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(54) Method of building a lined tunnel

(57) A method of building a lined tunnel in earth comprises the steps of excavating a tunnel in the earth by means of a forward moving excavating machine, placing a support structure behind the excavating machine after a tunnel part has been excavated, such that a ringshaped gap is formed between the support structure and the surrounding earth, providing a sealing means for sealing off the ringshaped gap towards the excavating machine, filling the ringshaped gap behind the sealing means by injecting therein a liquid lining material, such as liquid concrete, and allowing the lining

material to become solid and to harden. Separation means are provided in the tunnel lining before hardening of the lining material, so that the tunnel lining is divided into separate sections. The separation means are located on such places that the separate sections are free to shrink during hardening of the lining material and to follow settlements of the surrounding earth. Gaps formed between the separate sections are filled with a sealing means.

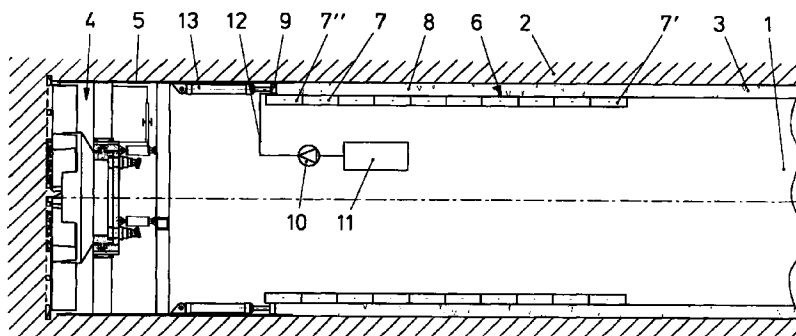


Fig. 1

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Description

[0001] The invention relates to a method of building a lined tunnel according to the preamble of claim 1.

[0002] Such a method, known as the extruded concrete lining (ECL) method, is disclosed in document DE-A-2932430. After the gap between the support structure, which may be a formwork that can be removed after the lining has been made, and the surrounding earth has been filled with lining material the lining material is kept at elevated pressure by external means. As a preferred lining material a special type of concrete is used, which experiences a volume increase during hardening e.g. by adding special additives. However, the use of such special types of concrete is expensive and often subject to restrictions which cannot always realized in applying the method.

[0003] To optimize the total costs of a tunnel build with the known method the use of simple, inexpensive types of concrete, preferably fibre-reinforced, is preferred. However such types of concrete will shrink a certain percentage during hardening. When after solidification of the lining material the support structure is removed the tunnel lining is free to shrink in radial direction. However, the capacity of the tunnel lining to shrink freely in axial direction during hardening is very limited. The front end of the tunnel lining, which is liquid over the first portion and solidified but not yet fully hardened over the second portion, is subjected to a compression force exerted by the excavating (boring) machine. The compression force at the front end of the lining prevents or at least minimizes the initiation of cracks in the lining during initial hardening and shrinking of the concrete. However, due to friction forces between the tunnel lining and the surrounding earth the compression force in the tunnel lining will gradually decrease and at a certain distance from the front end of the tunnel lining the compression force will be zero. Because of the fact that the period of final hardening of the tunnel lining is relatively long with respect to the envisioned speed of the building process (the hardening period may be 30 days or even more and the speed of the building process may be about 50 metres per day) the part of the tunnel lining where the compression is zero will be of significant length.

[0004] The continuing hardening in that part of the tunnel lining and the limitation of free shrinkage in longitudinal direction will cause the initiation and propagation of cracks through the entire thickness of the wall of the tunnel lining, said cracks consequently detrimentally affecting the water-tightness of the tunnel lining.

[0005] Another cause of the initiation and propagation of cracks in the tunnel lining can be found in the instability of the foundation (earth) on which the tunnel is resting. The tunnel is subjected to forces due to settlements, in axial but also in radial direction, in which case the tunnel lining should be allowed to follow settlements and to crack (detrimentally affecting watertightness) or

should resist the forces, resulting in an uneconomical lining thickness and/or reinforcement (fibres, bars).

[0006] A possibility to ensure watertightness of a tunnel lining and at the same time allowing the developments of cracks (cracks as such, provided they are within certain limits, do not affect the required strength of the lining i.e. capability to resist external forces) is to include a watertight second means. Examples of such watertight means can be found in document WO 94/24416 (steel layer at outside) and document DE-A-1216915 (plastic layer at outside). Both the alternatives are technically difficult to apply in the extruded concrete lining method and also expensive.

[0007] It should be mentioned that the application of a watertight secondary lining at the inside of the primary (concrete) lining has the disadvantage that waterpressure may build up between primary and secondary lining requiring a secondary lining of uneconomically strength to resist that pressure.

[0008] An alternative might be a watertight material which is sprayed against the inside of the primary lining or a relative thin watertight sheet having such a surface contact with the primary lining that full bonding is achieved so as to avoid the building up of waterpressure over a significant area between primary lining and internal watertight means. However, such materials having the required properties and required lifetime, which for this type of application (a tunnel) may be as long as one hundred years, are not yet known as proven and economic.

[0009] The object of the invention is to provide an improved method of building a lined tunnel of the type mentioned in the beginning (extruded concrete lining method) which allows the use of simple, inexpensive material for the tunnel lining without the need for additional watertight means along the full length of the tunnel.

[0010] This object is achieved with a method according to claim 1.

[0011] Due to the fact that the separate sections of the tunnel lining are free to shrink during hardening of the lining material, so that tensile forces in the material are avoided, these sections are free of cracks. The sections as such are watertight. Only the gaps between the sections of tunnel have to be provided with sealing means. Moreover, the tunnel lining can follow settlements.

[0012] Preferred embodiments of the method according to the invention are claimed in the dependent claims.

[0013] The invention will now be explained in the description of preferred embodiments of the method according to the invention with reference to the drawings, wherein:

Fig. 1 is a schematic longitudinal section of the front part of a lined tunnel with an excavating machine showing the method according to the invention, Fig. 2 is a schematic representation of a tunnel lining with separation means,

Fig. 3 shows the tunnel lining of Fig. 2 after hardening of the tunnel lining,

Fig. 4 shows separation means in a tunnel lining in the form of grooves,

Fig. 5 shows separation means in a tunnel lining in the form of ringshaped separation elements, 5

Fig. 6 a schematic representation of a tunnel lining with longitudinally and circumferentially extending separation means,

Fig. 7 a schematic representation of a tunnel lining with helically extending separation means. 10

[0014] Fig. 1 shows schematically the front part of a tunnel 1 in surrounding earth 2, the tunnel 1 being provided with a lining 3.

[0015] When building the tunnel 1 a tunnel is excavated in the earth 2 by means of a forward moving excavating or boring machine 4. Such a boring machine 4 may of any type known in the art and does not need any further explanation. In the region immediately behind the boring machine 4 the earth 2, which may be unstable, is supported by a shield 5 which is connected to the boring machine. 15

[0016] Behind the boring machine 4 a support structure 6 is placed in the excavated tunnel. Usually the support structure 6 is built up from support elements 7 placed behind one another. 20

[0017] Between the support structure 6 and the surrounding earth which may be covered by the shield 5, a ringshaped gap 8 is formed. At the front end of the support structure 6 a sealing means 9 is provided between the support structure 6 and the shield 5 sealing off the gap 8 towards the boring machine 4. The ringshaped gap 8 is filled with concrete by injecting liquid concrete into the gap 8. The liquid concrete may be supplied by a concrete pump 10 with pumps the liquid concrete from a reservoir 11 through a conduit 12 extending through the sealing means 9 into the gap 8. 25

[0018] The concrete in the gap 8 is supported by the support structure 6 and is kept under pressure in that the sealing means 9 is connected to the boring machine 4 by means of hydraulic cylinders 13 which transfer at least part of the axial force exerted on the boring machine 4 to the concrete in the gap 8. 30

[0019] The concrete in the gap 8 is allowed to solidify whereafter further support by the support structure is not necessary anymore. 35

[0020] Usually the support structure 6 moves with the boring machine 4 in that after the boring machine 4 has moved over a certain distance, the support element 7' at the rear end of the support structure 6 is placed in front of the support element 7'' at the front end of support structure 6. 40

[0021] It is however also possible that the support elements remain in place and become part of the tunnel lining. In this case a new support element will be placed at the front end of the support structure after the boring machine has moved over a certain distance. 45

[0022] The solidified concrete is finally allowed to harden, thus forming the final tunnel lining 3.

[0023] The method described so far is known as the extruded concrete lining (ECL) method. The method is also described in document DE-A-2932430.

[0024] When ordinary, preferably fibre-reinforced concrete is used as material for the tunnel lining, the concrete will shrink during hardening, which will lead to tensile stresses and the occurrence of cracks in the tunnel lining. As mentioned earlier cracks can also occur as a result of settlement of the surrounding earth. The result of cracks is that the tunnel lining is not sufficiently watertight anymore. As the location of the cracks can normally not be predicted, the tunnel lining has to be provided with watertight means over its entire length. 15

[0025] With the method according to the invention the uncontrolled forming of cracks in the tunnel lining is prevented.

[0026] Before hardening of the concrete, separation means are provided in the tunnel lining so that the tunnel lining is divided into separate sections. Fig. 2 shows schematically a part of a tunnel lining. The separation means are indicated with 14 and the ringshaped sections with 15. The separation means 14 extend in circumferential direction such that ringshaped sections 15 are formed with a length L1. The length of the sections 15 is chosen such that each section 15 is free to shrink in axial direction during hardening of the concrete. Free to shrink means that the tensile stresses in the concrete are negligible or sufficiently low so as to prevent the initiation of cracks in the concrete. The length L1 depends on the friction between the tunnel lining and the surrounding earth. The friction can be decreased by greasing e.g. injection of bentonite. The friction may already be low by virtue of beneficial properties of the surrounding earth. 20

[0027] When the sections 15 of the tunnel lining 3 shrink the length of the sections will decrease to L2 as shown in Fig. 3. Gaps between the sections 15 which are indicated with 16 in Fig. 3 have to be bridged by sealing means in order to obtain a watertight tunnel lining. 25

[0028] A tunnel lining which is divided into separate sections which are connected to one another through more or less flexible sealing means can also follow settlements of the surrounding earth, so that the formation of cracks as a result of settlements of the surrounding earth is also prevented. 30

[0029] There are several ways of providing separation means in the tunnel lining 3. 35

[0030] It is possible to provide weakened areas on predetermined places in the tunnel lining 3 such that cracks in the tunnel lining occurring as result of shrinkage of the hardening tunnel lining will only form in the weakened areas. In this way the tunnel lining is divided into separate sections. 40

[0031] As shown in Fig. 4, weakened areas may be provided by making grooves 17 (e.g. circumferential 45

grooves) in the solidified but not yet hardened tunnel lining 3. The grooves between the separate sections are filled with a sealing means 18.

[0032] It is also possible (Fig. 5) to insert separation elements 19 (e.g. rings) on predetermined places in the tunnel lining 3. These separation elements 19 may be inserted during injection of the liquid concrete for the tunnel lining or thereafter but before the concrete is solidified. The separation elements may extend over a part (as shown in Fig. 5) of or the whole radial thickness of the tunnel lining. In the former case the remaining part of the radial thickness of the tunnel lining may be considered as a weakened area in which a crack will occur during hardening of the tunnel lining. In the latter case separate sections are already formed upon insertion of the separation elements. The separations may have any configuration e.g. stright, inclined, curved, S- or Z shaped.

[0033] In a preferred embodiment the separation elements comprise the sealing means between the sections of the tunnel lining.

[0034] In case the sealing means have to be able to follow the decrease of the length of the adjacent sections of the tunnel lining during hardening and/or imposed settlements, the sealing means should have spring characteristics or be combined with separate spring means.

[0035] A sealing means with spring characteristics or a combination of sealing means and spring means may be designed in several different ways (see e.g. Norbert Klawe and Alfred Haack: Tiefbaufugen - Fugen- und Fugenkonstruktionen in Beton- und Stahlbetonbau).

[0036] The spring characteristics of the sealing means or the combination of sealing means and spring means may be such that a compression force is maintained in the sections of the tunnel lining during hardening. In this case the length of the sections of the tunnel lining may be increased with respect to the situation wherein no additional axial force is exerted on the section during hardening.

[0037] A remaining compression force in the sections of the tunnel lining can also be achieved by applying active compression means in combination with the sealing means. An example of such active compression means is shown in EP-A-0 021 702. The active compression means may also comprise wedges or jacks, controlled by manpower or a power unit.

[0038] Unequal radial loadings on the tunnel lining will cause bending moments in the lining. For an extensive discussion of the loading on tunnel lining and the corresponding hoop forces, bending moments and radial displacements reference is being made to a publication by H. Duddeck and J. Erdmann "Structural design models for tunnels", published in Tunneling '81, the Institute of Mining and Metallurgy, pag. 83-91, 1981. The bending moments in the full circular lining may together with the hoop stresses have a significant impact on the required thickness of the lining if longitudinal cracking of that lin-

ing is to be avoided.

[0039] In certain earth conditions however it may be allowable that where the highest bending moments occur the lining will crack longitudinally and that the lining will elliptically deform within certain limits until a new equilibrium of forces is obtained.

[0040] Allowing for such a behaviour may result in a reduction of the required lining thickness and a corresponding reduction in costs. For quality control however it is a far better option not to rely on spontaneous cracking but to provide the tunnel lining with longitudinally extending separation means thus dividing the tunnel lining in sections in circumferential direction. The gaps between these sections can be provided with sealing means to ensure watertightness of the total lining. The longitudinal extending separation means can be similar to the circumferentially extending separation means described above.

[0041] Of course, a tunnel lining may have both types of separation means, as is shown schematically in Fig. 6, wherein the longitudinally extending separation means are indicated with 20 and the axially extending separation means with 14.

[0042] Instead of separation means extending in circumferential direction, the tunnel lining may be provided with separation means extending helically along the tunnel lining, as shown schematically in Fig. 7, wherein the separation means are indicated with 21.

[0043] The tunnel lining 3 is preferably an extruded single layer. The extrusion in one or more stages or a multilayer lining e.g. concrete with different properties is also possible. The single layer may be provided with an internal secondary layer for e.g. safety purposes (fire protection, protection against collision of cars, trams), architectural purposes or any other purpose. The secondary layer is however not essential for the tunnel lining of the invention.

[0044] If suitable materials for the secondary lining become available in the future the secondary lining may provide such a watertightness or additional watertightness that sealing means in the joints between the sections of the tunnel lining can be omitted or that the sealing properties of the sealing means may be reduced. It is also envisaged that an internal secondary lining which, as mentioned before, may be sprayed onto the single layer (primary lining) or may consist of a thin watertight sheet, might facilitate an easy movement of a sliding support structure e.g. of the type described in EP-A-0 301 188.

[0045] Usually concrete will be used for a tunnel lining. However, also other suitable materials may be used.

[0046] It will evident for a skilled person that the present invention is not limited to the embodiment described above. Essential for the invention is that an extruded tunnel lining is divided into separate sections with sealing means between these sections.

Claims

nal direction of the tunnel lining.

1. Method of building a lined tunnel in earth comprising the steps of excavating a tunnel in the earth by means of a forward moving excavating machine, placing a support structure behind the excavating machine after a tunnel part has been excavated, such that a ringshaped gap is formed between the support structure and the surrounding earth, providing a sealing means for sealing off the ring-shaped gap towards the excavating machine, filling the ringshaped gap behind the sealing means by injecting therein a liquid lining material, such as liquid concrete, and allowing the lining material to become solid and to harden, thus forming a tunnel lining, **characterised by** providing separation means in the tunnel lining before hardening of the lining material, so that the tunnel lining is divided into separate sections, the separation means being located on such places that the separate sections are free to shrink during hardening of the lining material and to follow settlements of the surrounding earth, and filling gaps formed between the separate sections with a sealing means.
2. Method according to claim 1, wherein the separation means comprise weakened areas provided on predetermined places in the tunnel lining, such that cracks in the tunnel lining occurring as a result of shrinkage of the hardening lining material or following settlements of the surrounding earth will form only in the weakened areas.
3. Method according to claim 1, wherein separation means comprise separate separation elements inserted on predetermined places in the tunnel lining, said separation elements extend over a part of or substantially the whole radial thickness of the tunnel lining:
4. Method according to claim 3, wherein the separation elements comprise the sealing means between the sections of the tunnel lining.
5. Method according to claim 3, wherein the separation elements act as a spring in the direction the movements of the adjacent sections of the tunnel lining.
6. Method according to claim 3, wherein the separation means comprise active compression means.
7. Method according to anyone of claims 1 to 6, wherein the separation means extend in circumferential direction of the tunnel lining.
8. Method according to anyone of claims 1 to 6, wherein the separation means extend in longitudinal direction of the tunnel lining.
9. Method according to anyone of claims 1 to 6, wherein the separation means extend helically along the tunnel lining.

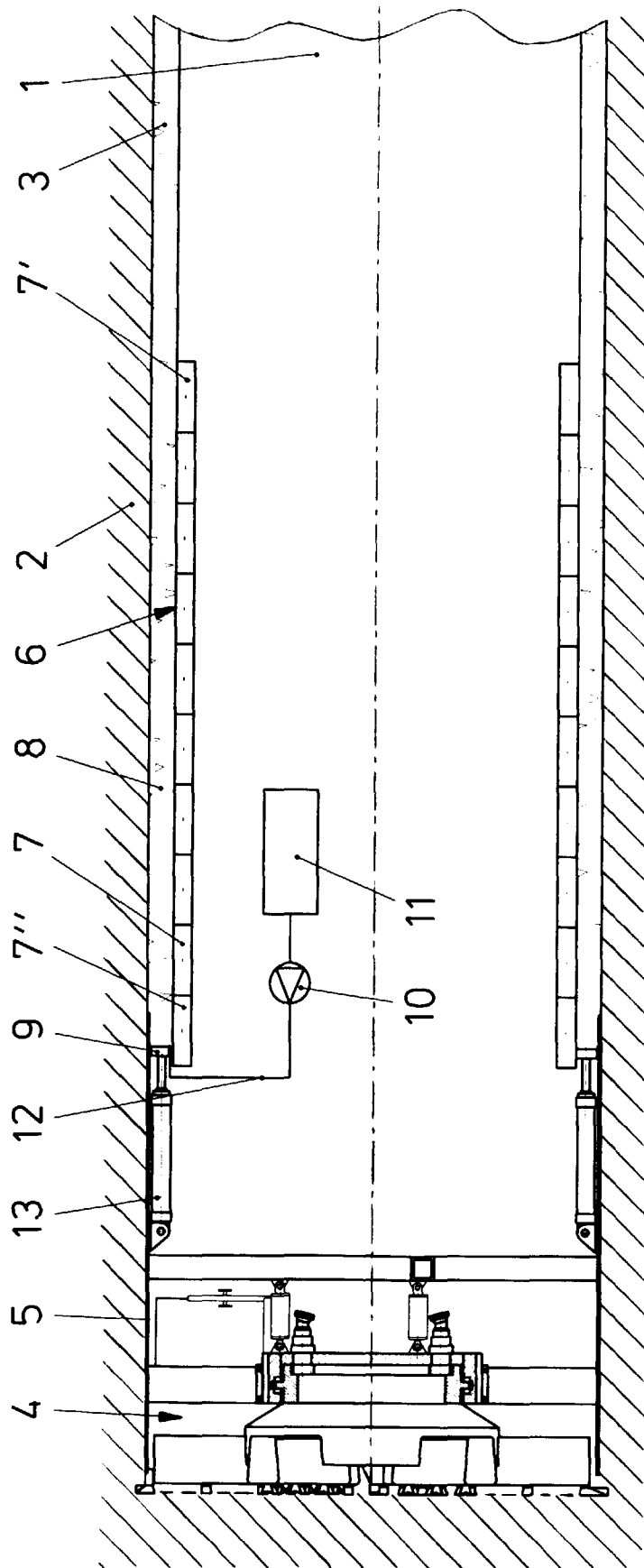


Fig. 1

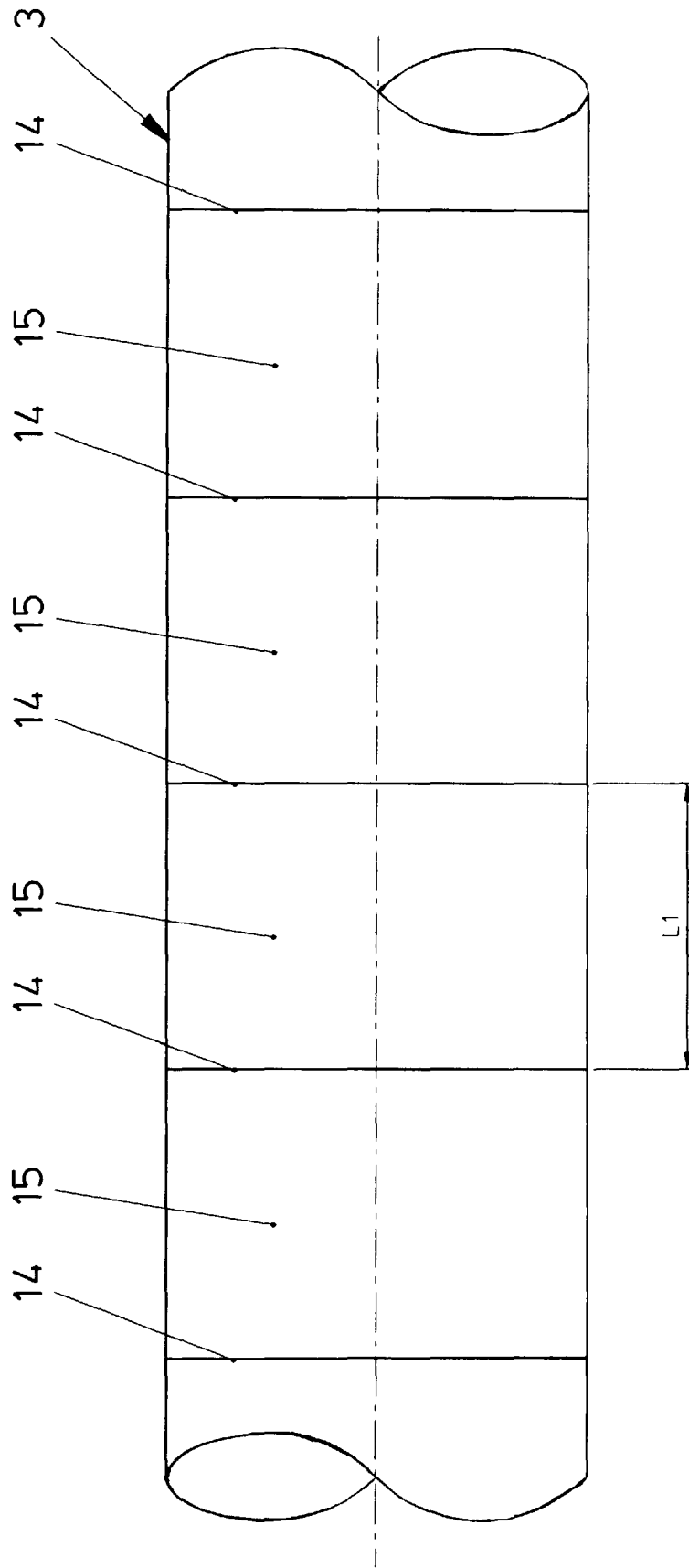


Fig. 2

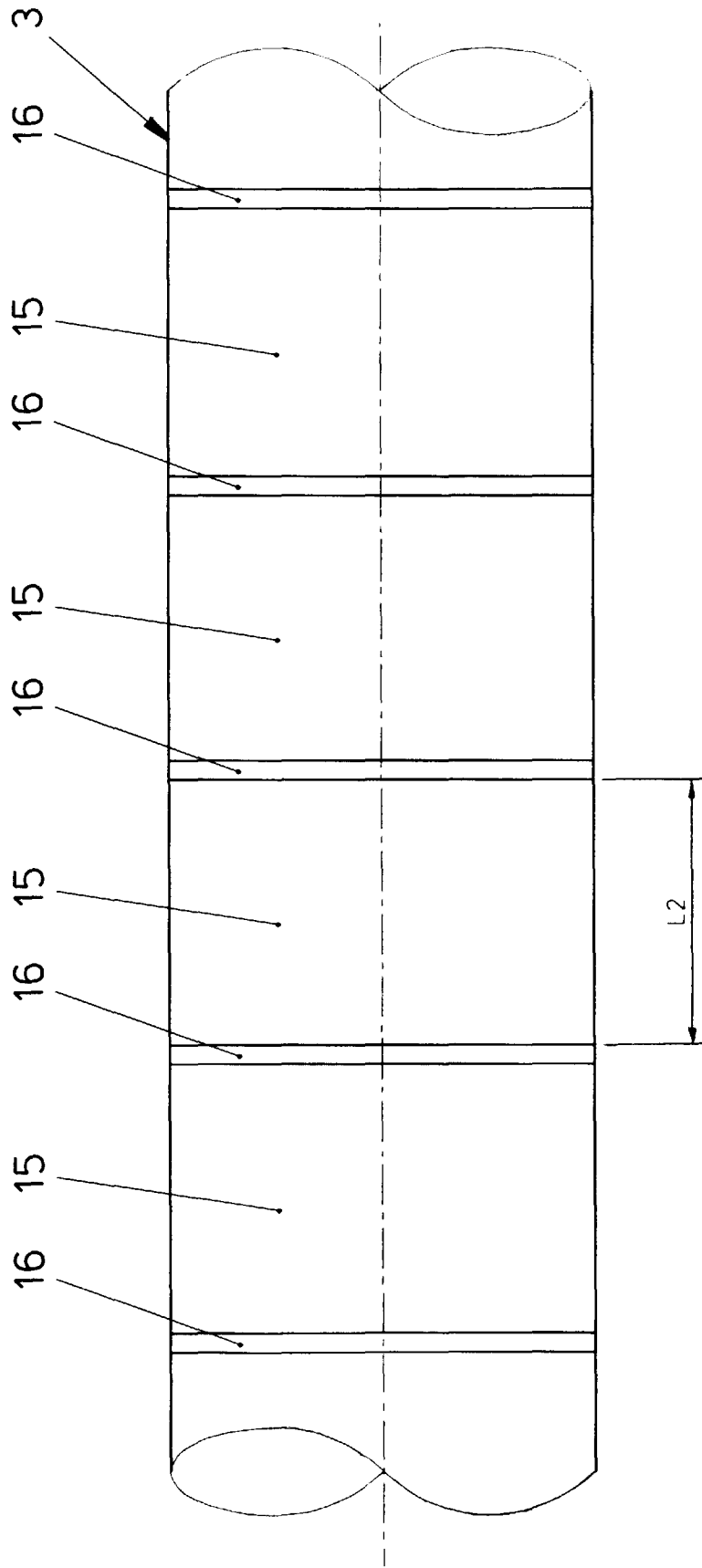


Fig. 3

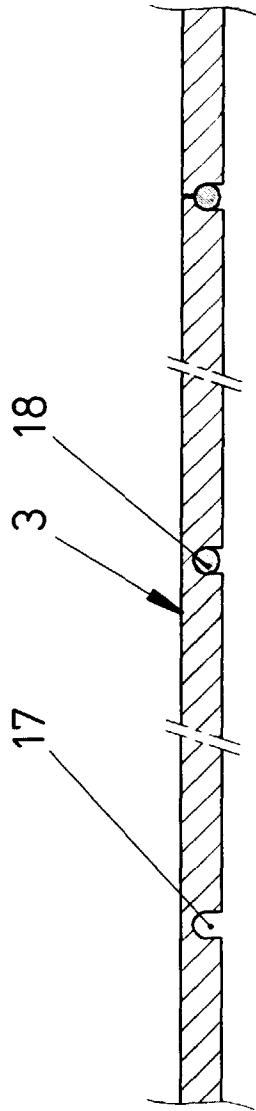


Fig. 4

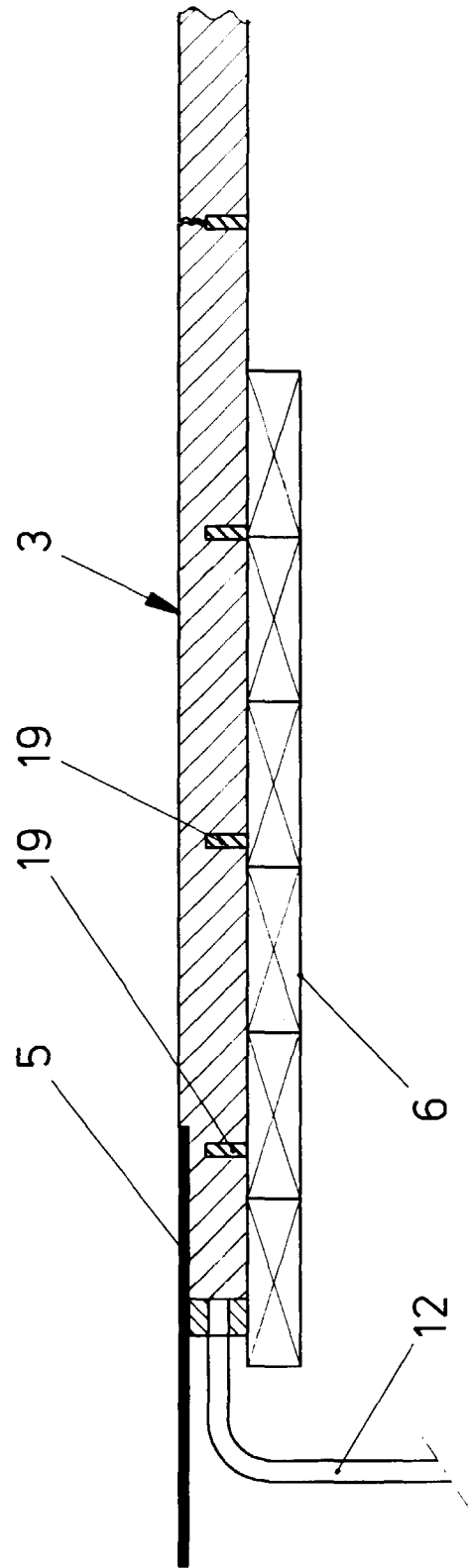


Fig. 5

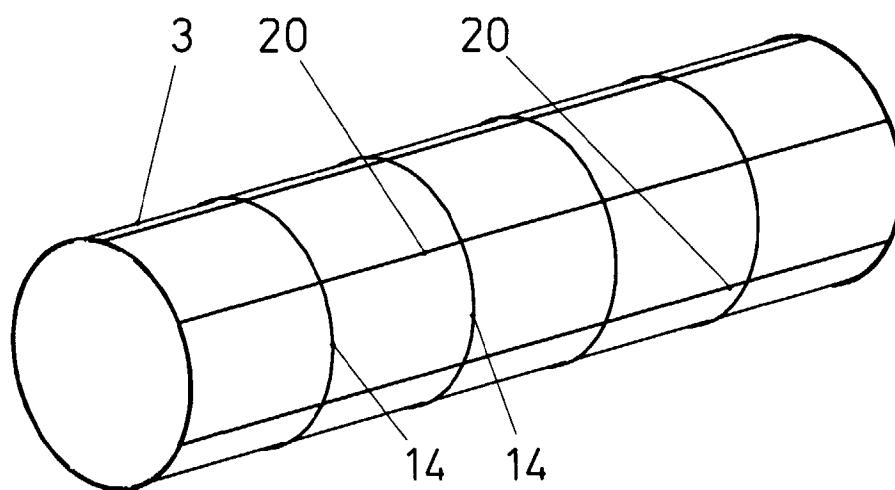


Fig. 6

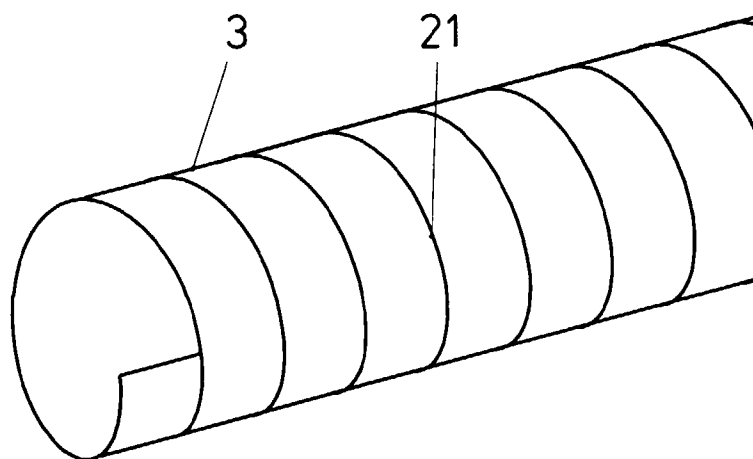


Fig. 7



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EUROPEAN SEARCH REPORT

Application Number
EP 97 20 2520

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB 2 057 035 A (LOCHER & CIE AG) * page 1, line 70 - line 90; figures * ---	1,2,7,8	E21D9/06 E21D11/10 E21D9/08
A	GB 2 146 371 A (DYCKERHOFF & WIDMANN AG) * page 2, line 84 - line 114; figures * * page 3, line 51 - line 82 * ---	1-4,7,8	
D,A	DE 29 32 430 A (HOCHTIEF AG HOCH TIEFBAUTEN) * the whole document * ---	1	
A	DE 40 01 949 A (PUTZMEISTER MASCHF) * figures * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			E21B E21D
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 19 January 1998	Examiner Fonseca Fernandez, H
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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