Jan. 17, 1939. F. DONALDSON 2,144,013

METHOD OF AND APPARATUS FOR CONSTRUCTING CONCRETE TUNNELS

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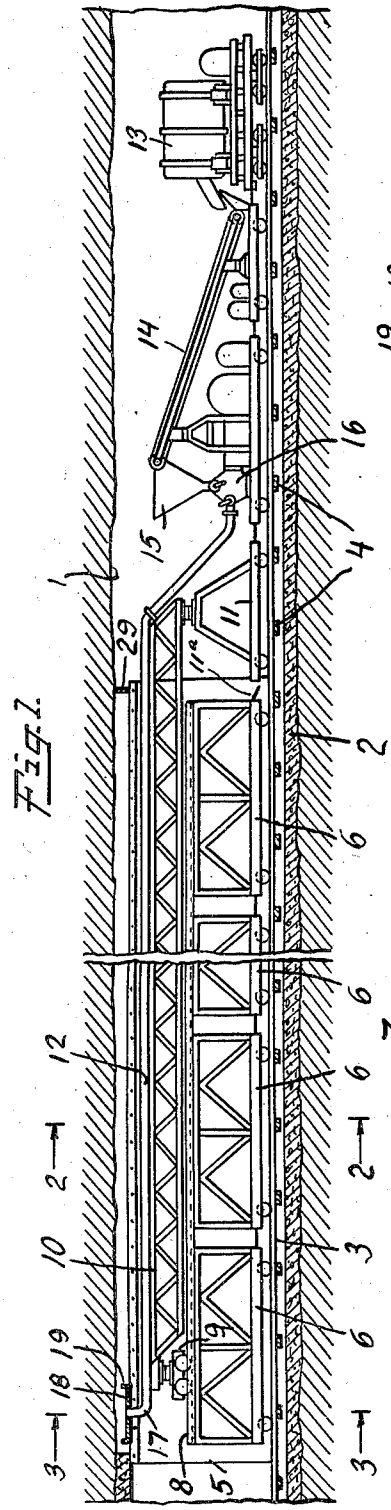

Fig. 1.

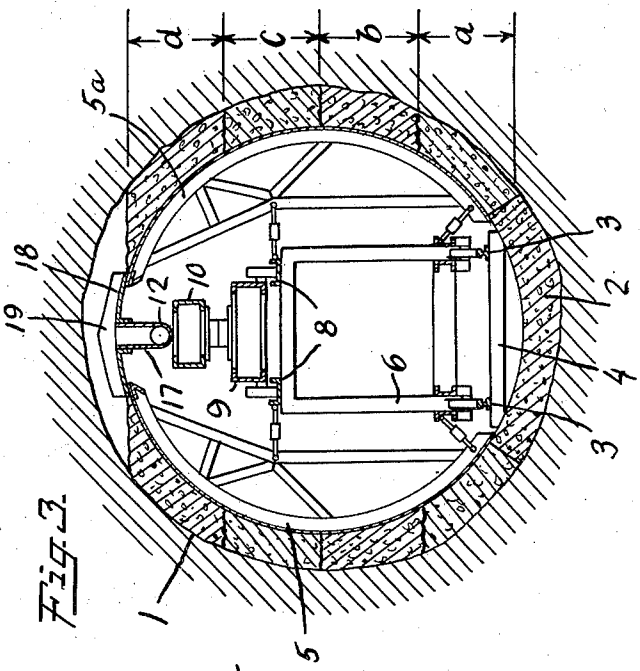

Fig. 3.

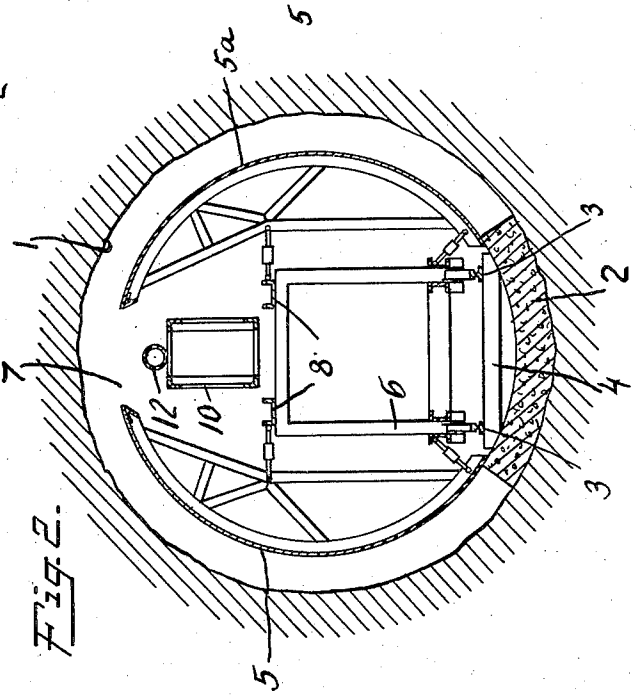

Fig. 2.

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Fig. 4.

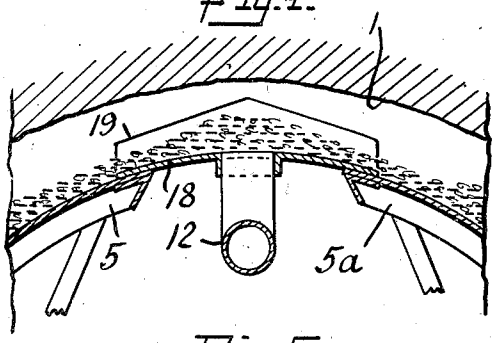



Fig. 6.

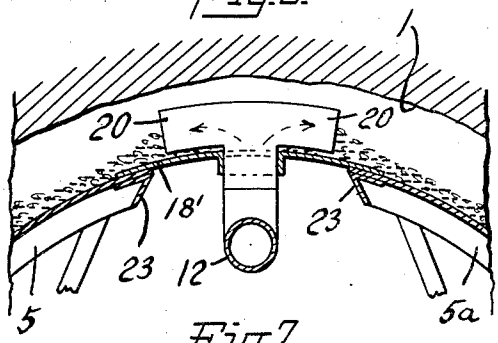



Fig. 5.

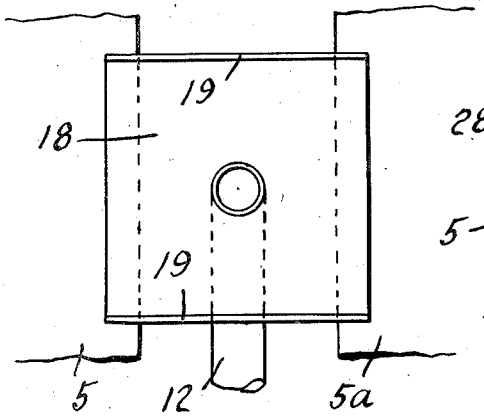



Fig. 7.

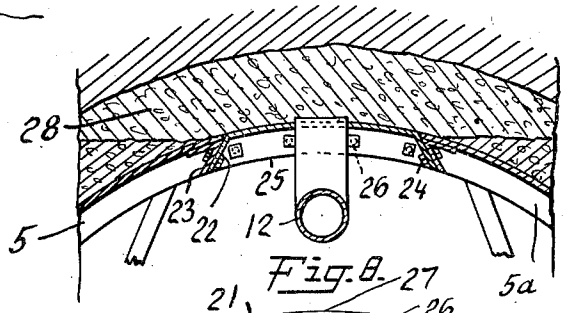



Fig. 8.

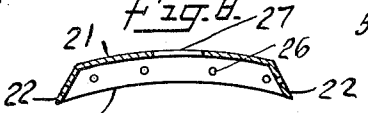



Fig. 9.

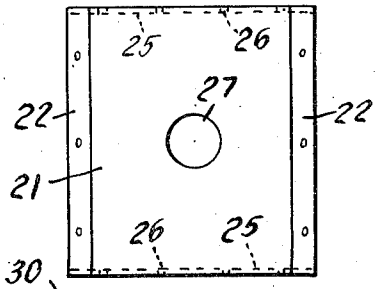



Fig. 10.

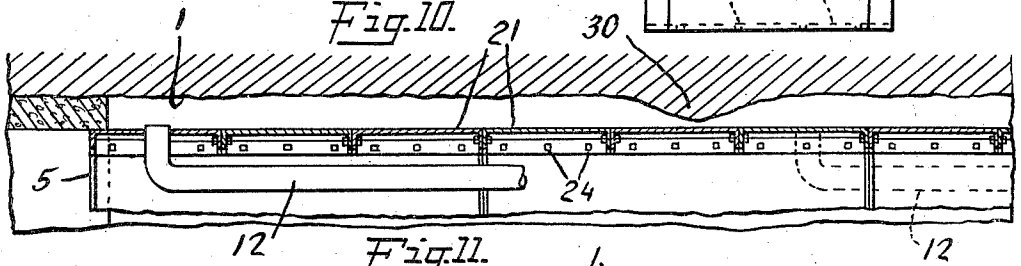
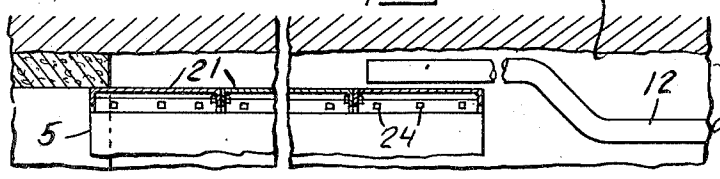



Fig. 11.

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## METHOD OF AND APPARATUS FOR CONSTRUCTING CONCRETE TUNNELS

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Application February 27, 1937, Serial No. 128,127

11 Claims. (Cl. 25—131.6)

This invention relates to the art of constructing tunnels and more particularly to the art of lining them with concrete.

The principal object of the invention is to so improve the method of, and apparatus for forming a concrete tunnel lining that the operations are simplified and facilitated, the work is expedited, economies are effected in the cost of constructing the tunnel, and a concrete lining of superior quality is obtained.

The improved method, and a preferred form of apparatus for carrying out the method, are illustrated somewhat diagrammatically in the accompanying drawings, in which:

Figure 1 is a longitudinal section through a portion of a tunnel showing the apparatus positioned therein for forming the concrete lining of the tunnel;

Fig. 2 is a transverse section taken on the line 2—2 of Fig. 1;

Fig. 3 is a transverse section taken on the line 3—3 of Fig. 1;

Fig. 4 is a transverse section through the discharge end of the concrete delivery pipe;

Fig. 5 is a plan view of Fig 4;

Fig. 6 is a transverse section corresponding with Fig. 4 but showing a modified construction of the discharge end of the concrete delivery pipe;

Fig. 7 is a transverse section illustrating the manner in which the key section of the lining is formed;

Fig. 8 is a transverse section of one of the segmental key forms employed when the crown or key portion of the lining is formed;

Fig. 9 is a plan view of the key form shown in Fig. 8;

Fig. 10 is a longitudinal section further illustrating the manner in which the key section of the lining is formed, and

Fig. 11 is a longitudinal section illustrating a modified procedure for forming the key section of the lining.

In general, the apparatus comprises means for supporting within the tunnel to be lined, a series of form sections the outer faces of which are spaced from the walls of the tunnel to define the annular space to be filled with the concrete. At the crown of their arch the form sections are not transversely continuous but they are so constructed as to leave a longitudinal open slot between them. The concrete delivery pipe is movably supported interiorly of the form sections and below the longitudinal slot, its discharge end being directed upwardly through the slot and arranged to distribute the concrete laterally into the spaces behind the forms. The delivery pipe, and also the concrete plant, if so desired, can thus be moved unimpeded back and forth through the tunnel at will, thereby making it possible to build up the concrete behind the forms in strata or layers as the delivery pipe is reciprocated in the tunnel. After the side walls of the tunnel have been built up in this fashion to the level of the longitudinal slot at the top of the forms, segmental key forms are positioned from within the tunnel to close the slot. Concrete is then forced into the space above the segmental key forms and distributed longitudinally of the tunnel to form the crown section of the lining. This may be accomplised in several different ways as will later appear. After the concrete forming the walls and crown section of the lining has set, the segmental key plates are removed and the forms are then collapsed and moved to an adjacent section of the tunnel to be lined, where the operations are repeated.

Referring to the drawings, the tunnel to be lined is indicated at 1. Preferably the first step is to line the floor section of the tunnel to form the invert 2. A track 3, whose rails may be supported on cross ties 4, is then laid on the invert. In some cases, it may be possible to position the track directly on the floor of the tunnel, or support it in some other suitable way and to form the invert 2 while the side walls of the tunnel lining are being formed, or as a final step after the side walls are formed and after the trackage has been removed.

Collapsible form sections 5 and 5a, spaced from the walls of the tunnel 2 and defining the annular space to be filled with concrete, are mounted on coupled trucks 6 adapted to be propelled along the tracks 3. The form sections 5 and 5a are not transversely continuous at the crown of their arch nor are they spanned by any connecting ribs or other elements. On the contrary, they are spaced apart to form a longitudinal unobstructed slot or opening indicated at 7 which extends throughout the entire length of the form sections.

A track 8 is mounted on the trucks 6. On this track there runs an auxiliary truck 9. The truck 9 supports one end of a truss 10, the other end of which is supported by a truck 11 operating on the main track 3. The truss 10 supports the concrete delivery pipe 12. Concrete may be prepared in a mixer 13 and discharged onto a conveyor 14 which feeds it to a hopper 15. The hopper delivers the concrete to a pump 16 which forces it through the delivery pipe to its discharge end.

The mixer, conveyor and pump, together with the motor means for operating them are all mounted on one or more trucks running on the main track 3 as shown in Fig. 1. These trucks are preferably coupled to the truck 11 which supports the end of the truss 12. It will thus be seen that while the trucks 6, and the forms carried by them, are permitted to remain stationary, the concrete plant and the truck 11 may be propelled back and forth longitudinally along the track 3.

The discharge end of the delivery pipe 12 is turned upwardly as shown at 17 and projects into the longitudinal slot 7 between the form sections 5 and 5a. The upper end of the discharge pipe may be connected to a flat plate 18 (Figs. 4 and 5) which slidably rests upon and overlaps the edges of the form sections 5 and 5a. The plate 18 may have side flanges 19 which direct the concrete issuing from the discharge pipe laterally into the spaces behind the forms. If desired, the plate 18 may be made of flexible material such as fairly stiff rubber. The means just described for distributing the concrete as it issues from the delivery pipe is preferably used when the concrete is delivered by means of a pump. If desired, the concrete may be conveyed and delivered by means of a blower, and when a blower is used the distributing means at the end of the delivery pipe 12 is preferably constructed as shown in Fig. 6. In this case the discharge end of the delivery pipe projects through a plate 18' slidably supported by the upper edge of the form sections and above this plate the delivery pipe has lateral branches 20 which direct the concrete laterally into the spaces behind the forms.

It will now be seen that the longitudinal unobstructed gap or slot 7 at the top of the forms makes it possible to position the concrete delivery pipe 12 below this gap where it can be mounted on the travelling truss 10, and to turn the discharge end of the delivery pipe upwardly so that it projects through the slot. The pipe can, therefore, be reciprocated back and forth at will as there is nothing to obstruct the movement of the upturned end of the delivery pipe, and the mounting of the pipe on the travelling truss 10, makes it easy to reciprocate the pipe by propelling the truck 11, and the concrete plant if so desired, back and forth on the track 3. This facilitates pouring the concrete behind the forms 5 and 5a in layers or strata, as indicated in Fig. 3. In other words, when the parts are in position shown in Fig. 1 the truss 10 can be moved continuously to the right (as viewed in this figure) as the concrete is being deposited and this will result in forming a layer of concrete throughout the length of the forms up to the desired depth, as indicated at *a* in Fig. 3. During the return movement of the truss 10 another layer *b* of concrete can be deposited in a similar manner, or the truss 10 can be returned to the starting position shown in Fig. 1 and the layer *b* deposited during the next movement of the truss 10 to the right as viewed in Fig. 1. Additional layers of concrete *c* and *d* may likewise be deposited during reciprocation of the truss 10 until the concrete surrounding the forms 5 and 5a has reached the slot at the top of the forms as shown in Fig. 3. Pouring the concrete in this manner results in a lining having superior qualities, such as greater strength, than if the discharge pipe were allowed to remain in one position until the concrete reached the top of the forms and then the pipe were moved to deposit a similar section of concrete. When the concrete is deposited in that fashion, for every position of the discharge pipe, the concrete near the floor of the tunnel spreads in the direction of the tunnel and converges towards the outlet of the discharge pipe. This results in diagonal seams between the successively formed masses of concrete.

After the concrete walls have been built up to the level indicated in Fig. 3, the slot 7 at the top of the forms is closed by inserting therein a series of sectional segmental key plates or forms 21 shown in Figs. 7, 8 and 9. These plates may have longitudinal flanges 22 adapted to be bolted to flanges 23 at the edges of the forms as indicated at 24. They may also have a transverse flange 25 at each end adapted to be bolted to the corresponding flange of the adjacent plate through bolt holes 26. The key plates may be positioned and bolted in place from within the tunnel. Certain of the key plates 21 may have an opening 27 to receive the end of the concrete discharge pipe. After the key plates 21 have been positioned as shown in Fig. 10 the discharge end of the concrete delivery pipe is inserted through the opening 27 in the innermost key plate of the series as also shown in this figure. Concrete is then pumped through the discharge pipe 12 and flows longitudinally of the tunnel until it fills up the space above the key plates and forms the crown portion of the lining as indicated at 28 in Fig. 7. A bulkhead indicated at 29 in Fig. 1 is positioned preferably at the near end of the series of forms so as to retain the concrete forced into the space above the key plates. The bulkhead 29 may, however, be positioned at any other suitable point along the length of the forms and after the space above the key plates has been filled with concrete up to the bulkhead the delivery pipe 12 may then be advanced beyond the bulkhead and inserted through the opening 27 of a perforated key plate positioned at this point. Likewise, should the concrete forced into the space above the key plates meet an obstruction in the ceiling of the tunnel indicated at 30, the delivery pipe may be moved to the dotted line position shown in Fig. 10, just beyond the obstruction and its end inserted in the opening 27 of a perforated key plate located at this point.

The system of filling the space above the key plates illustrated in Fig. 10 is preferably used when the concrete is forced in place by a pump. When a blower is used the concrete may be forced into the space above the key plates in the manner shown in Fig. 11. In this case the delivery end of the discharge pipe 12 projects into the space above the key plates and is directed toward the rear of the tunnel. As the concrete is blown into the space above the key plates the pipe 12 is gradually withdrawn and the concrete builds up and fills the space to the rear of the discharge pipe while it is being withdrawn.

After the concrete forming the walls and crown section of the lining has set, the key plates 21 are removed and the form sections 5 and 5a are collapsed. The truck 11 is then coupled with the form supporting trucks 6 by the coupler 11a and the entire aparatus is propelled along the track 3 until the forms are in proper position for forming the next adjacent section of the tunnel lining. The truck 11 is then uncoupled from the trucks 6 to permit reciprocation of the truss 10 and the delivery pipe while the trucks 6 and the forms remain stationary. The operations described above are then repeated.

Heretofore it has been necessary to support the delivery pipe in the space above transverse ribs

which connect the upper portions of the forms. Sometimes the pipe is stationary and is made in sections so that it can be lengthened or shortened as the lining is formed. This requires enough space above the form ribs to facilitate bolting additional sections on the delivery pipe, or removing sections from it, but as this space is necessarily limited any operations that must be performed within it are materially impeded. Sometimes the delivery pipe located above the form ribs is movable longitudinally but the space above the ribs does not permit of properly supporting the pipe to make it freely and readily reciprocable and moreover as the pipe is withdrawn it tends to sag. Hence the length of the series of form sections employed for completing one section of the tunnel lining is limited by the practicable span of the delivery pipe.

My method and apparatus make it possible to utilize the main space within the tunnel between the forms to support the delivery pipe, where there is enough room to support it properly, as by the truss **10**, so that it will not sag and so that it is capable of free reciprocating movement. As there are no ribs or other elements spanning the upper portions of the forms, but on the contrary a longitudinal slot located at this position, the discharge end of the delivery pipe may be directed upwardly through the slot where it can deliver the concrete laterally behind the forms, and there will be no obstructions to impeded free movement of the end of the pipe in the slot. The free and easy reciprocation of the delivery pipe facilitates and expedites the work and effects economies in the cost of constructing the tunnel. By the use of my method and apparatus a longer series of forms can be employed, i. e., each section of the tunnel lining can be made longer than heretofore, and moreover the lining can be built up in longitudinal layers each of which may be of any desired depth depending upon the rate at which the concrete is delivered and the rate at which the delivery pipe is moved longitudinally of the tunnel while the concrete is being deposited.

While I have described the concrete delivery pipe as being supported below the slot at the crown of the forms, with its discharge end projecting upwardly through the slot, it is obvious that the pipe or some portion of it might lie within the slot because the slot necessarily has some depth. Such an arrangement is contemplated by the expression used in the specification and claims to the effect that the delivery pipe is supported below the slot. The important consideration is that the delivery pipe is so supported as not to be principally positioned in the crown or key space located wholly above the slot in my arrangement and located above the transverse ribs or other connecting elements at the crown of the forms in the prior arrangements.

I claim:

1. Apparatus for lining a tunnel with concrete or the like comprising a series of forms arranged in end-to-end relationship, lengthwise of the tunnel, and each comprising two sections, with one section arranged at each side of the tunnel and the sections being spaced at the arch of the tunnel, means for supporting the sections of the several forms in spaced relation to the walls of the tunnel and with the space at the arch of the tunnel between the several forms in alignment to provide a slot extending substantially the length of said forms, a delivery pipe supported below said slot and having a discharge end projecting upwardly therethrough, means for delivering concrete through said pipe, distributing means at the discharge end of the pipe overlying at least one of the sides of said slot for directing the concrete laterally to the space behind the forms, and means for supporting the delivery pipe for longitudinal movement whereby it may be moved back and forth in said slot throughout substantially the length of the series of forms.

2. Apparatus for lining a tunnel with concrete or the like comprising a series of forms arranged in end-to-end relationship, lengthwise of the tunnel, and each comprising two sections, with one section arranged at each side of the tunnel, and the two sections being spaced at the arch of the tunnel, means for supporting the sections of the several forms in spaced relation to the walls of the tunnel, and with the space at the arch of the tunnel between the several forms in alignment to provide a slot extending substantially the length of said forms, a delivery pipe supported below said slot and having a discharge end projecting upwardly therethrough, means for delivering concrete through said pipe, distributing means at the discharge end of the pipe overlying at least one of the sides of said slot for directing the concrete laterally to the space behind the forms, means for supporting the delivery pipe for longitudinal movement, whereby it may be moved back and forth in said slot throughout substantially the length of the series of forms, means for supporting the concrete delivery means for movement longitudinally of the tunnel, and connections whereby the delivery pipe and the concrete delivering means may move as a unit.

3. Apparatus for lining a tunnel with concrete or the like comprising a series of forms arranged in end-to-end relationship, lengthwise of the tunnel, and each comprising two sections, with one section arranged at each side of the tunnel and the sections being spaced at the arch of the tunnel, means for supporting the sections of the several forms in spaced relation to the walls of the tunnel and with the space at the arch of the tunnel between the several forms in alignment to provide a slot extending substantially the length of said forms, a delivery pipe supported below said slot and having a discharge end projecting upwardly therethrough, means for delivering concrete through said pipe, distributing means at the discharge end of the pipe overlying at least one of the sides of said slot for directing the concrete laterally to the space behind the forms, means for supporting the delivery pipe for longitudinal movement whereby it may be moved back and forth in said slot throughout substantially the length of the series of forms, and a plurality of segmental key forms adapted to be positioned in said slot from within the tunnel when the discharge end of the delivery pipe has been removed from said slot, and when so positioned to close said slot.

4. Apparatus in accordance with claim 3 in which certain of the segmental key forms have an opening to receive the discharge end of the concrete delivery pipe.

5. Apparatus for lining a tunnel with concrete or the like, comprising a main track positioned in the tunnel, a series of trucks for operating on said track, a series of forms mounted on said trucks and held in spaced relation to the walls of the tunnel, said forms being arranged in end-to-end relationship lengthwise of the tunnel, and each comprising two sections, with one section positioned at each side of the tunnel, and the two sections of each form being spaced at the arch

of the tunnel, with said spaces being in alignment to provide a slot extending substantially the length of said forms, an auxiliary track supported by said trucks, an auxiliary truck for operating on the auxiliary track, a truss having one end thereof supported by said auxiliary track, another truck operating on said main track and supporting the other end of said truss, a concrete delivery pipe supported by said truss below said slot and having a discharge end projecting upwardly through said slot, means for delivering concrete through said pipe, and distributing means at the discharge end of the pipe overlying at least one of the sides of said slot for directing the concrete laterally to the space behind the forms.

6. Apparatus for lining a tunnel with concrete or the like, comprising a main track positioned in the tunnel, a series of trucks for operating on said track, a series of forms mounted on said trucks and held in spaced relation to the walls of the tunnel, said forms being arranged in end-to-end relationship lengthwise of the tunnel, and each comprising two sections, with one section positioned at each side of the tunnel, and the two sections of each form being spaced at the arch of the tunnel, with said spaces being in alignment to provide a slot extending substantially the length of said forms, an auxiliary track supported by said trucks, an auxiliary truck for operating on the auxiliary track, a truss having one end thereof supported by said auxiliary track, one of the trucks operating on said main track supporting the other end of said truss, a concrete delivery pipe supported by said truss below said slot and having a discharge end projecting upwardly through said slot, means for delivering concrete through said pipe, and distributing means at the discharge end of the pipe overlying at least one of the sides of said slot for directing the concrete laterally to the space behind the forms, a concrete plant mounted on another of the trucks for operating on the main track and coupled with the truck on the main track which supports one end of said truss, whereby the concrete plant and said truss, and the delivery pipe supported by it, may be moved back and forth as a unit, while the trucks supporting the forms remain stationary, and means for coupling the truck on the track which supports one end of said truss with the trucks that support the forms, so that the entire apparatus including the forms may be moved longitudinally of the tunnel.

7. Apparatus for lining a tunnel with concrete or the like comprising a series of forms arranged in end-to-end relationship, lengthwise of the tunnel, and each comprising two sections, with one section arranged at each side of the tunnel and the sections being spaced at the arch of the tunnel, means for supporting the sections of the several forms in spaced relation to the walls of the tunnel and with the space at the arch of the tunnel between the several forms in alignment to provide a slot extending substantially the length of said forms, a delivery pipe supported below said slot and having a discharge end projecting upwardly therethrough, means for delivering concrete through said pipe, distributing means at the discharge end of the pipe overlying and resting upon the opposite edges of the form sections which define the slot which extends lengthwise of said forms for directing concrete laterally to the space behind the forms, and means for supporting the delivery pipe for longitudinal movement whereby it may be moved back and forth in said slot throughout substantially the length of the series of forms.

8. The method of lining a tunnel with concrete or the like, which comprises positioning a series of forms, each of which comprises two sections, with one section arranged at each side of the tunnel, and the sections being spaced at the arch of the tunnel, in spaced relation to the walls of a tunnel, conducting a stream of concrete through the main space in the tunnel between said forms and then upwardly through a slot in the crown of the forms and there distributing it laterally behind the forms, and moving the stream of concrete being distributed behind the forms along the space between said form sections and longitudinally of the tunnel.

9. The method of lining a tunnel with concrete or the like, which comprises positioning a series of forms, each of which comprises two sections, with one section arranged at each side of the tunnel, and the sections being spaced at the arch of the tunnel, in spaced relation to the walls of a tunnel, conducting a stream of concrete through the main space in the tunnel between said forms and then upwardly through a slot in the crown of the forms and there distributing it laterally behind the forms, and reciprocating the stream of concrete being distributed behind the forms along the space between said form sections and longitudinally of the tunnel, to build up the side walls of the lining.

10. The method of lining a tunnel with concrete or the like, which comprises positioning a series of forms, each of which comprises two sections, with one section arranged at each side of the tunnel, and the sections being spaced at the arch of the tunnel, in spaced relation to the walls of a tunnel, conducting a stream of concrete through the main space in the tunnel between said forms and then upwardly through a slot in the crown of the forms and there distributing it laterally behind the forms, moving the stream of concrete being distributed behind the forms along the space between said form sections and longitudinally of the tunnel, to build up the side walls of the lining substantially to the level of said slot, thereafter closing said slot and then depositing concrete in the space above the closed slot to form the crown portion of the lining.

11. The method of lining a tunnel with concrete or the like, which comprises positioning a series of forms, each of which comprises two sections, with one section arranged at each side of the tunnel, and the sections being spaced at the arch of the tunnel, in spaced relation to the walls of a tunnel, conducting a stream of concrete through the main space in the tunnel between said forms and then upwardly through a slot in the crown of the forms and there distributing it laterally behind the forms, moving the stream of concrete being distributed behind the forms along the space between said form sections and longitudinally of the tunnel, to build up the side walls of the lining substantially to the level of said slot, thereafter closing said slot from within the tunnel and then forcing concrete in a direction longitudinally of the tunnel into the space above the closed slot to form the crown portion of the lining.

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