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(54) **Method for consolidating and impermeabilizing the ground around a tunnel**

Verfahren zur Konsolidierung und Wasserabdichtung des Bodens um einen Tunnel

Procédé pour consolider et imperméabiliser le sol autour d'un tunnel

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Description

[0001] This invention relates to a method for consolidating and impermeabilizing a portion of ground around a tunnel which has to be excavated beneath the level of a water table.

[0002] In order to consolidate a portion of ground around a tunnel which has to be excavated it is known that artificial conglomerate structures extending longitudinally and at a distance from each other around the portion of ground which has to be excavated can be formed by techniques known as "jet grouting". As is known, these techniques are based on mixing particles of the soil with binders, usually cementitious mixtures, which are injected at high pressure through radial nozzles of small size formed close to the lower extremity of a tubular shaft which is caused to rotate and rise towards the surface. The jets of binder disaggregate and mix with the surrounding soil, generating a column of conglomerate which once hardened constitutes a consolidation of the ground.

[0003] JP 10 205274 A discloses a method for consolidating a portion of ground above a tunnel which has to be excavated, comprising the steps of:

preliminarily excavating a pilot heading in the bedrock prior to the excavation of a tunnel,

- a) forming, by inserting a rod of a jet grouting equipment from the internal surface of the pilot heading, a plurality of primary blocks of artificial conglomerate spaced apart from each other above the portion of ground which has to be excavated, in a vertical plane transverse to the axis of the tunnel which has to be excavated,
- b) forming, by means of said jet grouting equipment, a plurality of infill blocks of artificial conglomerate each located between two consecutive primary blocks to firmly connect them together, forming a continuous arch-shaped structure of artificial conglomerate,
- c) repeating steps a) and b) so as to form, by means of said jet grouting equipment, further continuous arch-shaped structures adjacent and firmly attached to those previously formed, producing a continuous structure of artificial conglomerate.

[0004] US 4370077 and WO 02/12638 disclose additional methods for consolidating.

[0005] The object of this invention is to provide a method for creating a tubular shell structure of artificial conglomerate which extends continuously around the ground which has to be excavated in order to construct a tunnel beneath a water table. In particular it is intended to provide a stable and leakproof structure regardless of any inhomogeneities in the ground and the inevitable deviations from the vertical occurring in the columnar formations formed by jet grouting techniques.

mations formed by jet grouting techniques.

[0006] This and other objects and advantages are achieved in accordance with the invention through a method as defined in claim 1. Other important features of the method according to the invention are defined in the dependent claims.

[0007] A preferred but non-restrictive embodiment of the invention will now be described; reference is made to the appended drawings, in which:

- Figures 1 to 5 are diagrammatical views in vertical cross-section of the main steps in the method according to the invention, and
- Figure 6 is an enlarged diagrammatical view of a detail in Figure 5.

[0008] With reference initially to Figure 1, G diagrammatically indicates the ideal transverse cross-section of a substantially tubular shell of consolidated and sealed ground which it is desired to construct around a portion of ground T in which a tunnel is to be excavated. The portion of ground T lies beneath the level of the water table W and comprises a type of ground which is suitable for the construction of cylindrical columns of consolidated ground using jet grouting techniques. Jet grouting equipment and procedures are well known in the field of soil mechanics. As a consequence only items of specific importance and interest for the purpose of implementing the invention will be described in the remainder of this description. In respect of the parts and elements not illustrated in detail reference may therefore be made to any jet grouting system of a known type.

[0009] As used here the terms and expressions indicating positions and orientations, such as "outer", "radial", "transverse", "longitudinal", are to be understood to refer to the central axis or longitudinal direction of the tunnel which has to be excavated. Thus the term "radially outer" indicates a distal position from the central longitudinal axis x of the tunnel.

[0010] Operating with jet grouting equipment (not illustrated) located on worksurface S above ground portion T, a first series of blocks of artificial conglomerate 10, 11 arranged in an annular geometrical arrangement in a transverse vertical plane are formed around ground portion T. These blocks, which are hereinafter referred to as primary blocks, are vertical columnar members of limited height, spaced apart from each other around the ground portion T and vertically aligned in pairs. By positioning the equipment at a particular point on worksurface S, lower block 10 is first formed, followed by upper block 11 which is in vertical alignment with the lower block which has just been formed (Figure 1). Thus two separate arch portions with opposing concavities are obtained (Figure 2). Subsequently lateral columnar blocks or members 12 each of a height which is generally greater than individual primary blocks 10, 11 are formed (Figure 3).

[0011] After the primary blocks and the lateral blocks have achieved a predetermined degree of setting or hard-

ening, a second set of infill blocks 20, 21 of artificial conglomerate which firmly join together the primary blocks previously formed is formed using a jet grouting technique (Figure 4). As in the case of the primary blocks, in the case of the infill blocks too the deepest block 20 which connects two consecutive primary blocks 10 of the lower arch is first formed, and then the upper secondary block 21 which connects two consecutive primary blocks 11 of the upper arch.

[0012] A continuous closed ring structure of artificial conglomerate is thus obtained (Figure 5).

[0013] Infill blocks 20, 21 each form a radially outer portion 22 which extends transversely between two consecutive primary blocks in such a way as to partly cover lower surfaces 13, 14 of two consecutive primary blocks in the lower arch and the upper surfaces 15, 16 of two consecutive primary blocks of the upper arch (Figure 6).

[0014] Diameter D2 of the outer portions 22 of the infill blocks is preferably equal to the diameter D1 of the primary blocks incremented by approximately twice the maximum expected deviation in drilling through which the blocks are obtained. For example, in the case of infill blocks located at a depth of 20 m, in order to ensure at least partial coverage of the outer surfaces of both the adjacent primary blocks the diameter of the corresponding infill block must be increased by $20 \text{ m} \times 2/100 \times 2 = 0.8 \text{ m}$ with respect to the diameter D1 of the primary blocks. Diameter D2 of the outer portions 22 is greater than that of the intermediate part 24 between two primary blocks. This increase in diameter is obtained by slowing the rising movement of the shaft (not illustrated) bearing the injection nozzles for the cementitious mixture.

[0015] As illustrated diagrammatically in Figure 6, the outer portion of each infill or secondary block performs a sealing action between the two primary blocks against which it is formed. The lithostatic and hydrostatic pressure acting on outer surface 23 of an infill block is transferred to the outer surfaces 13-16 of the primary blocks, thus reducing permeability along the contact surfaces between the primary blocks and the infill blocks.

[0016] While the primary blocks are being formed, the pressure of the injected cementitious mixture may carry bodies such as blocks, masses, wood, lignite, coal deposits, etc., to the periphery of the primary blocks. When on the vertical interface surfaces between the primary blocks and the infill blocks, bodies of this kind might give rise to preferential routes for the passage of water. However these passages are stopped up externally by the outer portions 22 of the infill blocks. It should also be noted that some degree of amalgamation and intimate combination between the primary blocks and the infill or secondary blocks is obtained whenever the infill blocks are made when the primary blocks have not yet completely hardened.

[0017] When forming all the primary, lateral or infill blocks of conglomerate, injection of the cementitious mixture may be preceded by a stage of jetting, optionally with the simultaneous injection of pressurised air, to

break up the ground and remove the finest particles in preparation for subsequent injection of the cementitious mixture or grout.

[0018] Once the annular structure (Figure 5) has been completed, the method continues with the formation of another block adjacent and firmly connected to the previous block, thus forming a tubular shell within which a tunnel can then be excavated. Ground T is excavated from the interior of the shell with the simultaneous injection of pressurised air from compressors. The pressure of the air within the shell only partly compensates for the (lithostatic) thrust of the ground and the hydrostatic thrust, which act from the outside. The resulting pressure has a hooping effect which compresses the blocks of artificial conglomerate against each other, improving the stability of the shell.

Claims

1. A method for consolidating and impermeabilizing a portion of ground (T) around a tunnel which has to be excavated beneath the level of a water table (W), comprising the steps of:

a) forming, by means of a jet grouting equipment located on a work surface (S) above the ground portion (T), a plurality of primary blocks of artificial conglomerate (10, 11) spaced apart from each other around the portion of ground (T) which has to be excavated, in a vertical plane transverse to the axis of the tunnel which has to be excavated,

b) forming, by means of said jet grouting equipment, a plurality of infill blocks of artificial conglomerate (20, 21) each located between two consecutive primary blocks to firmly connect them together, where each infill block (20, 21) has a radially outer portion (22) which extends transversely over radially outer surfaces (13-16) of two consecutive primary blocks (10, 11), forming a continuous closed ring structures of artificial conglomerate,

c) repeating steps a) and b) so as to form, by means of said jet grouting equipment, further continuous closed ring structures adjacent and firmly attached to those previously formed, producing a continuous tubular structure of artificial conglomerate.

2. A method according to claim 1, wherein step b) includes the step of forming, by means of said jet grouting equipment, pairs of vertically aligned infill blocks (20, 21), first forming a lower infill block (20) and then an upper infill block (21).
3. A method according to claim 1, wherein step a) includes the step of forming, by means of said jet grout-

ing equipment, pairs of vertically aligned primary blocks (10, 11), first forming a lower primary block (10) and then an upper primary block (11).

4. A method according to claim 1 or 3, wherein two separate arches with opposing concavities comprising primary blocks (10, 11) are obtained on completion of step a). 5
5. A method according to claim 4, wherein step a) is followed by the step of 10
 - a1) forming, by means of said jet grouting equipment, lateral columnar blocks or members (12) which join the opposing extremities of the two separate arches of primary blocks (10, 11). 15
6. A method according to claim 1 or 5, wherein step b) takes place after the primary blocks (10, 11) or the lateral blocks (12) have reached a predetermined intermediate degree of setting or hardening. 20
7. A method according to claim 1, wherein step b) includes the step of 25
 - b1) forming, by means of said jet grouting equipment, the outer portions (22) of the infill blocks (20, 21) with a diameter (D2) which is greater than the diameter (D1) of the primary blocks (10, 11). 30
8. A method according to claim 7, wherein step b1) includes the step of forming, by means of said jet grouting equipment, the outer portions (22) of the infill blocks (20, 21) with a diameter (D2) which is greater than the diameter of the portions (24) of the infill blocks located between two consecutive primary blocks. 35
9. A method according to claim 7 or 8, wherein step b1) includes the step of slowing the rising movement of a rotating shaft, of said jet grouting equipment, provided with nozzles for injection of the cementitious mixture. 40
10. A method according to claim 7, wherein in step b1*) the diameter (D2) of the outer portions (22) of the infill blocks (20, 21) is equal to the diameter (D1) of the primary blocks (10, 11), increased by approximately twice the maximum expected deviation in drilling through which the blocks are formed. 45
11. A method according to any one of the preceding claims, wherein the jet grouting operations for forming any of the blocks (10, 11, 12, 20, 21) are preceded by a corresponding step of jetting with water, by means of said jet grouting equipment. 50

12. A method according to claim 11, wherein the jetting with water takes place with the simultaneous injection of pressurised air, by means of said jet grouting equipment.

13. A method according to claim 1, wherein step c) is followed by the step of

d) excavating a tunnel within the tubular structure of artificial conglomerate with the simultaneous injection of pressurised air.

Patentansprüche

1. Verfahren, um einen Teil des Erdbodens (T) rund um einen Tunnel zu verfestigen und wasserundurchlässig zu machen, der unterhalb des Grundwasserspiegels (W) gegraben werden soll, wobei das Verfahren folgende Schritte umfasst:

a) Ausbilden mit Hilfe eines Düsenstrahlgeräts, das auf einer Arbeitsfläche (S) oberhalb des Erdbodenteils (T) angeordnet ist, von einer Vielzahl von Primärblöcken aus künstlichem Konglomerat (10, 11), die rund um den Erdbodenteil (T), der abgegraben werden soll, voneinander in einer vertikalen Ebene quer zur Achse des Tunnels beabstandet sind, der gegraben werden soll,

b) Ausbilden mit Hilfe des Düsenstrahlgeräts von einer Vielzahl von Füllblöcken aus künstlichem Konglomerat (20, 21), von denen jeder zwischen zwei aufeinander folgenden Primärblöcken angeordnet ist, um diese fest miteinander zu verbinden, wobei jeder Füllblock (20, 21) einen radialen Außenteil (22) besitzt, der quer über radiale Außenflächen (13-16) von zwei aufeinander folgenden Primärblöcken (10, 11) verläuft, wodurch ein durchgehender, geschlossener Ringaufbau aus künstlichem Konglomerat gebildet wird,

c) Wiederholen der Schritte a) und b), um mit Hilfe des Düsenstrahlgeräts weitere fortlaufende, geschlossene Ringaufbauten auszubilden, die neben den vorher ausgebildeten Ringaufbauten liegen und an diesen fest angebracht sind, wodurch ein durchgehender, rohrförmiger Aufbau aus einem künstlichen Konglomerat hergestellt wird.

2. Verfahren gemäß Anspruch 1, wobei der Schritt b) einen Schritt aufweist, in dem mit Hilfe des Düsenstrahlgeräts Paare von vertikal ausgerichteten Füllblöcken (20, 21) ausgebildet werden, wobei zuerst ein unterer Füllblock (20) und dann ein oberer Füllblock (21) ausgebildet wird.

3. Verfahren gemäß Anspruch 1, wobei der Schritt a) einen Schritt aufweist, in dem mit Hilfe des Düsenstrahlgeräts Paare von vertikal ausgerichteten Primärblöcken (10, 11) ausgebildet werden, wobei zuerst ein unterer Primärblock (10) und dann ein oberer Primärblock (11) ausgebildet wird. 5
4. Verfahren gemäß Anspruch 1 oder 3, wobei man zwei getrennte Bögen mit entgegengesetzter Konkavität erhält, die Primärblöcke (10, 11) umfassen, wenn der Schritt a) beendet ist. 10
5. Verfahren gemäß Anspruch 4, wobei auf den Schritt a) folgender Schritt folgt: 15
- a1) Ausbilden mit Hilfe des Düsenstrahlgeräts von seitlichen Säulenblöcken oder Elementen (12), die die gegenüber liegenden Endpunkte der beiden getrennten Bögen aus Primärblöcken (10, 11) verbinden. 20
6. Verfahren gemäß Anspruch 1 oder 5, wobei der Schritt b) ausgeführt wird, nachdem die Primärblöcke (10, 11) oder die Seitenblöcke (12) einen vorgegebenen Zwischengrad der Abbindung oder der Aushärtung erreicht haben. 25
7. Verfahren gemäß Anspruch 1, wobei der Schritt b) folgenden Schritt aufweist: 30
- b1) Ausbilden mit Hilfe des Düsenstrahlgeräts der Außenteile (22) der Füllblöcke (20, 21) mit einem Durchmesser (D2), der größer als der Durchmesser (D1) der Primärblöcke (10, 11) ist. 35
8. Verfahren gemäß Anspruch 7, wobei der Schritt b1) einen Schritt aufweist, in dem mit Hilfe des Düsenstrahlgeräts die Außenteile (22) der Füllblöcke (20, 21) mit einem Durchmesser (D2) ausgebildet werden, der größer als der Durchmesser der Teile (24) der Füllblöcke ist, die zwischen zwei aufeinander folgenden Primärblöcken angeordnet sind. 40
9. Verfahren gemäß Anspruch 7 oder 8, wobei der Schritt b1) einen Schritt aufweist, in dem die Aufwärtsbewegung einer rotierenden Welle des Düsenstrahlgeräts verlangsamt wird, die mit Düsen zum Einspritzen des zementartigen Gemischs versehen ist. 45
10. Verfahren gemäß Anspruch 7, wobei im Schritt b1) der Durchmesser (D2) der Außenteile (22) der Füllblöcke (20, 21) gleich dem Durchmesser (D1) der Primärblöcke (10, 11) ist, der um etwa das Doppelte der erwarteten Maximalabweichung beim Bohren vergrößert wurde, mit dem die Blöcke ausgebildet werden. 50
11. Verfahren gemäß irgendeinem der bisherigen Ansprüche, wobei vor den Düsenstrahlarbeiten, mit denen irgendeiner der Blöcke (10, 11, 12, 20, 21) ausgebildet wird, ein entsprechender Schritt erfolgt, bei dem mit Hilfe des Düsenstrahlgeräts Wasser ausgestoßen wird.
12. Verfahren gemäß Anspruch 11, wobei der Wasserausstoß gleichzeitig mit dem Einblasen von Druckluft mit Hilfe des Düsenstrahlgeräts erfolgt.
13. Verfahren gemäß Anspruch 1, wobei auf den Schritt c) folgender Schritt folgt: 55
- d) Ausgraben eines Tunnels im rohrförmigen Aufbau aus künstlichem Konglomerat, wobei gleichzeitig Druckluft eingeblasen wird.
- ### Revendications
1. Procédé pour consolider et imperméabiliser une partie de sol (T) autour d'un tunnel qui doit être creusé en dessous du niveau de la nappe phréatique (W), comprenant les étapes consistant à:
- a) former, au moyen d'un équipement d'injection de ciment situé sur une surface de travail (S) au-dessus de la partie de sol (T), une pluralité de blocs primaires de conglomerat artificiel (10, 11) espacés les uns des autres autour de la partie de sol (T) qui doit être creusée, dans un plan vertical transversal à l'axe du tunnel qui doit être creusé,
- b) former, au moyen dudit équipement d'injection de ciment, une pluralité de blocs de remplissage de conglomerat artificiel (20, 21), chacun situés entre deux blocs primaires consécutifs pour les relier fermement l'un à l'autre, où chaque bloc de remplissage (20, 21) comporte une partie extérieure de façon radiale (22) qui s'étend transversalement par-dessus des surfaces extérieures de façon radiale (13 à 16) de deux blocs primaires consécutifs (10, 11), formant une structure annulaire fermée continue de conglomerat artificiel,
- c) répéter les étapes a) et b) afin de former, au moyen dudit équipement d'injection de ciment, des structures annulaires fermées continues supplémentaires adjacentes et fermement fixées à celles auparavant formées, produisant une structure tubulaire continue de conglomerat artificiel.
2. Procédé selon la revendication 1, dans lequel l'étape b) comprend l'étape consistant à former, au moyen dudit équipement d'injection de ciment, des paires de blocs de remplissage alignés verticalement (20,

- 21), en formant d'abord un bloc de remplissage inférieur (20) et puis un bloc de remplissage supérieur (21).
3. Procédé selon la revendication 1, dans lequel l'étape a) comprend l'étape consistant à former, au moyen dudit équipement d'injection de ciment, des paires de blocs primaires verticalement alignés (10, 11), en formant d'abord un bloc primaire inférieur (10) et puis un bloc primaire supérieur (11). 5 10
4. Procédé selon la revendication 1 ou 3, dans lequel deux arches séparées avec des concavités opposées comprenant des blocs primaires (10, 11) sont obtenues lors de l'achèvement de l'étape a). 15
5. Procédé selon la revendication 4, dans lequel l'étape a) est suivie par l'étape consistant à : a1) former, au moyen dudit équipement d'injection de ciment, des blocs ou éléments latéraux en colonne (12) qui joignent les extrémités opposées des deux arches séparées de blocs primaires (10, 11). 20
6. Procédé selon la revendication 1 ou 5, dans lequel l'étape b) a lieu après que les blocs primaires (10, 11) ou les blocs latéraux (12) ont atteint un degré intermédiaire prédéterminé de prise ou de durcissement. 25
7. Procédé selon la revendication 1, dans lequel l'étape b) comprend l'étape consistant à : b1) former, au moyen dudit équipement d'injection de ciment, les parties extérieures (22) des blocs de remplissage (20, 21) avec un diamètre (D2) qui est supérieur au diamètre (D1) des blocs primaires (10, 11). 30 35
8. Procédé selon la revendication 7, dans lequel l'étape b1) comprend l'étape consistant à former, au moyen dudit équipement d'injection de ciment, les parties extérieures (22) des blocs de remplissage (20, 21) avec un diamètre (D2) qui est supérieur au diamètre des parties (24) des blocs de remplissage situés entre deux blocs primaires consécutifs. 40
9. Procédé selon la revendication 7 ou 8, dans lequel l'étape b1) comprend l'étape consistant à ralentir le mouvement ascendant d'un arbre rotatif, dudit équipement d'injection de ciment, pourvu de buses pour l'injection du mélange cimentaire. 45 50
10. Procédé selon la revendication 7, dans lequel, dans l'étape b1), le diamètre (D2) des parties extérieures (22) des blocs de remplissage (20, 21) est égal au diamètre (D1) des blocs primaires (10, 11), augmenté d'approximativement deux fois l'écart prévu maximum du forage à travers lequel les blocs sont formés. 55
11. Procédé selon une quelconque des revendications précédentes, dans lequel les opérations d'injection de ciment pour former un quelconque des blocs (10, 11, 12, 20, 21) sont précédées par une étape correspondant d'injection d'eau, au moyen dudit équipement d'injection de ciment.
12. Procédé selon la revendication 11, dans lequel l'injection d'eau a lieu avec l'injection simultanée d'air sous pression, au moyen dudit équipement d'injection de ciment.
13. Procédé selon la revendication 1, dans lequel l'étape c) est suivie par l'étape consistant à : d) creuser un tunnel à l'intérieur de la structure tubulaire de conglomérat artificiel avec l'injection simultanée d'air sous pression.

FIG. 1

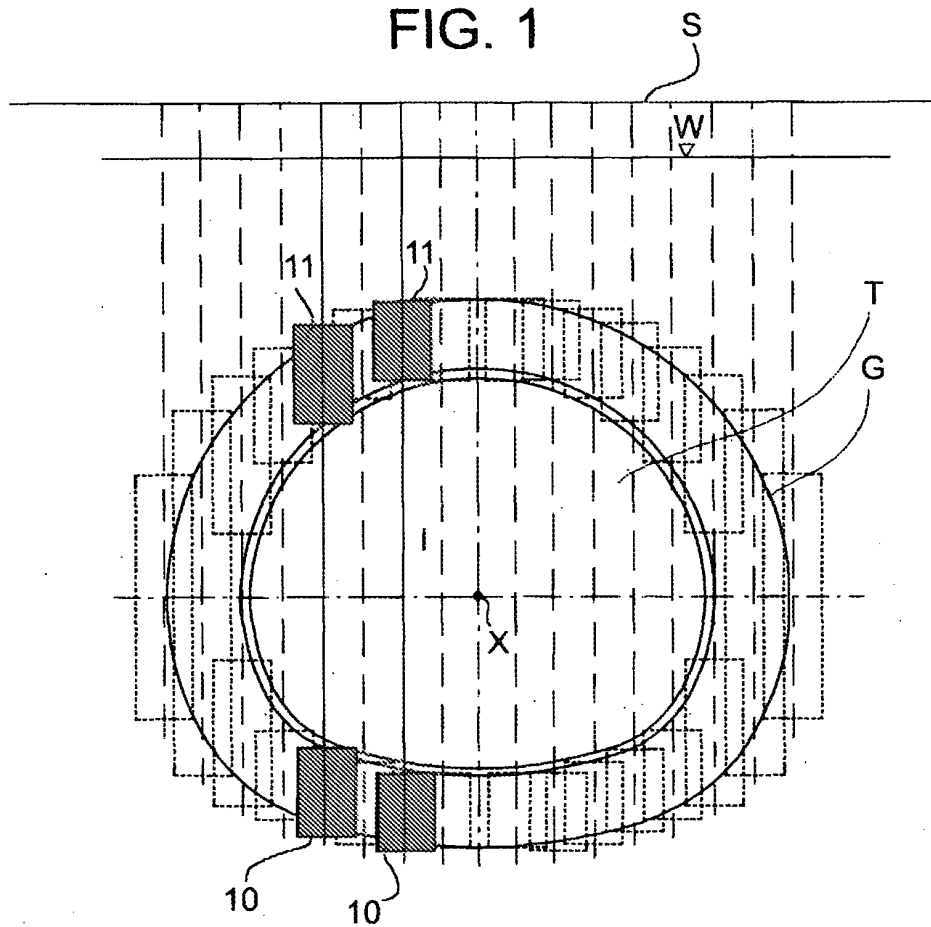


FIG. 2

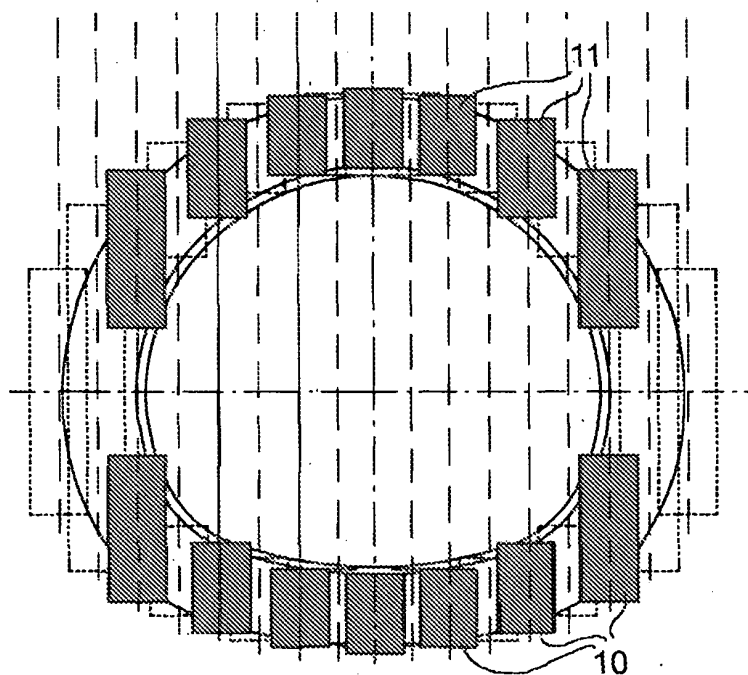


FIG. 3

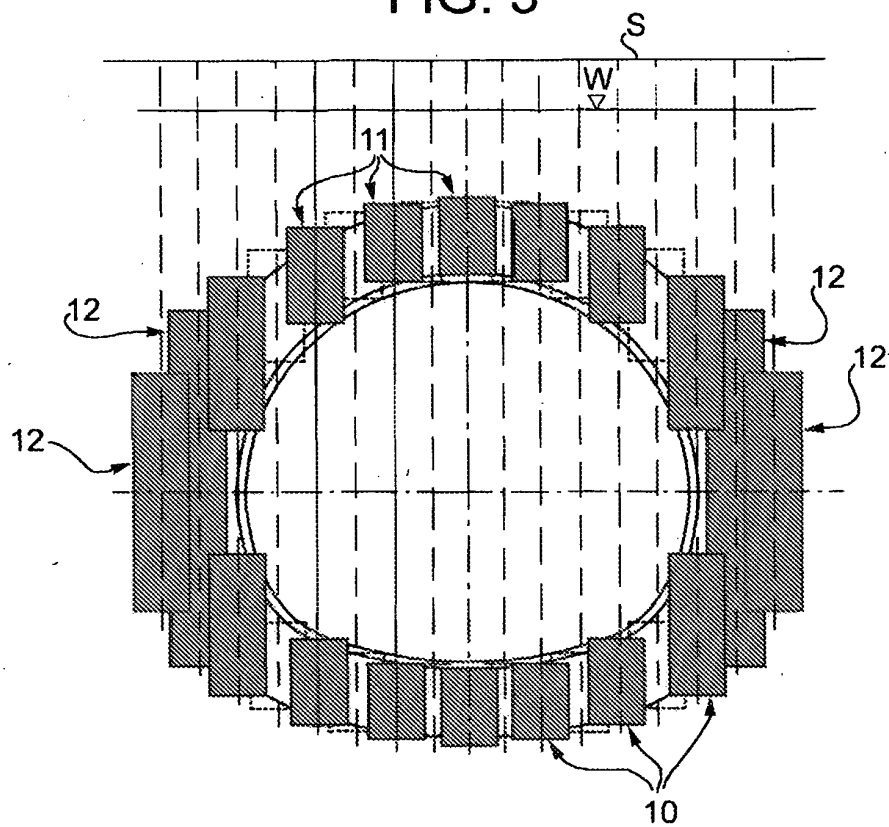


FIG. 4

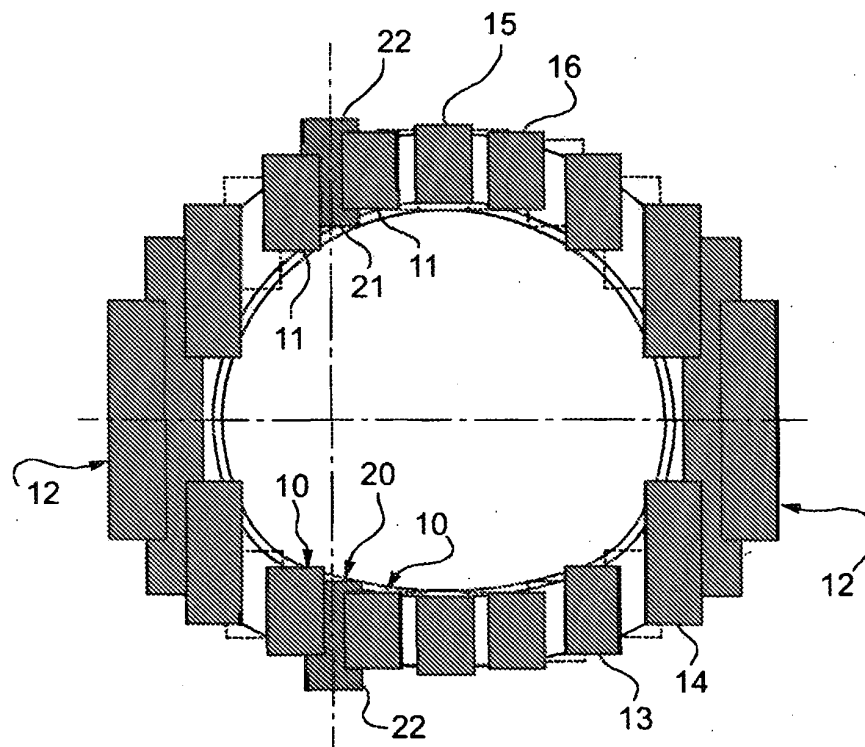


FIG. 5

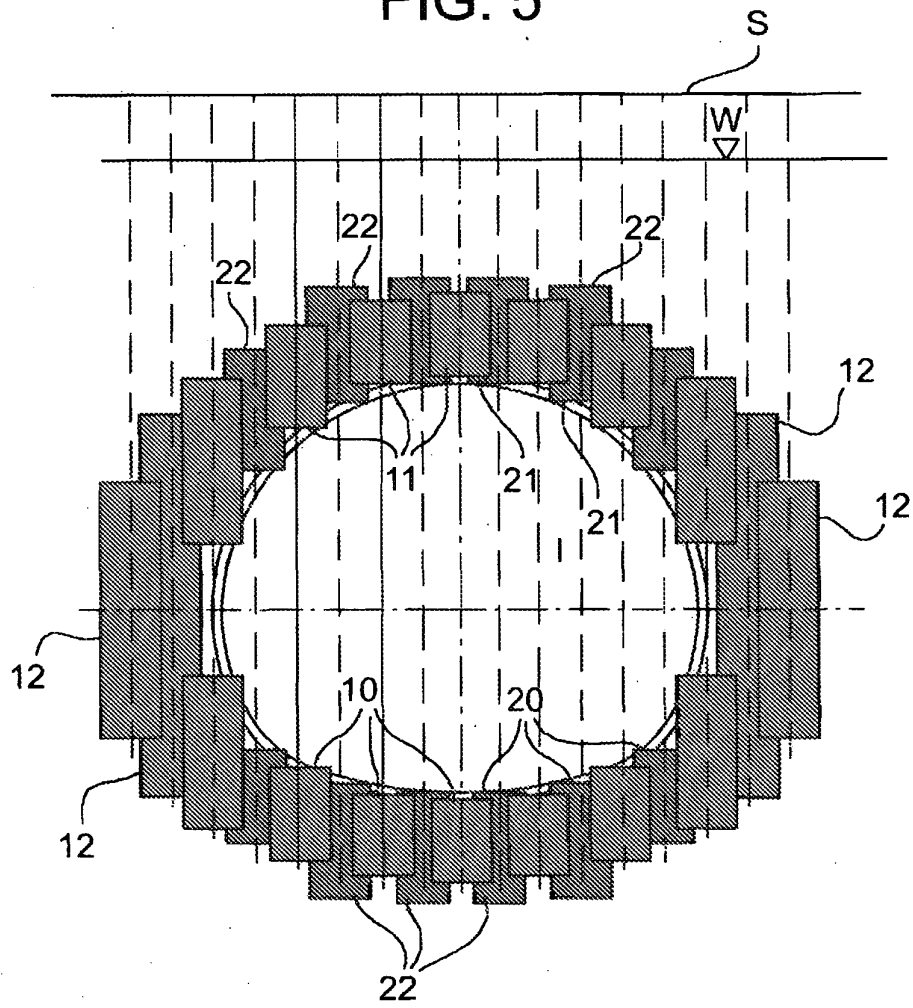
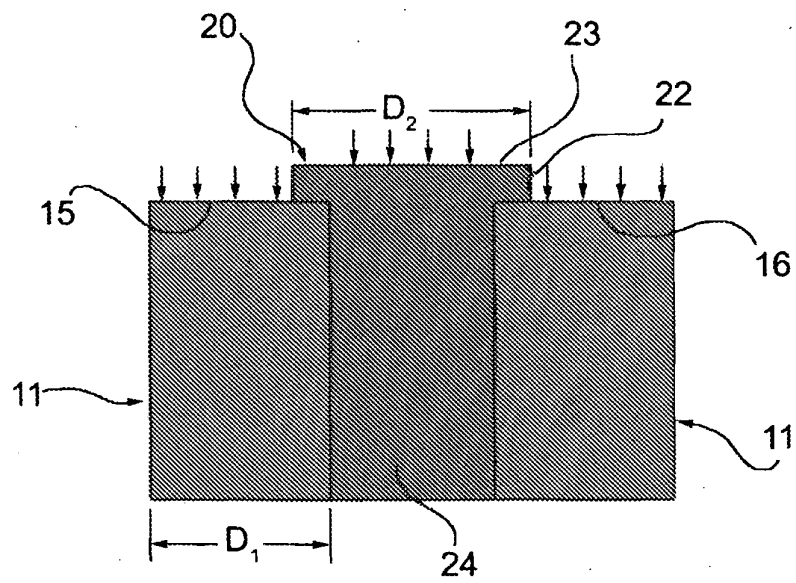


FIG. 6



REFERENCES CITED IN THE DESCRIPTION

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