United States Patent [19]

Bernold

[11] **3,855,801**

[45] **Dec. 24, 1974**

[54] **TUNNEL STRUCTURE**

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[73] Assignee: **Hans Walter Pfeiffer**, a part interest

[22] Filed: **Mar. 15, 1973**

[21] Appl. No.: **341,600**

Related U.S. Application Data

[62] Division of Ser. No. 170,770, Aug. 11, 1971, Pat. No. 3,751,929, which is a division of Ser. No. 798,747, Feb. 12, 1969, Pat. No. 3,601,945.

[52] **U.S. Cl.** ..... **61/45 R**, 61/42

[51] **Int. Cl.** **E01g 5/00**

[58] **Field of Search** ..... 61/84, 85, 45 R, 42; 52/670, 671, 672, 673, 674, 675

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Primary Examiner—Dennis L. Taylor

Attorney, Agent, or Firm—Mandeville & Schweitzer

[57] **ABSTRACT**

Disclosed herein is a new and improved tunnel structure or the like for a tunnel being driven in a predetermined direction through an excavation having a workface. The new tunnel structure includes a lining of concrete installed in sections; a front formwork assembly closing off the lining toward the workface; the formwork comprising end overlapping, self-supporting, panel-shaped structural elements being provided with pockets which are in spaced relation, are alternatively pressed out toward opposing sides, are successively arranged, in the concrete forming the lining, in rectilinear rows extending transversely to the direction of driving and through which pockets the rod-like connecting members are passed; the rod-like members are passed through the pockets in the area of overlap of the structural elements; the concrete for the lining sections initially being introduced and vibrated behind the panel-shaped, self-supporting structural elements serving as a permanent formwork; and in each section of lining of the tunnel structure, the end of the structural elements which are forwardmost in the direction of driving are maintained free of concrete for connection, by means of the rod-like connecting means, with the rear ends of the next-to-be installed structural elements of the next section of the lining to be installed.

5 Claims, 27 Drawing Figures

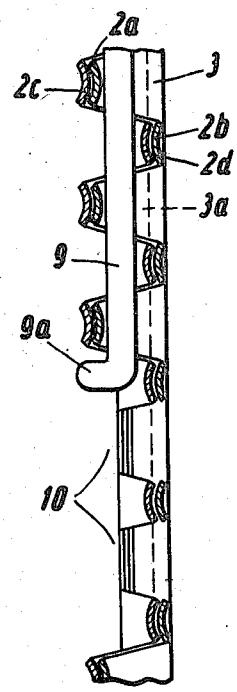


Fig. 1

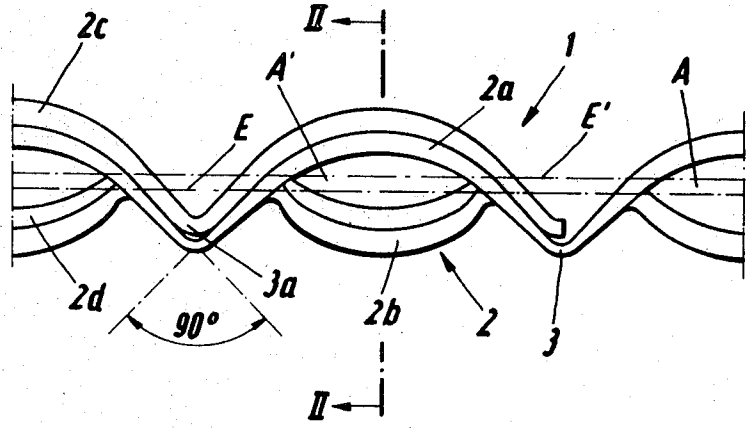


Fig. 2

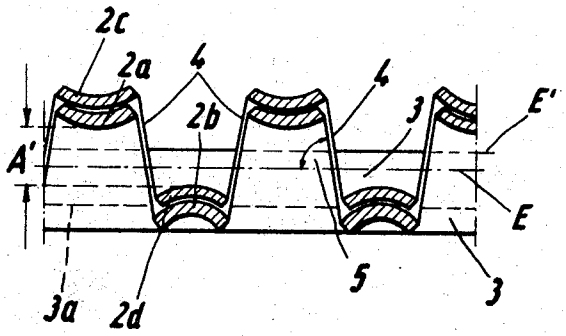


Fig. 3

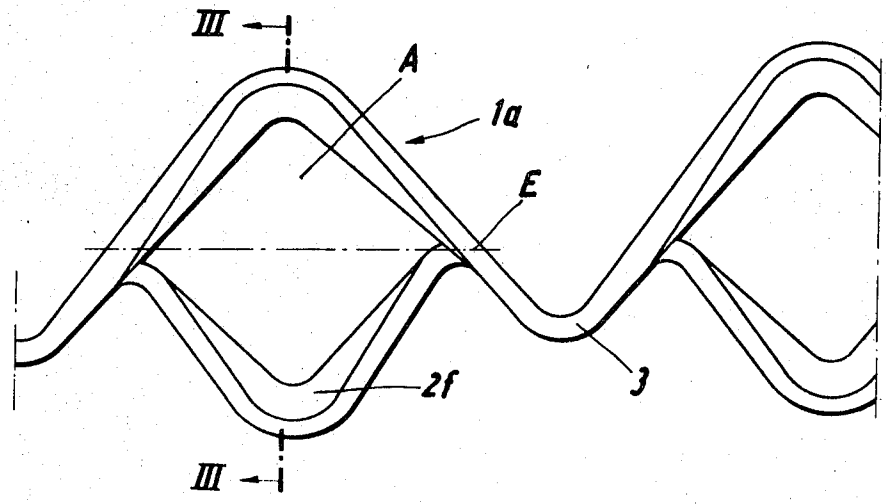
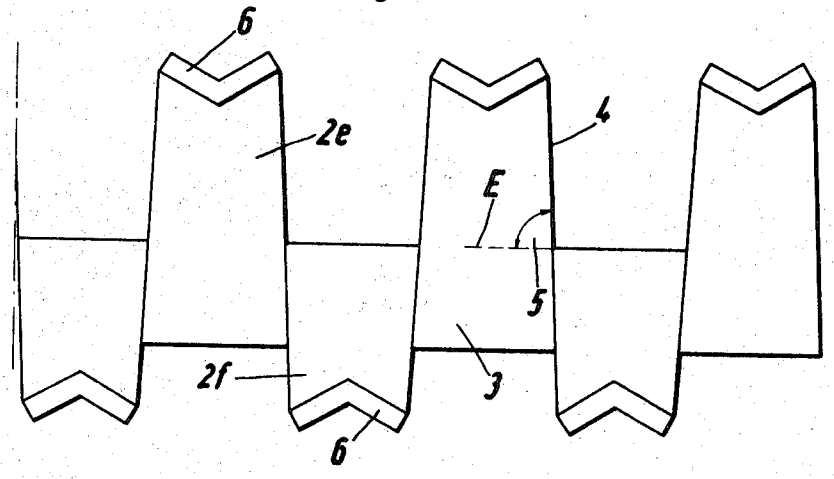


Fig. 4



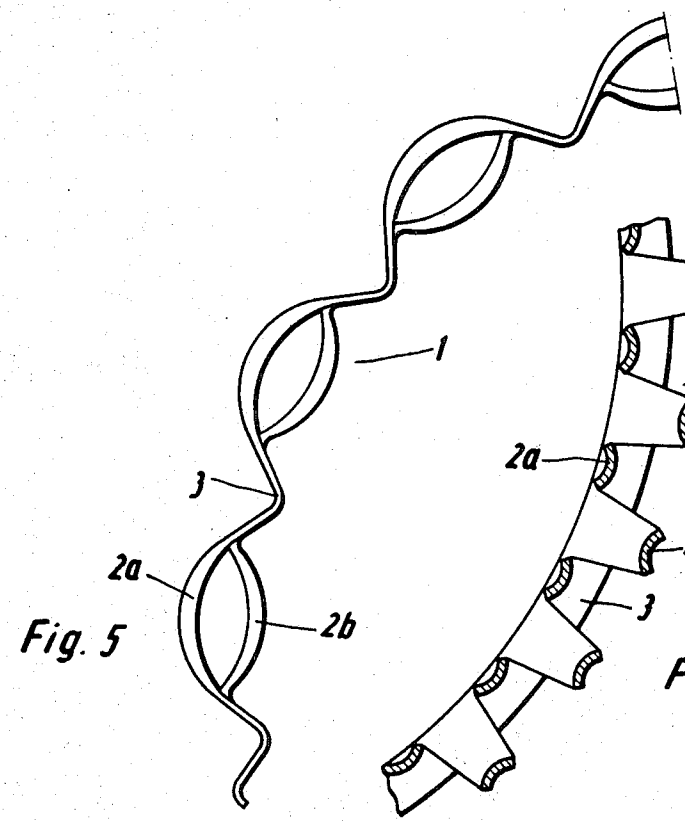


Fig. 5

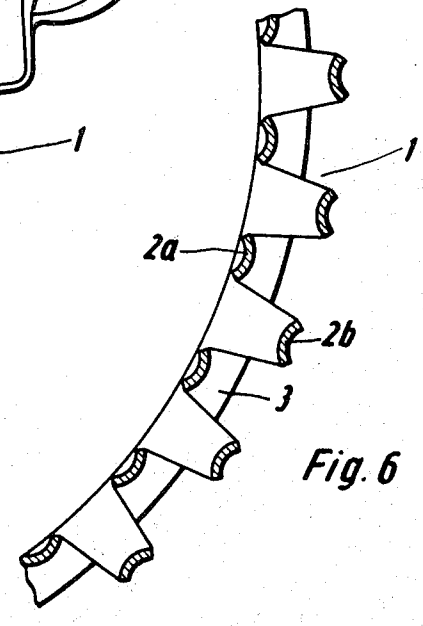


Fig. 6

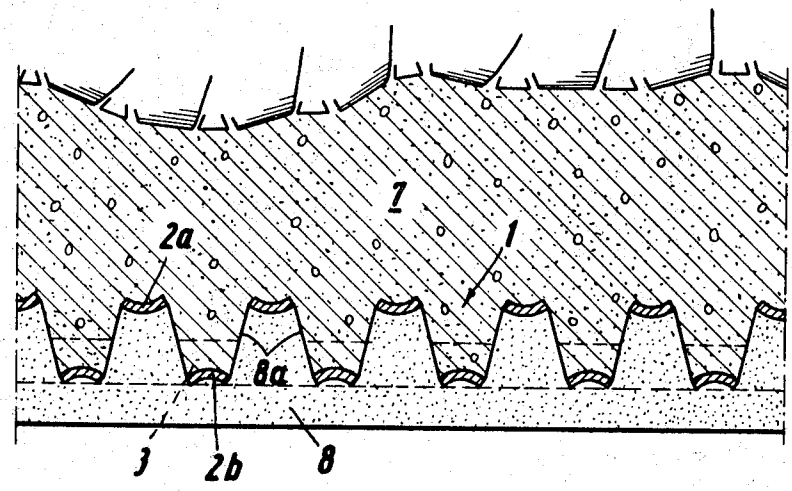


Fig. 7

Fig. 8

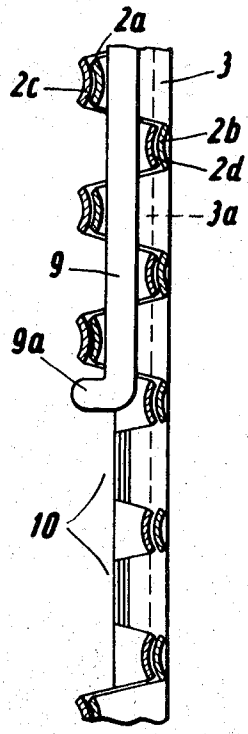


Fig. 9

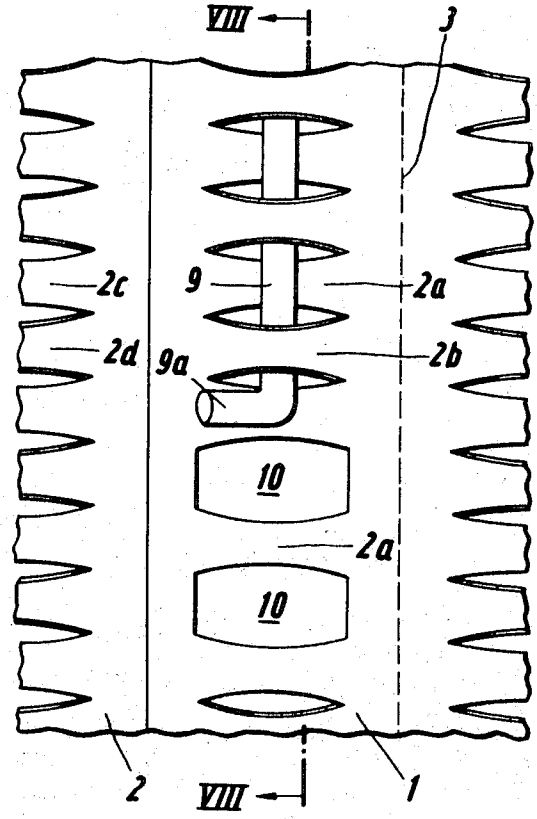


Fig. 10

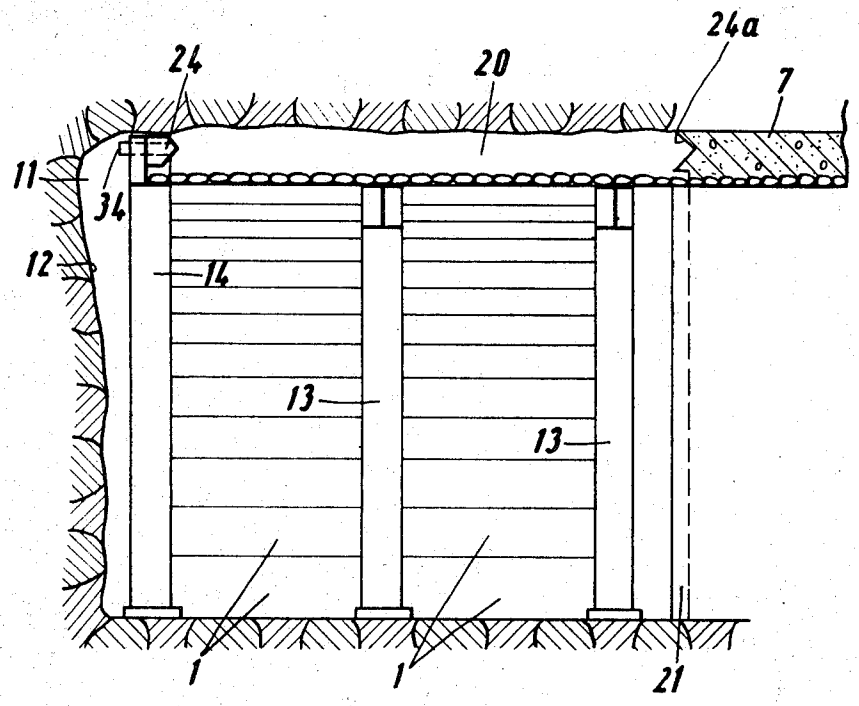
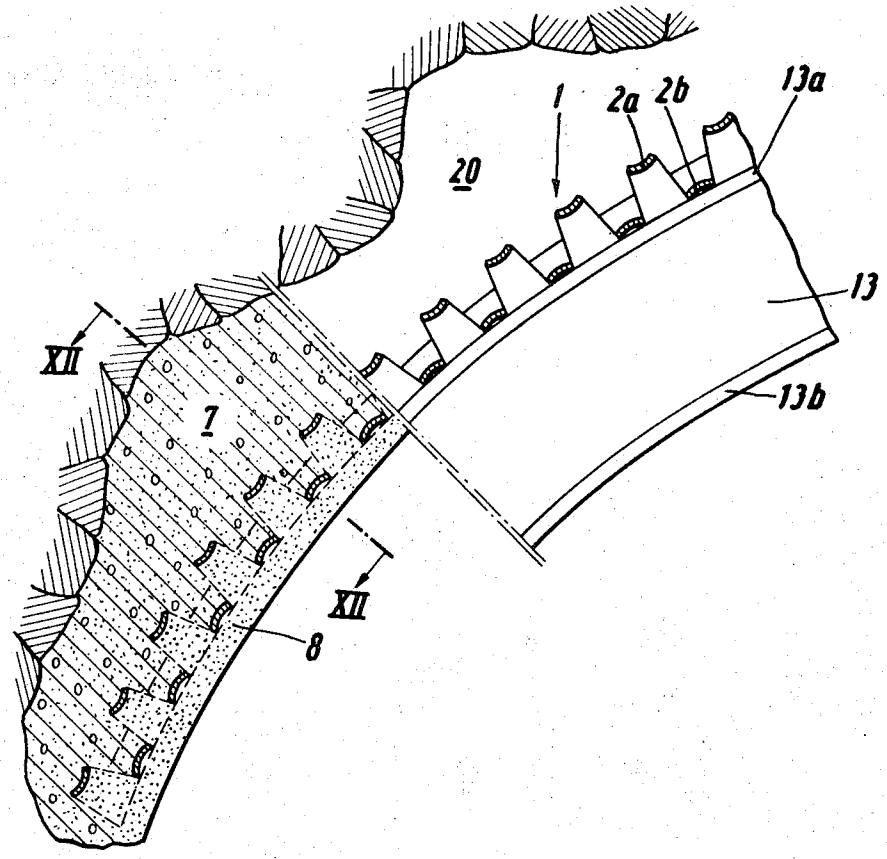


Fig. 11



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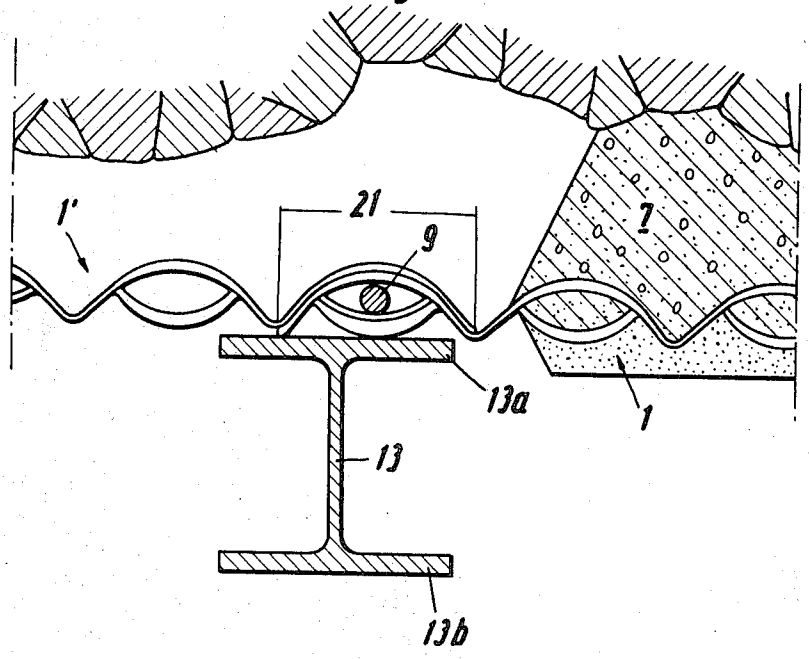

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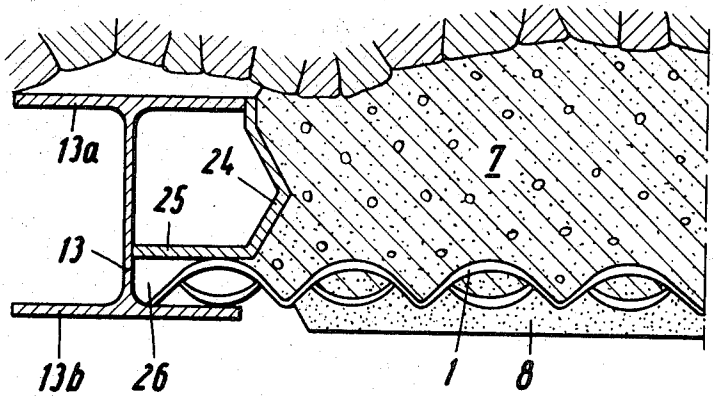

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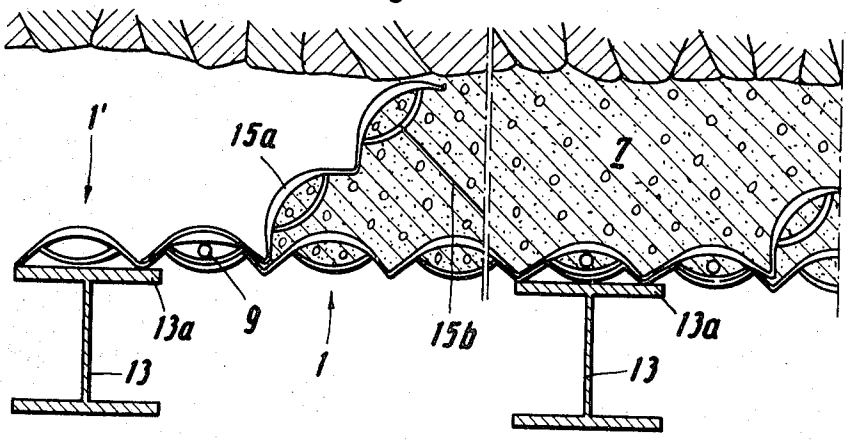

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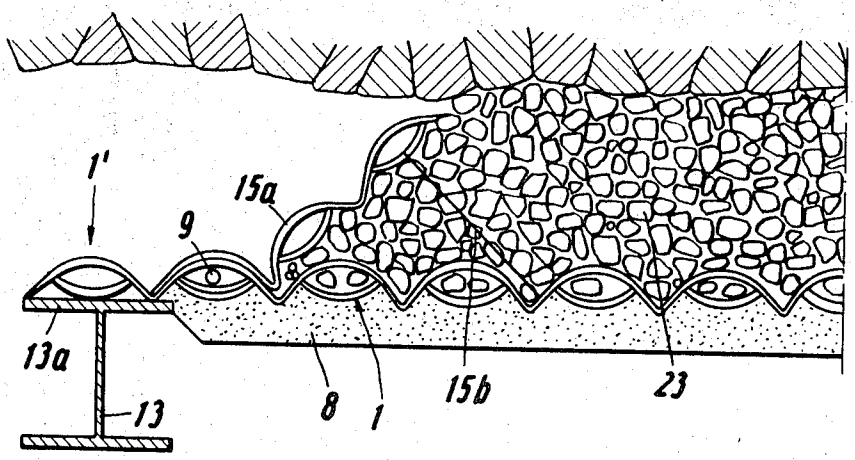

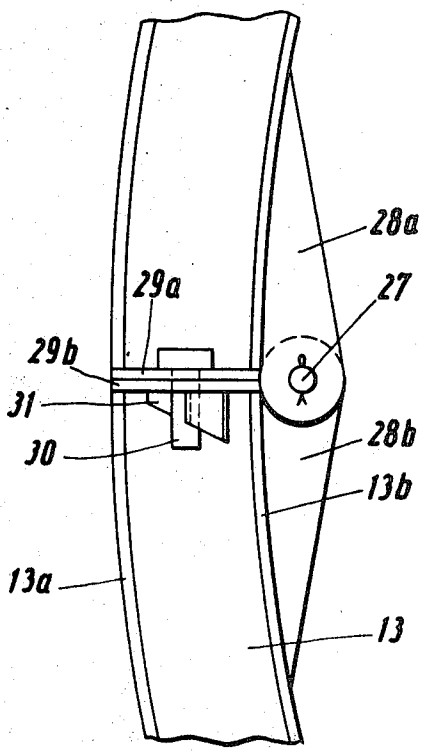

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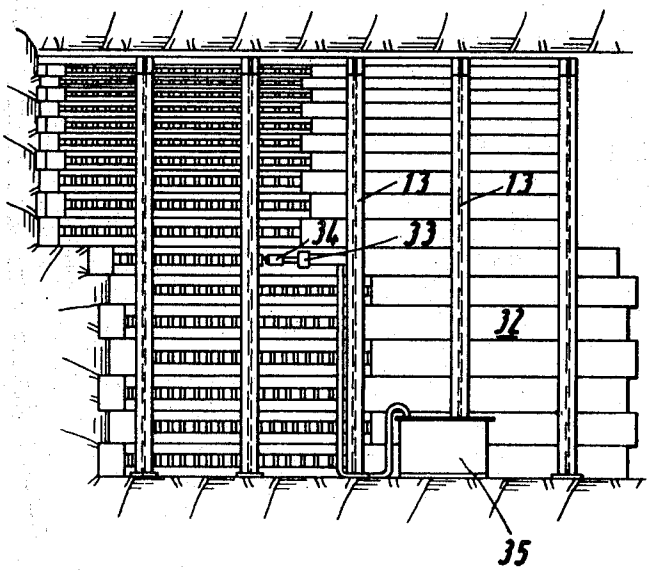


Fig. 17

Fig. 18

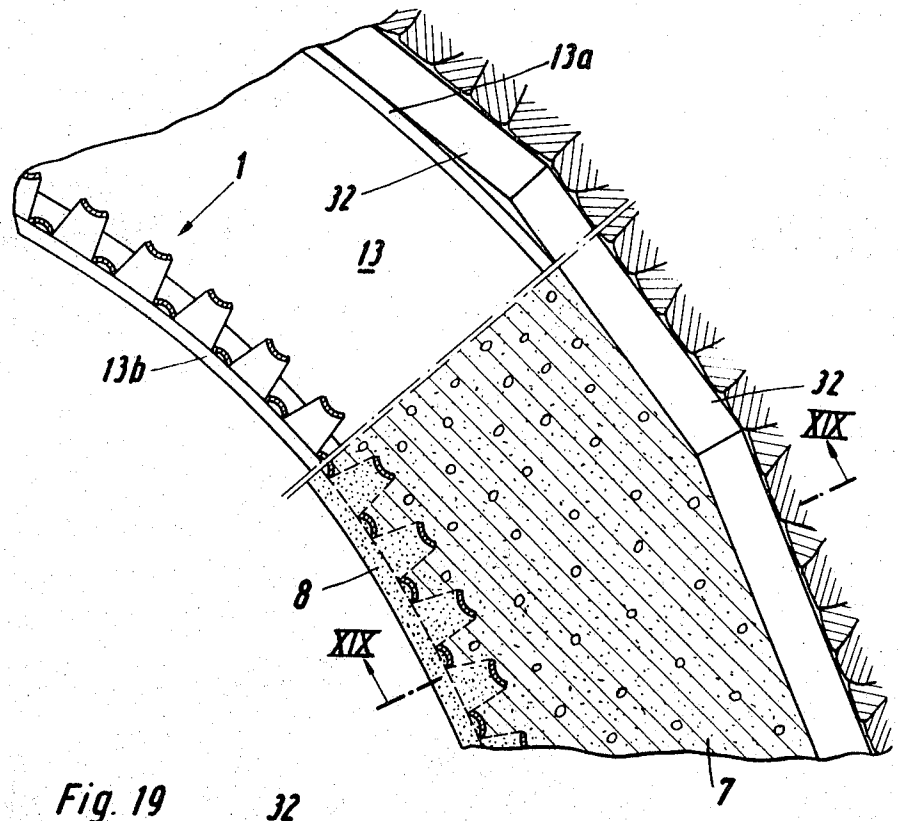
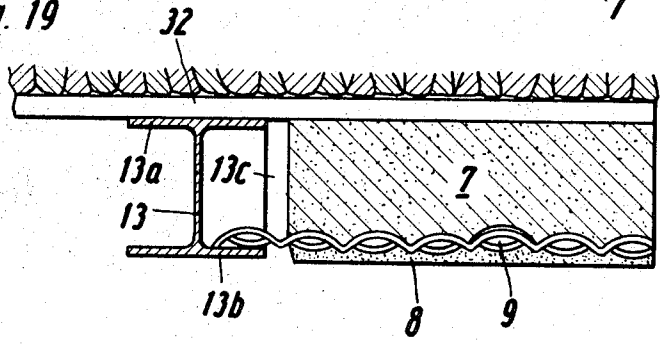


Fig. 19



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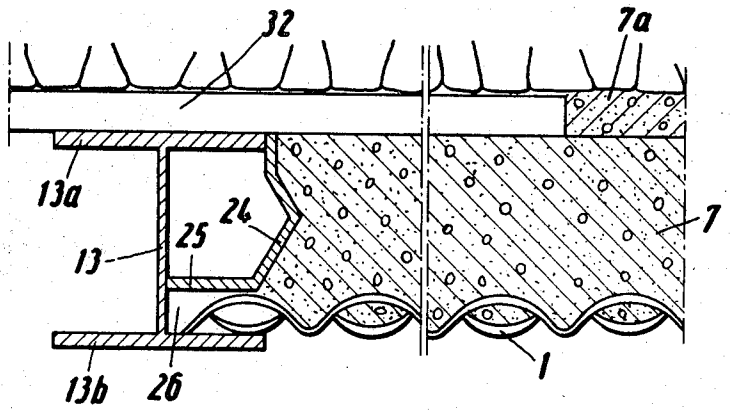


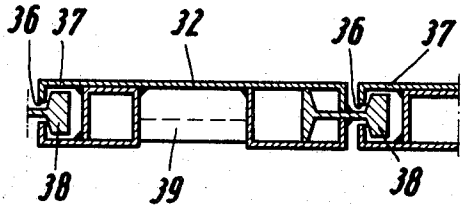
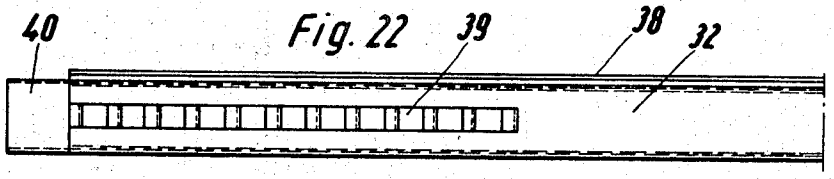


Fig. 21

Fig. 22



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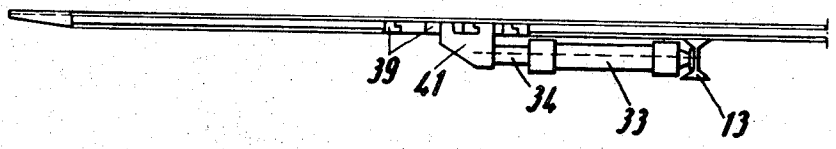


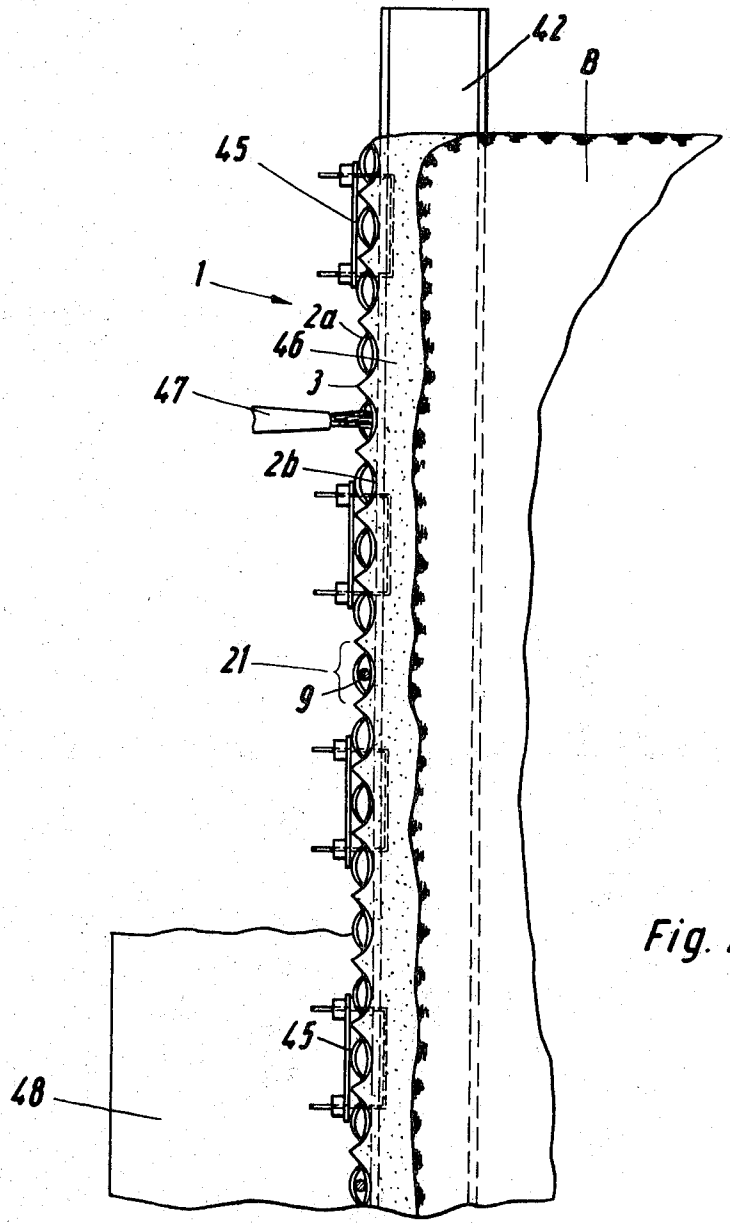


Fig. 24

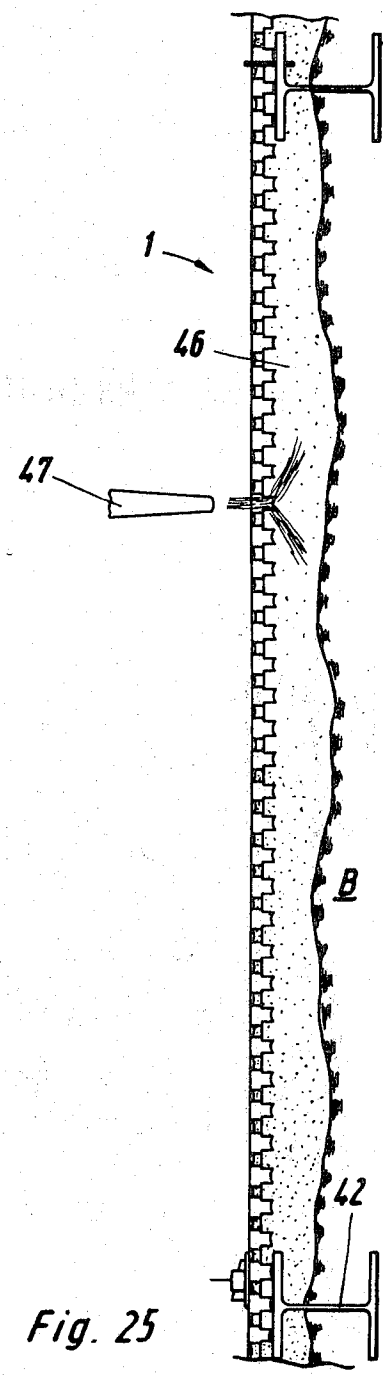


Fig. 25

Fig. 26

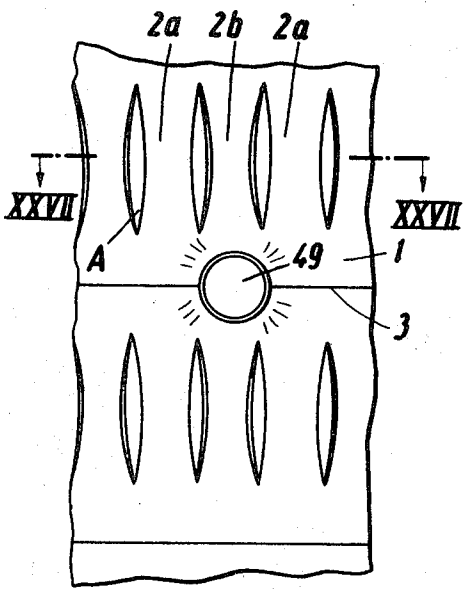
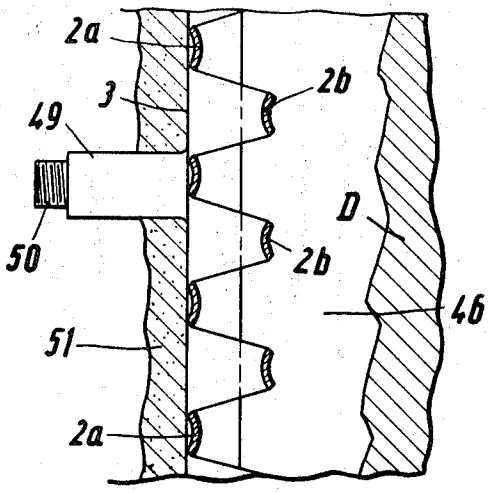


Fig. 27



TUNNEL STRUCTURE

RELATION TO COPENDING APPLICATIONS

This application is a division of application Ser. No. 170,770, filed Aug. 11, 1971, now U.S. Pat. No. 3,751,929, which, in turn was a division of application Ser. No. 798,747, filed Feb. 12, 1969 now U.S. Pat. No. 3,601,945. The drawings and specification herein are identical with those on file in copending and related application Ser. No. 262,216 now abandoned.

According to the present invention, there is provided a panel-like structural unit particularly for use as permanent formwork and reinforcement in concrete constructions, said unit being formed with corrugations, at least one creast of which is depressed at intervals to form a row of pockets for receiving a connecting element extending longitudinally of the corrugations, whereby overlapping units are connectable, the pockets each decreasing in width, considered longitudinally of the corrugations, with increase in depth of the pocket.

When the edges of two units are overlapped, the pockets (formed both by the depressed portions and the portions of the crest intermediate the depressed portions) of the units mate together.

By virtue of the wedge form given to the pockets, the units mate readily both when the units are flat, and when they are deformed to construct an arch during tunnel construction.

Inter-engagement of the units in the overlap zone is additionally facilitated by the fact that the pockets are arched to reduce their width, for example being of U- or V-form cross-section.

According to another advantageous aspect of the invention, the edges defining the pockets merge substantially along a straight line with the troughs adjacent the crest or crests in which the pockets are formed. This simplifies manufacture of the unit because it is possible to use a tool simpler than that used for conventional units. At the same time, flexural strength is increased, thus enabling the units to be installed with greater unsupported lengths.

A particularly favourable cross-sectional form for the corrugations is obtained where the sides of the troughs include between them an angle of about 90°, because in this way the corrugations lie tightly adjacent one another in the overlap zone and offer particularly high resistance to pressure and tension.

The panel-like structural unit according to the present invention is used to line tunnels and galleries. In this case, the unit acts as permanent formwork which is back-filled with concrete and optionally covered with a sealing compound on that side facing the tunnel.

In concrete construction, it is common practice to use permanent formwork consisting essentially of a framework of supporting elements and rods, wire netting or full-length panels secured between them.

However, tunnels and galleries have to be lined under circumstances differing from those encountered in normal concrete construction, such as the ground pressure whose effect is largely governed by the nature of the surrounding rock, and for which appropriate allowance has to be made.

This aspect of the invention is based on the recognition that ideal progress in tunnel driving can only be made when the concrete vault is installed simultaneously with the advance in the tunnel profile. In any mountain, except in quicksand where the water pressure is a critical factor, a subterranean cavity or hollow can remain open for a certain period of time without any need for support, i.e., without any signs of detectable ground pressure occurring and putting strain upon any lining installed. The relaxation zones around the cavity are gradually formed and over a period of time are propagated further and further into the rock because the pressure takes some time to develop because as a rule the mountain only undergoes plastic deformation some time after relaxation has been absorbed by the lining.

Accordingly, it is a further object of the invention to provide a process by means of which a concrete lining of the requisite thickness can be erected in this relatively short period of time before ground pressure is applied, in order thus to facilitate considerably faster and more economic tunnel driving.

According to a feature of the invention, this object is achieved by installing erection arches whose external outline corresponds substantially to the internal cross-section of the lined tunnel or gallery to be constructed, right up to the working face after blasting and removal of the debris, sealing off the cavity to be concreted at its front end by frontal formwork, and placing the panel-like units provided by this invention on the erection arches in alignment with the previously installed units, and back-filling the space between the units and the tunnel with concrete, which is preferably vibrated, up to the tunnel apex. In this way, it is possible to produce a lining which is strong enough to withstand the ground pressure as soon as it begins to occur so that extremely fast progress can be made. Experience has shown that ground pressure actually begins to exert its effect when the freshly installed concrete lining is completed and has acquired the requisite bearing strength. The minimum period which can be expected in any rock and within which the lining has to be installed, is beaten without any difficulty during installation of the lining.

By virtue of the process according to the invention, it is possible to produce a concrete lining adapted to the tunnel and which, having been vibrated, lies tight against the workface and prevents further disintegration of the rock through foreign influences such as air and water in particular. The lining which is load-bearing immediately it has been installed distributes the pressure of the weaker rock to stronger layers of rock and thus eliminates the danger zone directly behind the workface. At the same time, the units supported by the erection arcs and simultaneously acting as formwork and reinforcement, prevent the concrete jacket from cracking under the effect of blasting so that one disadvantage affecting making safe with pneumatically applied concrete is eliminated.

The process according to the invention thus enables a concrete supporting structure to be erected in a single operation on the construction site itself, the ground pressures occurring being absorbed by a homogeneous structure of rock-concrete formwork and reinforcement of the erection arches without affecting progress in any way. In addition, the panel-like structural units acting as formwork and reinforcement may be designed in such a way as to produce a firm bond between the concrete and a sealing compound sprayed on to that surface facing the tunnel.

In the event of tunneling in swelling ground, a temporary, movable sheet-like support, consisting of elongated, plate-like lances two to three times longer than the interval between the arches, is with advantage used to make safe the roadway lying exposed between the workface and the lining. The lances are provided along their longitudinal sides with interengaging guides which permit bending around a longitudinal axis and limited deviation from the longitudinal direction between two adjacent lances.

A particularly favourable and practical design for the mutually guiding lances is obtained by arranging on one longitudinal edge of the lance a guide channel open at both ends which is accessible from the edge through a longitudinal slot, and on the other longitudinal edge a slide member of T-form cross-section which engages with clearance in the adjacent guide channel. Tooth-like ribs with which a device for moving the lance forwards may be releasably engaged, may be provided on that side of the lance facing the tunnel. To prevent the lances, parts of which are permanently situated in the concrete, from bonding with the concrete, they are preferably made from steel, being ground smooth on the outside. The lances are also fitted with a point which tapers conically at that end facing the tunnel.

The device for moving the lances forwards may consist of a pneumatic cylinder which, on the extendable rod of the piston, has a claw for engaging in the tooth-like ribs on the lances, and whose cylinder is arranged to be supported by the side face of an erection arch.

The panel-like units may also be used for performing another function frequently required in building construction, namely to make safe exposed ground and rock. It has been found that this function can be performed in a unique advantageous manner by arranging the permanent formwork in front of and at a distance from the area to made safe and filling the space behind the formwork with concrete introduced through the formwork. It is particularly easy with an arrangement such as this to introduce the concrete by spraying it through at a right-angle to the structural unit.

To strengthen a trench, the permanent formwork is secured to driven vertical pilot beams, backfilled and extended downwards in sections as excavation continues.

It is necessary to strengthen a tunnel surface and if it is intended to protect the formwork against corrosion, the the spray-through process referred to above may be applied, or alternatively a cement mortar containing a waterglass additive is initially sprayed on to that surface of the permanent formwork facing the tunnel, after which the space left between formwork and tunnel wall is filled with concrete.

The invention is described in detail by way of example only in the following with reference to the accompanying drawings, wherein:

FIG. **1** is a front elevation of two structural units overlapping at the point at which they are joined.

FIG. **2** is a partial section through the units shown in FIG. **1** on the line I—I.

FIG. **3** is a front elevation of a modified embodiment of the structural unit.

FIG. **4** is a section through FIG. **3** on the line III—III.

FIG. **5** is a front elevation corresponding to FIG. **1** of a structural unit installed in an arched position, the arching running parallel to the rows of pockets.

FIG. **6** is a section through the unit shown in FIG. **1** which is arched about an axis extending transversely of the rows of pockets.

FIG. **7** is a partial section through a completed tunnel or gallery lining.

FIG. **8** is a longitudinal section through a joint between two overlapping structural units.

FIG. **9** is a plan view of the joint shown in FIG. **8.**

FIG. **10** is a longitudinal section through a tunnel in the course of construction.

FIG. **11** shows a tunnel lining partly in section and partly as a front elevation.

FIG. **12** is a section through FIG. **11** on the line XII—XII.

FIG. **13** is a section corresponding to FIG. **12** through a frontal formwork closing a concreting section.

FIG. **14** shows the arrangement illustrated in FIG. **13** after the formwork has been backfilled with gravel.

FIG. **15** illustrates another possibility of producing frontal formwork.

FIg. **16** is a partial elevation of an erection arch of the kind used to line a tunnel.

FIG. **17** is a longitudinal section through a tunnel in the course of being lined, lances being used to support the swelling rock.

FIG. **18** illustrates a tunnel lining of the kind shown in FIG. **17** partly in section and partly in side elevation.

FIG. **19** is a section through FIG. **18** on the line XVIII—XVIII.

FIG. **20** is a sectional view corresponding to FIG. **19** of another embodiment for frontal formwork in cases where lances are used.

FIG. **21** is a section through adjacent lances.

FIG. **22** is a plan view of a lance.

FIG. **23** is a side elevation of a lance.

FIG. **24** is a vertical partial section through a tunnel whose vertical wall consisting of soil has been made safe by the process according to the invention.

FIG. **25** is a plan view of FIG. **24.**

FIG. **26** is a partial elevation of a a structural unit provided with an injection socket.

FIG. **27** is a section through FIG. **26** on the line XXVI—XXVI.

FIG. **1** is a front elevation of two partly overlapping panel-like structural units **1, 2** in which curved pockets are arranged in rows, radiating alternately from a central plane, E, E′. The upwardly curved pockets in the unit towards the bottom of the drawing are denoted by the reference **2***a*, whilst the downwardly directed pockets are denoted by the reference **2***b*. Similarly, the upper unit is provided with upwardly directed pockets **2***c* and downwardly directed pockets **2***d*. As shown in the Figure, the pockets **2***a* and **2***b* and the pockets **2***c* and **2***d* lying one behind the other form full-length openings A which even when two units are placed one on top of the other, as shown in the Figure, leave free an opening A′ for accommodating a rod-like connecting element. The pockets **2***a* and **2***b* and the pockets **2***c* and **2***d* each begin flat on the centre plane E and E′ and, as shown in FIG. **2,** form troughs which are concave from the outsides and which are most pronounced at the tops of the pockets.

Arranged between each of the rows of pockets **2***a*, **2***b* and **2***c*, **2***d* is a full-length corrugation **3, 3***a* which forms a recess directed to only one side of the unit, in the drawing downwards from the centre plane, E, E′, and

whose apex is substantially level with that portion of the pockets 2*b* and 2*d* which extends furthest downwards. The walls of the corrugations forming the arms of the V include an angle of about 90° between them. The side walls of the corrugation each merge smoothly with the (in the drawing) upwardly directed pockets 2*a*, 2*c*. Since the structural units are identical in shape, the corrugations 3, 3*a* also interengage exactly in the overlap zone.

The design and relative positions of the pockets are shown in the sectional diagram in FIG. 2. In this case, the section is taken through those portions of the pockets 2*a*, 2*b* and 2*c*, 2*d* extending fruthest outwards, i.e., through the region in which the concave arching of the pockets is at its most pronounced. Through the arching of the pockets, the pockets which lie one behind the other form openings which lie one behind the other substantially in the centre plane of the unit and each of which taper inwards funnel-like from the side edge of the pocket. As shown in FIG. 2, those edges 4 of the pockets which define its end faces include with the planes E, E′ an angle 5 of less than 90°. As a result, the pockets are wedge-like in shape as seen from the side. The gaps between two successive pockets are similarly wedge-shaped. This makes it easier to fit the pockets into one another in the overlap zone, whilst the structural units lying one above the other assume relative to one another exactly the position shown in FIG. 2 in which a connecting element can be inserted into the opening A′ lying one behind the other. The opening A′ also remains intact for the insertion of a thinner connecting element of somewhat smaller internal cross-section in cases where structural units arched around an axis extending transversely of the corrugations are overlapped.

In the panel-like unit 1*a* shown in FIGS. 3 and 4, which is suitable for example for larger dimensions, the downwardly directed pockets 2*f* project beyond the apex of the corrugations 3. Those portions projecting furthest outwards, both of the upwardly directed pockets 2*e* and of the downwardly directed pockets 2*f*, form flat V-shaped flutes 6 which, compared with FIG. 4, again produce a substantially funnel-like cross-sectonal form in the longitudinal openings A surrounded by the pockets.

The panel-like structural units shown in FIGS. 1 to 4 can be installed not only flat but also, as shown in FIGS. 5 and 6, arched, for example for lining tunnels. For this purpose, a structural unit 1 may be arched around an axis parallel to the direction of the rows of pockets, as shown in FIG. 5, or around an axis extending transversely of the rows of pockets as shown in FIG. 6. The corrugations provided between the rows of pockets allow bending in both the aforementioned directions.

FIG. 7 is a section through a tunnel lined with the structural unit according to the invention. For this purpose, units are initially joined together in an arrangement substantially corresponding to the required internal cross-section of the tunnel. The generally irregular gap left between the rock and the unit 1 is filled with pneumatically applied or lean-mixed concrete 7. At the same time, the concrete 7 also fills the spaces behind the pockets 2*b*, projecting towards the centre of the tunnel, between the corrugations 3. In the embodiment shown, that surface of the lining facing the tunnel is coated with a sealing material 8 applied by spraying or any other suitable method. The material 8 penetrates into those spaces which, on the tunnel side, extend up to the backs of the pockets 2*a*. At the same time, a permanent, reliable bond can be obtained on those surfaces 8*a* on which the material 8 comes into contact with the concrete 7 The same effect is obtained even when the surface facing the tunnel is sprayed with concrete rather than with the material 8, or otherwise coated. In addition, the special design of the structural unit in any case guarantees an absolutely firm bond between the initially free-flowing coating material and the unit 1.

FIG. 8 is a section through a joint between two overlapping structural units. As already explained with reference to FIG. 1, the pockets 2*a*, 2*b* and 2*c*, 2*d* lie on one another and fit in one another. In this way, and through engagement of the corrugation 3*a* of the upper unit with the corrugation 3 of the unit beneath it, the two units are held precisely in their positions relative to one another. The two elements are prevented from being separated from one another by means of a mandrel- or rod-like connecting element 9 which acts as a lock and which at one end is bent around substantially at a right-angle. To enable the connecting element 9 to be inserted into the longitudinal opening, two pockets 2*b* and 2*d* have been hollowed out in the embodiment shown in the proximity of the joint between the two structural units. In this way, free zones are formed at the points denoted by the reference 10 from which the connecting element 9 can be introduced.

The same circumstances arise out of FIG. 9 which is a plan view of a joint.

When used as illustrated in FIG. 7, the concave depressions or troughs which, as mentioned earlier on, are arranged at and are at their most pronounced at the tops of the pockets 2*a–f*, have the advantage that the surface facing the tunnel is uneven and promotes particularly firm adhesion of the sealing material. To ensure that the material 8 adheres firmly, bridges have to be formed between the areas in which the material 8 penetrates into the gaps between the outwardly directed pockets. In the case of pockets which are arched outwards at their apices, the so-called bridge is thinnest at its centre. With pockets showing the aforementioned design, a considerably larger proportion of the composition used for sealing rebounds when it is sprayed on so that losses are inevitable and considerable expense involved in applying the composition.

Through the inwardly directed arching of the pockets at their apices, it is also possible to avoid cavities in the concrete which are particularly undesirable in the proximity of the sealing layer because they detrimentally affect the firm bond with this layer.

The process for lining tunnels and galleries is described in detail in the following.

In FIG. 10, the tunnel or gallery in the course of construction is denoted by the reference 11. The front end of the advance, known as the workface, from which another round is completed with the next drilling and blasting operation, is shown at 12. Erection arches 13 are erected at suitable intervals apart in the tunnel, extending into the immediate proximity of the workface 12. The external outline 13 of the erection arches 13 corresponds substantially to the internal cross-section of the completed tunnel. The front erection arch 14 whose outer profile substantially corresponds to the excavation line of the tunnel, is provided with frontal

formwork **24** which will be described in detail further on.

After the erection arches **13, 14** have been erected true to profile, the panel-like structural units **1** are placed on the outsides of the arches. The units **1** form a permanent formwork which at the same time acts as reinforcement for the completed concrete lining. In the embodiment shown, the panel-like units **1** are again provided with pockets directed to both sides, radiating from the centre plane of the unit and accordingly may be overlapped with and fastened to one another both along their longitudinal sides and along their narrow sides. The rear ends of the units **1,** as seen in the direction of progress, are arranged on the front ends of the units of the already completed concreting **7** in the zone **21** so that a firm bond is obtained between the successively prepared lining sections. In addition, a substantially dovetail-like recess **24***a* is formed in the end face of the finished concreting **7,** whose function is also to provide a firm link to the following new concreting section. When the panel-like structural units are installed in the manner described, a cavity **20** is formed between them and the rock adjoining the tunnel excavation line, being filled with concrete following the installation of the units **1** progressing in an upward direction. The concrete is consolidated by vibration. In order to fill the last cavity remaining, situated at the tunnel apex, concrete is forced through a socket **34** extending through the frontal formwork. For this purpose, a hose coming from a suitable concrete pump is attached to the socket **34.**

As apparent from the foregoing, the lining extending into the immediate proximity of the workface forms a strong, reliable support for the tunnel, even when the concrete is still liquid, which is already installed before the ground pressure begins to exert its influence. Installation does not interfere with the boring operations at the workface **12.** The arrangement consisting of erection arches, structural units and concrete backfilling is so strong that it is able to withstand explosive blasts.

FIG. **10** diagrammatically illustrates a lining produced by the process according to the invention. With normal friable rock, substantially the following procedure is adopted in practice:

On completion of blasting and debris clearance, two erection arches are erected true to profile and provided with iron spacer sections (not shown in the drawing). The panel-like structural units are then arranged panel by panel in an upward direction on both sides of these arches to form a ring, and at the same time backfilled with concrete which is consolidated by vibration. The frontal formwork **24** facilitates clean processing of the concrete.

When driving the first metre of a tunnel, a quick-setting binder may be added to the concrete so that drilling and blasting may be continued straightaway. As soon as an adequate safety zone has been established inside the mountain, addition of the quick-setting binder may be stopped. The other erection arches are set at intervals of **1** to **2** metres apart, depending upon the ground pressure. Larger intervals between the arches are not recommended for economic reasons, because otherwise panel-like structural units of considerable thickness would have to be used.

To drive a tunnel in normal rock, **21** erection arches for example may be used. In this way, it is possible to obtain a permanently supported tunnel section **20** metres long in which the lining withstands any vibration during blasting until the concrete jacket has set. After a tunnel section of this kind has been completed, the erection arches are dismantled at the rear and reinstalled at the front.

If the rock allows, the lining may remain up to 10–12 metres behind the workface and may be installed by a second working party. However, the erection arches must be installed up to a point immediately behind the workface and must be keyed in such a way that lateral displacement under the effect of the explosives is impossible. The erection arches, which in the embodiment shown are of I-profile, are of such dimensions that they are able to absorb the stresses occurring without distortion, and can be used and re-used. As soon as the erection arches towards the rear end of the lining have been removed, that surface of the panel-like units facing the tunnel should be coated with a sealing compound. The sealing compound is normally applied by spraying.

If the tunnel is being driven in highly friable rock, it is advisable to prepare the concrete lining with the aid of two erection arches and the requisite connecting elements. The profile of the arches is chosen in dependence upon the thickness of the concrete supporting structure which is in turn governed by the ground pressure.

On completion of blasting and debris clearance, the two erection arches are erected true to profile and anchored. They are erected as described above. Installation of the panel-like structural units and introduction of the concrete are also carried out as described above. The interval between the arches may amount to between 0.6 and 2.0 metres.

A quick-setting binder should be added to the concrete in cases where the concreting in sections is repeated at time intervals of less than 10 hours.

After the second round, i.e., on completion of the blasting operations and debris clearance, the rear arch is removed and reinstalled in front of the other arch. The panel-like structural units are joined to those already concreted in after they have been placed on the outer flange of the previous arch. More concrete is then introduced. The sealing compound should be applied at some distance from the workface, although it is also possible to apply the compound directly after the lean-mixed concrete has been introduced.

If ground pressure allows, between **6** and **8** erection arches may be used and the operation carried out substantially on the lines described earlier on.

As a precautionary measure and for generally making safe, a layer of gunite may be applied either over the entire or only the endangered part of the before the erection arches are set up. In special cases, roof bolts may also be fitted for safety before the erection arches are set up.

The lining according to the invention is shown in the right-hand part of FIG. **11,** the left-hand part of which is a section through the lining after concreting. As shown in the Figure, the panel-like structural units **1** lie on the outer flange **13***a* of the erection arch **13** before concreting. The pockets **2***a*, **2***b* arranged in rows extend transversely of the tunnel axis in the embodiment shown.

The space between the rock and the structural units **1** is filled with concrete **7.** The concrete penetrates into the gaps behind the pockets directed towards the tun-

nel. When a sealing layer **8** is applied, preferably by spraying, to the surface facing the tunnel, the sealing compound bonds with the concrete by virtue of the fact that it penetrates from the tunnel side into the spaces behind the pockets directed towards the rock.

FIG. **12** is a section through FIG. **11** on the line XII—XII showing how the freshly installed unit **1'** is joined to the unit **1** concreted in during the previous working stage. Concreting and hence tunnel driving progresses from right to left in FIG. **12.** The units are laid one on top of the other in zone **21** with their adjoining edges so that the pockets directed to both sides from the centre plane of the elements engage in one another. In doing so, they leave free an opening in which a connecting rod **9** holding the adjacent elements together is inserted. The front end of the last unit **1** to be concreted in must project beyond the end of the concrete **7** in order to be able to make the connection.

To prevent the concrete form flowing out frontwards from the space between the units **1, 1'** and the rock during concreting, a seal or closure must be provided at the front end of a concrete section. An embodiment serving this purpose is shown in FIG. **13.** Another structural unit **1'** is joined to the last element **1** to be concreted in the manner described above, except that the overlap of the front unit **1'** over the rear unit **1** is made so large that the front unit with the overlapping portion **15***a* can be bent up to the rock adjoining the tunnel excavation line. To prevent the concrete subsequently introduced behind the preceding unit **1** from pushing out the closure formed by the portion **15***a*, a holding wire **15***b* may be fastened between the portion **15***a* of the front unit **1'** and the unit **1** adjoining it in a direction opposite to that in which the tunnel is being driven.

FIG. **14** illustrates an embodiment of the invention in which the units **1** and **1'** are backfilled with round gravel **23,** grit, pervious or aerated concrete, rather than with concrete. This type of lining is used for those parts of the tunnel at which water has to be removed. The structural units are installed in the same way as described above. An adequately thick water-tight layer **8,** for example of gunite, is applied on the tunnel side. Every 5 to 8 metres an expansion joint is provided which is preferably sealed with flexible jointing tape. The water issuing from the rock flows through cavities present in the gravel **23** and the like to the bottom of the tunnel where suitable outlets are provided to prevent accumulation and hence the build up of pressure. If the water is to be displaced behind the structural units, cement may be injected into the back filling **23.**

Another method of sealing the cavity to be concreted at its front end, is shown in FIG. **15.** The sealing means is in the form of an erection arch which forms a frontal formwork. The frontal formwork consists of a box-like projection attached to that side facing the cavity to be concreted which extends over the entire length of the arch.

The box forming the frontal formwork consists of a wedge-like projection **24** which extends out from the outer flange **13***a* of the arch **13** and which is closed by a web **25** parallel to the inner flange **13***b* of the erection arch. The web **25** is at a distance from the flange **13***b* wide enough to allow insertion of a structural unit **1.** In this way, a cavity **26** is formed, accommodating the front end of the last element to be installed. This end remains free during concreting as shown in FIG. **15.** The wedge-like projection **24** of the frontal formwork leaves a corresponding recess in the end face of the completed concrete section into which the concrete of the next concreting section penetrates so that a substantially dovetail-like union is established between the concrete initially introduced and the concrete subsequently introduced. When the concrete is sufficiently hard, arches removed from the completed tunnel section are reinstalled, in accordance with the progress of the tunnel, so that the arch adjoining the front end of the new concreting section again has frontal formwork and through its outer flange **13***a* closely follows the tunnel excavation line.

FIG. **16** illustrates a joint between two arch sections forming one erection arch. Hinged flaps **28***a* and **28***b* are secured to the inner flanges **13***b* of the arches. A bolt **27** which forms the hinge spindle is pushed through the coincident openings in the hinged flaps **18***a* and **18***b* and suitably secured in position.

Transverse flanges **29***a* and **29***b* are secured to the adjoining end faces of the arch sections between the outer flange **13***a* and the inner flange **13***b*. These transverse flanges have openings through which a set bolt **30** extends. In the shank of the bolt there is a transverse opening whose function is to accommodate a wedge **31.** By introducing the bolt **30** and knocking in the wedge **31,** a first connection is established between the arch sections.

When the tunnel is driven in swelling rock, and the tunnels walls have to be strengthened up to the workface, the procedure described in the following with reference to FIGS. **17** to **23** may be adopted. As shown in FIG. **17,** the front erection arches **13** are installed as guide arches for lances **32** moved hydraulically forwards which strengthen the walls of the tunnel. This means that the outer flange **13***a* is located at such a distance from the rock surrounding the excavation line that the lances **32** lie tight against the rock. The web depth of the guide arches corresponds to the thickness of the lining to be installed.

After the arches have been installed true to profile and anchored, the lances **32** are introduced. As will explained further on, the lances form a jacket which surrounds the tunnel. They are moved forwards by a pneumatic cylinder **33** which, through its extendable piston rod **34,** engages the lance to be pushed forward and at its opposite end is supported by a guide arch. The pump and the supply vessel for the pressure liquid for feeding the cylinder **33** is shown at **35.**

FIG. **18** is an illustration corresponding substantially to FIG. **11.** As shown in the Figure, the panel-like units **1** are placed on the inner flange **13***b* while the lances **32** are supported by the outer flanges **13***a*. The cavity between the flanges ans the lining units is filled with concrete **7** in the manner described above. Accordingly, the rear ends of the lances are situated in the concrete.

The arrangement shown in FIGS. **17** and **18** is again shown in FIG. **19** in a section on the line XVIII—XVIII of FIG. **18.** The cavity to be concreted is in this case closed by blocks or boards **13***c* adapted to the shape of the arches, being arranged between the lances **32** and the units **1.**

In cases where an arch corresponding to FIG. **15** with frontal formwork is used, the arrangement shown in FIG. **20** is obtained. The lances again lie on the outer flanges **13***a* of the arches **13,** while the front end of the

unit **1**, initially to be kept free from the concrete, engages in the cavity **26** of the frontal formwork **24, 25.** When the lances are moved forwards, a cavity **7***a* in which concrete is injected is formed between the concrete **7** and the rock.

As shown in FIG. **21**, the lances **32** are in the form of panel-like or plate-like hollow bodies which are two to three times longer than the intervals between the arches **13.** Situated on each narrow side there is a guide **37** open at both ends which is accessible from outside through a longitudinal slot **36** and in which a slide **38** of substantially T-form cross-section attached to the adjacent lance engages. The guides **37** and the slots **36** are made so large by comparison with the slides that the lances **32** can be adapted to the tunnel profile (cf. FIG. **18**). A certain amount of lateral movement is guaranteed at the same time.

As shown in FIG. **22,** the lances **32** are provided on that side facing the tunnel with tooth-like ribs **39** with which, as shown in FIG. **20,** the hydraulic cylinder **33** engages, being provided with corresponding claws **41** at the end of its extendable piston rod **34.** The cylinder **33** is supported by one of the arches **13,** preferably that arch provided with frontal formwork adjoining the last section to be concreted at its front end. The cylinder **33** which as shown in FIG. **17** is provided with a pressure-medium pump, is always attached to that lance **32** which is to be moved forward. By virtue of the fact that the lances are individually moved forward, there is no need for an expensive hydraulic installation. Since the lances are never joined with the concrete, they are ground smooth on the outside. Each lance **32** is provided with a point **40** which is concave towards the tunnel side.

The particular lining section may be concreted after the point of the lance has been moved forward by approximately **1** metre. The panel-like structural units are placed on the inner flange **13***b* of the arches and are assembled from the ground towards the ridge. At the same time, the concrete is introduced between the units and the lances and compacted by vibration. The frontal formwork ensures clean processing of the concrete.

In order to be able to inject concrete into the highest part of the cavity formed behind the units, a socket is preferably arranged on the arch provided with frontal formwork, to which a hose delivering the concrete under pressure may be attached.

The strengthening of the tunnel section preceding the completed lining section by the lances is extremely adaptable and may be carried out with minimum auxiliary forces. The use of the new panel-like structural element for making safe exposed ground and rock and the process applied to this end is described in the following with reference to FIGS. **24** to **27.**

Hitherto, it has been common practice to safeguard the sidewalls of a trench against collapse by initially driving in double-T vertical pilot beams before the beginning of excavation. As excavation progresses, arrisss timbers are placed between the vertical pilot beams. Since the arriss timbers should not exceed a certain length with a view to transportation and handling, the vertical pilot beams also have to be arranged at correspondingly intervals. In many cases, the arris timbers cannot be recovered, so that they remain in the ground, rot and cause subsidence.

In conventional methods of construction, formwork for the foundations has to be set up at a distance from the system strengthening the walls of the trench, consisting of vertical pilot beams and arris timbers, after the trench has been excavated. By virtue of the fact that enough space for the labourers must be available between the strengthening system for the walls of the trench and the formwork for the building, the trench must be considerably larger than the ground plan of the completed building. After the foundations have been laid, this space has to be refilled so that the excavated material accumulating here frequently has to be carried away in two shifts. This naturally involves considerable expense, particularly in the case of building works in large towns where limited space is available for the building site.

This disadvantages can be obviated by the process according to the invention. In FIG. **24,** the ground around the edge of the trench is denoted by the reference B. Double-T vertical pilot beams are driven in around the edge of the trench at suitable intervals which may be considerably larger than in cases where arris timbers are used. As excavation progresses, panel-like structural units **1** are secured to the inner flanges of the pilot beams **42.** As shown in FIGS. **24** and **25,** clamps **45** are used for fastening. It is also possible, however, to arrange the plate-like units behind that flange of the pilot beams **42** which faces the trench.

The panel-like structural units comprise pockets **2***a* and **2***b* arranged one behind the other in straight rows at certain intervals. A corrugation **3** is arranged between two parallel rows of pockets **2***a* and **2***b*. In the embodiment shown in FIGS. **24** and **25,** the rows of pockets and hence the corrugations, too, extend horizontally.

The pockets form an internal cross-section which tapers inwards from both end faces. This cross-sectional form is obtained by arching the pockets in their transverse direction. At the same time, openings A elongated between two adjacent pockets are formed as seen from the front, cf. FIG. **26.**

By virtue of their special design, the panel-like structural units **1** can be laid one on top of the other with their edges, as shown in FIG. **24** at **21.** At the same time, openings into which rod-like connecting elements **8** can be inserted are left free in the longitudinal direction of the rows of pockets.

As the trench progresses, permanent formwork is obtained in this way through the units **1** at a distance from the wall adjoining the trench at which the ground is exposed.

The space formed in this way is filled in accordance with the process of the invention by spraying concrete against the formwork through a spray nozzle **47.** If, as provided in accordance with the invention, the concrete is sprayed at a right-angle to the formwork and the units **1,** it penetrates through the formwork without rebounding in appreciable quantities and fills the space **46** immediately adjacent the ground B. The concrete sprayed at a right-angle to the formwork is distributed by virtue of the fact that the pockets **2***b* projecting towards the space **46** to be filled form convex surfaces to the concrete leaving the nozzle **47.**

In this way, the trench is not only protected against collapse during excavation, the formwork consisting of the panel-like units may readily be incorporated in the building **48** to be erected. Accordingly, there is no need

to make the trench larger than the area occupied by the ground plan of the structure.

The saving of excavated material and the ease with which the units can be handled, quite apart from the fact that they enable the gap extending up to the surrounding ground to be filled with concrete simply by spraying, represent the most important advantages of the invention.

If formwork consisting of the panel-like units is to be used to produce the concrete lining in a tunnel, it is as a rule necessary to protect the surface of the units facing the tunnel against corrosion. The easiest way of doing this, as shown in FIG. **27**, is to spray a cement mortar **51** containing waterglass on to the outside of the units facing towards the middle of the tunnel. In order to fill the space **46** between formwork and mountain D with concrete, the panel-like units are provided with connecting sockets **49** through which the concrete can be injected. The sockets are distributed in such a way that there is one socket for every **10** square metres of space to filled. For connection of the hose coming from the injecting machine, the sockets are provided with threaded rims **50** which are protected against soiling by suitable caps when the cement mortar **51** is being sprayed on. By virtue of the special shape of the panel-like units, a firm bond is obtained in this process both between the cement mortar **51** and the units and between the concrete injected into the space **46** and the externally applied layer of cement mortar because sufficient areas are available for contact between the two materials.

The sockets **49** are used to inject the concrete are with advantage provided on the corrugations **3** projecting inwards towards the tunnel.

I claim:

1. A tunnel structure or the like having a predetermined internal cross section for permanent installation in a tunnel excavation having a workface and being driven beneath the ground in a predetermined direction, said tunnel structure or the like, comprising

A. a plurality of structural panel units arranged in end overlapping manner as a permanent formwork having a cross section definitive of said predetermined internal tunnel cross section;

B. each of said structural panel units including

a. a series of parallel, longitudinal corrugations, the walls of which define crests lying in upper planes and troughs lying in lower planes, said corrugations being transverse to the direction of driving of said tunnel;

b. a series of bandlike pocket forming elements derived from portions of said crests between pairs of transverse cuts in said crests at predetermined intervals along said corrugations;

c. said bandlike pocket forming elements being of nonuniform width and being depressed from the plane of said crests into a pocket forming plane bridging said corrugation;

d. a series of longitudinally extending pockets having spaced upper wall portions defined by said crests and lower wall portions spaced alternately of said crests defined by said bandlike elements;

e. said pocket forming elements being narrowest at the longitudinal centerline of said pockets and widest at the opposite sides of said pockets;

f. said panel, in longitudinal elevation, thereby having rows of alternating wedge-shaped crest portions and wedge-shaped pocket forming elements separated by wedge-shaped gaps;

g. whereby said panel is readily matable with another panel of identical configuration by nesting therewith, said nested panels forming composite longitudinal pockets, the upper walls of which are defined only by said crest portions of the underlying nested panel and the lower walls of which are defined only by said pocket forming elements of said overlying panel;

C. rodlike members extending through said pockets to connect overlapped, nested end portions of said structural panel units;

D. said permanent formwork being inwardly spaced from walls of said excavation and defining a predetermined gap therebetween;

E. a concrete lining tightly filling said gap and pockets of said panel units, said lining comprising consecutively installed sections formed by introduction of concrete behind said formwork and vibration of said concrete in said gap to bond said lining to the walls of said excavation and said panel units;

F. front formwork means disposed in each section of lining of the tunnel structure at the ends of the structural panel units which are forwardmost in said direction of driving to maintain said ends free of concrete, thereby accommodating connection by rodlike members with the rear ends of the structural panel units of the next section of said formwork and said lining to be installed.

2. A tunnel structure or the like according to claim **1**, further characterized in that

A. said front formwork means at the forwardmost ends of each section of lining in the direction of driving is formed by the rearwardmost overlapping ends of said structural panel units for the formwork of the next installed lining section;

B. said overlapping panel unit portion being of predetermined length and being bent toward and against the walls of said tunnel excavation to close off said gap in the direction of tunnel driving.

3. A tunnel structure in accordance with claim **2**, in which

A. support wire means connect said next installed structural panel units with the structural panel units associated with the formwork for the preceding section of lining.

4. A tunnel structure or the like for a tunnel having a predetermined internal cross section being driven in a predetermined direction through a tunnel excavation having walls and a workface, said tunnel structure or the like, comprising

A. a plurality of temporary erection arches, each having said predetermined internal cross section of said tunnel;

B. a temporary workface erection arch having a web and inner and outer flanges, said temporary workface erection such arch being located immediately adjacent the workface and having a cross section generally corresponding to that of the tunnel excavation walls adjacent said workface;

C. a plurality of overlapping structural panel units supported by said temporary erection arches and defining a permanent formwork, said permanent

formwork and said excavation walls defining a gap therebetween;

D. a concrete tunnel lining disposed in said gap, said lining comprising consecutively installed sections of concrete; and

E. a front formwork means for closing off the permanent formwork proximate to said workface and for maintaining the front ends of the forwardmost structural panel units free of concrete.

5. The tunnel structure or the like of claim **4,** in which

A. said front formwork means comprises a box-shaped projection nested between said flange of said temporary workface arch;

B. the front wall of said projection closes off the last section of lining and includes a roof-like projection whose base portion projects beyond and over forward ends of the structural panel units;

C. said base portion being spaced from the inner flange of the workface erection arch a distance not less than the maximum height of said structural panel units.

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