plates 1 1 are supposed to be temporary, and intended, mainly, to constitute substantially a tubular air and water tight steel coffer-dam, inside of which the permanent lining can be built in the open and subject to rigid inspection and safe for the removal of bad work. After the said outer casing is wholly or partly in place and riveted and calked it will be lined with concrete 9, thoroughly rammed, and at the same time the spiral ribs 8 of the inner lining 1^1 will be set and bedded in the concrete, and this operation will be followed by riveting in the inner lining 1^1 to said ribs and calking its joints and by grouting behind said inner lining. It will be observed that the drawings show these inner lining-plates instead of being buckled as corrugated in a single continuous spiral corrugation $1^\times$, a cheap and practical construction where there is no occasion for longitudinal stiffeners.

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

1. The combination of a tunnel-bore with an impervious tunnel-lining formed of a plurality of spiral segmental wrought-metal plates inwardly flanged along their spiral edges substantially as set forth.

2. The combination of a tunnel-bore with an impervious tunnel-lining formed of a plurality of spiral segmental wrought-metal plates inwardly flanged along their spiral edges, joined with riveted and calked joints and forming continuous spirals, substantially as set forth.

3. The combination of a tunnel-bore with flanged spiral wrought-metal buckled plates riveted together to form the lining thereof.

4. The combination of a tunnel-bore with flanged spiral wrought-metal buckled plates riveted together and having their joints calked to form a water and air tight lining thereto.

5. The combination of spiral wrought-metal segmental tunnel-lining plates inwardly flanged at their spiral edges and making butt-riveted longitudinal joints with the adjacent plates of the same spiral, substantially as set forth.

6. The combination of spiral wrought-metal segmental tunnel-lining plates inwardly flanged at the spiral edges and making double-butt-riveted joints with the adjacent plates of the same spiral and rabbets formed in the ends of the plates to receive butt-plates, substantially as set forth.

7. The combination of spiral wrought-metal segmental tunnel-lining plates with inwardly-projecting flanges and stiffening-ribs riveted to the flanges, substantially as set forth.

8. The combination of spiral segmental wrought-metal tunnel-lining plates with inwardly-projecting flanges and longitudinal stiffening members riveted to the lining-plates, substantially as set forth.

9. The combination of spiral segmental flanged buckled wrought-metal tunnel-lining plates with inwardly-projecting flanges, longitudinal cylindrical surfaces between the buckles and longitudinal stiffening members riveted thereto, substantially as set forth.

10. The combination of spiral segmental wrought-metal tunnel-lining plates with in-

wardly-projecting flanges and inwardly-projecting stiffening-ribs riveted to the plates between said flanges, substantially as set forth.

11. The combination of spiral segmental wrought-metal tunnel-lining plates and a manhole-plate having a manhole-opening and forming part of a spiral, substantially as set forth.

12. The combination of a tunnel-lining formed of spiral segmental flanged wrought-metal plates with inwardly-projecting flanges and a manhole-section similarly flanged and adapted to form part of a spiral in said lining, substantially as set forth.

13. The combination of spiral segmental wrought-metal tunnel-lining plates with inwardly-projecting flanges, a similarly-flanged spiral segmental manhole-section having an inwardly-flanged manhole-opening, a manhole-casing riveted therein and a laterally-projecting flange formed on the manhole-casing, substantially as set forth.

14. In a tunnel-lining the combination of spiral segmental flanged lining-plates and tension splice members connecting the plates of adjacent spirals, substantially as set forth.

15. In a tunnel-lining the combination of metal lining-plates, longitudinal stiffening members and tension-splices splicing said longitudinal members, substantially as set forth.

16. The combination of spiral segmental flanged tunnel-lining plates, longitudinal stiffening members and tension splice-plates splicing said longitudinal members, substantially as set forth.

17. In a tunnel-lining the combination of flanged segmental metal lining-plates, a splice-plate secured on the back of a lining-plate and projecting beyond its forward edge and members uniting said splice-plate with the adjacent lining-plate, substantially as set forth.

18. In a tunnel-lining the combination of a flanged segmental lining-plate, a splice-plate secured on the back of said plate near and projecting beyond its forward edge, members uniting said splice-plate with the adjacent lining-plate and a tight dam inclosing the inner ends of said members, substantially as set forth.

19. In a tunnel-lining the combination of flanged segmental metal lining-plates, a splice-plate secured on the back of a lining-plate near and projecting beyond its forward edge, members uniting said splice-plate and the adjacent lining-plate a tight dam inclosing the inner ends of said members and material filling the interior of said dam, substantially as set forth.

20. The combination of spiral segmental wrought-metal tunnel-lining plates with inwardly-projecting flanges and riveted joints, a tension splice-plate shop-riveted to the outside of a lining-plate near and projecting beyond its forward spiral edge and members uniting said splice-plate and the adjacent spiral of the lining, substantially as set forth.

21. The combination of spiral segmental wrought-metal tunnel-lining plates with inwardly-projecting flanges and riveted joints, a tension splice-plate shop-riveted to the outside of a lining-plate near and projecting beyond its forward spiral edge, bolts holding together said splice-plate and the adjacent spiral of the lining and pins fitting closely in holes in said splice and lining plates, substantially as set forth.

22. The combination of spiral segmental wrought-metal tunnel-lining plates with inwardly-projecting flanges and riveted joints, a tension splice-plate shop-riveted to the outside of a lining-plate near and projecting beyond its forward spiral edge, bolts holding together the said splice-plate and the adjacent spiral of the lining-plate, tapered pin-holes reamed in position in said plates and tapered pins driven into said holes substantially as set forth.

23. In a tunnel-lining the combination of members passing through said lining and a riveted and calked closed box inclosing the inner ends of said members, substantially as set forth.

24. In a tunnel-lining the combination of members passing through said lining, a wrought-metal box inclosing the inner ends of said members and riveted and calked to the lining and a cover riveted and calked to said box, substantially as set forth.

25. In a tunnel-lining the combination of members passing through said lining, a wrought-metal box inclosing the inner ends of said members and riveted and calked to said lining, a wrought-metal cover riveted and calked to said box and material filling the interior of said box, substantially as set forth.

26. In a spiral wrought-metal tunnel-lining, the method of riveting longitudinal butt-joints consisting in holding back the riveting of the spiral joint so as to leave the forward part and end of the spiral free, springing said free end inwardly, introducing the arm of a riveter behind it, assembling with it a butt plate or plates and the end of another segment of lining, riveting up the longitudinal joint, removing the riveter, placing the said plate in final position and advancing the riveting of the spiral joint, substantially as set forth.

27. In a spiral wrought-metal tunnel-lining the method of assembling the lining consisting in holding back the riveting of the spiral joint so as to leave the forward segment or segments and the end of the spiral free, forcibly springing the said free end inwardly and backwardly into the lined portion of the tunnel and reversing the direction of the spiral thereof, assembling with it the end of another segment of lining, riveting up the longitudinal joint, forcibly holding inwardly and back-

wardly the forward end of the segment just added and reversing its spiral direction, similarly assembling another segment of lining therewith and so on, holding the segments thus assembled in the lined portion of the tunnel with the direction of their spiraling forcibly reversed until the heading of the tunnel is sufficiently advanced to permit them to be placed in final position and thereupon springing them into and fastening them in final position, substantially as set forth.

28. The combination of a tunnel-bore with a spiral segmental lining formed in a plurality of spirals, substantially as set forth.

29. The combination of a tunnel-lining formed of segmental metal lining-plates with flanged joints and plates in said joints having true outer surfaces and projecting beyond the general outer surface of the lining, substantially as set forth.

30. The combination of a tunnel-lining formed of segmental metallic lining-plates with flanged joints and plates in said joints having true outer surfaces and projecting beyond the general outer surface of the lining and set eccentric therewith, substantially as set forth.

31. In a tunnel-lining the combination of an external spiral riveted calked wrought-metal plate-casing with inwardly-projecting flanges and ribs and a concrete filling in which said ribs are bedded, substantially as set forth.

32. In a tunnel-lining the combination of an external spiral riveted calked wrought-metal buckled plate-casing with inwardly-projecting flanges and ribs and a concrete filling in which said ribs are bedded, substantially as set forth.

33. In a tunnel-lining the combination of an external spiral riveted calked wrought-metal plate-casing with inwardly-projecting flanges and ribs, an inner spiral riveted calked wrought-metal plate-lining with outwardly-projecting ribs and concrete filling the space between the two linings and having their projecting ribs bedded in said concrete, substantially as set forth.

34. In a tunnel-lining the combination of an external spiral riveted calked wrought-metal buckled plate-casing with inwardly-projecting ribs and flanges, an inner spiral riveted calked wrought-metal lining with outwardly-projecting ribs and concrete filling the space between the two linings and having their projecting ribs bedded in said concrete, substantially as set forth.

35. A new article of manufacture, a spiral, segmental, inwardly-flanged wrought-metal tunnel-lining plate adapted to be assembled with a plurality of similar plates and riveted and calked therewith to form an impervious spiral tunnel-lining, substantially as set forth.

36. A new article of manufacture, a spiral, segmental wrought-metal tunnel-lining plate inwardly flanged along its spiral edges and having its ends adapted to make butt-joints with the adjacent plates of the same spiral, substantially as set forth.

37. A new article of manufacture, a spiral segmental wrought-metal tunnel-lining plate inwardly flanged along its spiral edges and having end recesses adapted to receive butt-plates for joining it with the adjacent plates of the same spiral, substantially as set forth.

38. A new article of manufacture, a spiral cylindrical segmental flanged buckled wrought-metal plate.

39. A new article of manufacture, a spiral cylindrical segmental wrought-metal manhole-plate having flanges at its edges and a manhole-opening flanged with parallel flanges.

CHAUNCEY N. DUTTON.

Witnesses:

JACOB LORSCH,

MRS. M. WALSH.