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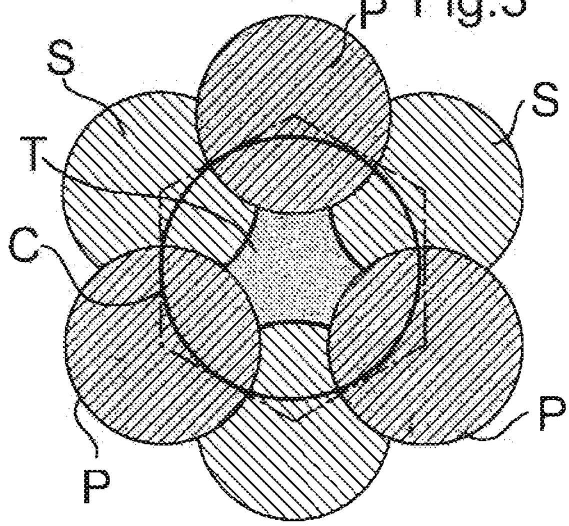
(54) A method of building a monolithic underground concrete structure

(57) Jet grouting methods are used to form a first plurality of parallel primary columns (P) which are spaced apart from each other and which are positioned with a spacing between them according to a predetermined reticular layout. A second set of secondary columnar blocks (S) is then formed, each of these blocks being interposed between and securely joining two consecutive primary blocks (P), thus providing at least one closed ring structure composed of a sequence of primary blocks alternating with secondary blocks which surround at least one central portion of soil. Finally, a tertiary columnar block (T) is formed in this central portion to securely join the surrounding primary (P) and secondary (S) blocks. These operations are repeated to produce a monolithic underground artificial conglomerate structure.

Fig.3



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Description

[0001] The present invention relates to a method of constructing a monolithic underground artificial conglomerate structure for the purposes of consolidation and/or waterproofing.

[0002] In order to consolidate volumes of soil having a clearly defined geometry, methods known as "jet grouting" are used to form columnar artificial conglomerate structures, spaced apart from each other, around the portion of soil to be excavated. These methods are based on the mixing of particles of the soil itself with binders, usually cement mixtures, which are injected at high pressure through small radial nozzles formed in the proximity of the lower end of a tubular shaft which is rotated and raised towards the surface. The jets of binder disgregate and are mixed with the surrounding soil, thus creating a column of conglomerate which, when hardened, consolidates the soil. The disgregating efficiency of the jet can be increased by the addition of injected water and/or pressurized air.

[0003] The object of the present invention is to propose a method of constructing monolithic artificial conglomerate structures which extend continuously in the soil. In particular, the aim is to form a stable waterproof structure, regardless of any non-uniformity of the soil and the inevitable deviations from the vertical of the columnar formations created by jet grouting.

[0004] This and other objects and advantages are achieved, according to the invention, by a method as defined in Claim 1. Other important characteristics of the method according to the invention are defined in the dependent claims.

[0005] Two preferred, but non-limiting, embodiments of the invention will now be described; reference will be made to the attached drawings, in which:

Figure 1 is a schematic cross section showing a group or cell of columnar blocks which, together with other similar contiguous groups, forms a monolithic artificial conglomerate structure;
Figure 2 is a view similar to Figure 1, showing a possible condition which may develop during the application of the method according to the invention;
Figure 3 is a schematic cross section of a cell of columnar blocks according to an embodiment of the method which is an alternative to that shown in Figure 1;
Figure 4 is a schematic view in vertical section of part of the cell of Figure 3;
Figure 5 is a schematic view in elevation of three contiguous cells of the type shown in Figure 3;
Figure 6 is a schematic plan view of part of a structure formed by cells of the type shown in Figures 3-5;
Figure 7 is a schematic view, similar to that of Figure 5, of a preferred embodiment of the method with cap formations joined together to form a continuous slab which is superimposed on the previously formed columnar blocks; and
Figure 8 is a schematic plan view of part of a structure according to the embodiment of Figure 7.

[0006] With reference to Figure 1 initially, the construction of a monolithic underground artificial conglomerate structure according to the invention is carried out in a sequence of steps in which ordered groups of columnar blocks of consolidated soil, closely and rigidly interconnected and called "closed cells" in this text, are constructed. One of these cells is shown in Figure 1. The columnar blocks P, S, and T which make up the cell are formed by jet grouting methods.

[0007] The equipment and methods for jet grouting are well known in the field of soil mechanics, and therefore they will not be described or illustrated in detail in this document. The shape, dimensions and function of the underground structure can vary according to requirements, and are not to be interpreted as limiting the scope of the patent in any way. For example, the invention can be used for constructing a substantially tubular shell of consolidated and waterproofed soil which is to be constructed around a portion of soil in which a tunnel is to be excavated.

[0008] Using jet grouting equipment (not shown) placed on a working surface above a portion of soil in which the structure is to be constructed, a first set of artificial conglomerate blocks P is formed, these blocks being positioned in a predetermined reticular geometrical layout. These blocks, referred to hereafter as primary columns, are vertical columnar elements whose height depends on the vertical thickness of the structure to be constructed. The primary columns P are parallel to each other and spaced apart from each other. In the example of embodiment shown in the drawings, the cells have a reticular layout with a triangular or hexagonal (honeycomb) mesh, in which the central axes of the primary columns P are positioned at the vertices of an equilateral triangle or at the non-consecutive vertices of a regular hexagon.

[0009] After the primary columns have reached a predetermined degree of setting or hardening, a jet grouting method is used to form a second set of columnar blocks or parallel secondary columns S of artificial conglomerate. Each secondary column S is interposed between, and securely joins, two primary columns P formed previously, causing the combined primary and secondary columns of each cell to form a closed ring structure. In the illustrated example, the secondary columns have their respective axes positioned on the vertices of the hexagon alternating with the vertices on which the axes of the primary columns are located.

[0010] After the secondary columns have reached a certain degree of hardening, a tertiary column T is formed, again by jet grouting, in the central space formed between the primary and secondary columns of each cell.

[0011] Because of the hardening of the primary columns, which theoretically have a circular cross section, the secondary columns have a cross section with concave lobes along their surfaces adjoining the primary columns. The tertiary columns have a cross section of multiple-lobed shape with concave lobes along their surfaces adjoining the primary and secondary columns. In the preferred embodiment of the invention, all the columns of each type (primary, secondary, tertiary) are formed with a constant jet grouting treatment intensity for each metre of column, for example with a jet having a flow rate of 300-320 1/min. at a pressure of 400-420 bars. The different shapes of the primary, secondary and tertiary columns correspond to different cross-sectional areas, this area in the secondary columns being about 60% of that of the primary columns, while in the tertiary columns it is about 30% of the area of the primary columns. Consequently, the specific energy per cubic metre of consolidated soil for the secondary columns is 160% of that of the primary columns, while it is 300% for the tertiary columns, assuming that the same jet grouting parameters are maintained for each linear metre of column.

[0012] The tertiary columns are formed in the spaces enclosed by the primary and secondary columns, and are therefore protected from any negative external effects such as movements of the water-table and the presence of soils with increasing permeability which could lead to losses of cement mixture from the outside of the cell.

[0013] Clearly, the primary and secondary columns of each cell are also primary and secondary columns of contiguous cells. The formation of the tertiary columns improves the overall strength by compensating for any deviations from the parallel arrangement of the previously formed columns. The tertiary columns closely bind all the surrounding columns, by which they are also protected, and therefore the cement mixture which is injected, or "jetted", scarifies and penetrates the surfaces of the primary and secondary columns facing the centre of the cell.

[0014] In some cases, the formation of the tertiary column remedies any untreated areas. As shown by way of example in Figure 2, an area Z of soil which has not been treated during the formation of the secondary column S because of a body A (for example a rock or a tree trunk) is subsequently reached by the cement mixture when the tertiary column T is formed. Even in soils with very high local horizontal permeability, the formation of the tertiary column takes place in the centre of a "well" formed by the primary and secondary columns of the cell, which confine the jetting mixture without making it flow out. This confining or sealing effect is multiplied as the operation proceeds.

[0015] Furthermore, the mutual "grooving" of the columns opposes their separation when the finished structure is stressed by a load, for example when part of the soil at one side of the structure is excavated.

[0016] Depending on the extension of the artificial conglomerate structure, the operating requirements and the soil conditions, the structure is completed by forming more or less numerous groups of cells simultaneously or in succession, until the whole area specified by the design is covered, thus providing a continuous monolithic structure. If required by the geometrical conditions, the closed cells can be formed with some columns vertical and some inclined, or with all the columns inclined.

[0017] With reference now to Figures 3-5, in a preferred embodiment of the method according to the invention it is possible to reinforce the joining of the component columns of the structure and to make the structure more waterproof and monolithic by forming caps C of substantially disc-like shape. These caps are widened upper and/or lower extensions of the tertiary columns T, and extend transversely so as to cover, at least partially, the ends of the primary and secondary columns which surround the tertiary columns concerned.

[0018] The caps C are formed by increasing one or more of the jetting parameters for the tertiary columns when the jetting nozzle has risen above the tops of the primary and secondary columns. The larger diameter of the cap can be obtained, for example, by increasing the pressure or the flow rate of the mixture, or by retarding the rising movement of the hollow shaft (not shown) which carries the cement mixture injection nozzles. If required by the soil condition or by the requirements of the construction, the caps C can be formed at both the bottoms and the tops of the primary and secondary columns, in other words at both ends of the structure. Alternatively, the caps can be formed on only one end of the structure, for example over the tops of the columns.

[0019] The diameter of the caps depends on the intensity of the jetting. As shown in Figure 6, the diameter can be specified in such a way that the caps of the contiguous closed cells are tangential to each other. Thus the vertical contact surfaces between the columns P, S and T are sealed by the caps of the tertiary columns and cannot form preferential paths for the flow of water through the structure.

[0020] The best results are obtained if the caps C, as shown in Figures 7 and 8, are extended in such a way that they are joined securely to each other, penetrating into each other and forming a continuous monolithic layer or slab of conglomerate which covers the underlying structure comprising the primary and secondary columns. The superimposed layer formed by the caps C seals off all possible paths for the infiltration of water and also greatly reinforces the overall rigidity of the structure. Experimental trials conducted by the applicant have demonstrated that a continuous layer formed by inter-penetrating caps gives excellent results when the soil below the conglomerate structure is excavated; the cap layer minimizes the deformation of the structure and the yielding due to the weight of the soil bearing on its top, and is of fundamental importance in ensuring that the joints between the columns do not open except to a negligible extent, and that any significant infiltration of water through the structure therefore continues to be impeded.

Claims

1. A method of constructing a monolithic underground artificial conglomerate structure, comprising the steps of:

   a) forming, by jet grouting methods, a first plurality of parallel primary columns (P) which are spaced apart from each other and are positioned with a spacing between them according to a predetermined reticular layout;
   b) forming, by jet grouting methods, a second plurality of secondary columnar blocks (S), each of which is interposed between and securely joins two consecutive primary blocks (P), thus providing at least one closed ring structure composed of a sequence of primary blocks alternating with secondary blocks which surround at least one central portion of soil;
   c) forming in the said central portion(s), by jet grouting methods, a corresponding tertiary column (T) which securely joins the surrounding primary (P) and secondary (S) blocks.

2. A method according to Claim 1, wherein the columnar blocks (P) are positioned in a reticular layout with a triangular or hexagonal mesh.

3. A method according to Claim 1, wherein step b) is carried out after the columnar blocks formed in step a) have reached a predetermined degree of setting or hardening.

4. A method according to Claim 1 or 3, wherein step c) is carried out after the columnar blocks formed in step b) have reached a predetermined degree of setting or hardening.

5. A method according to Claim 1, wherein the columnar blocks (P, S, T) are formed with a constant jet grouting intensity along their length.

6. A method according to Claim 5, wherein the secondary columnar blocks (S) have a cross section whose area is about 60% of that of the primary columnar blocks (P).

7. A method according to Claim 5 or 6, wherein the tertiary columnar blocks (T) have a cross section whose area is about 30% of that of the primary columnar blocks (P).

8. A method according to Claim 1, wherein step c) includes the step of
   forming, at one end at least of a tertiary columnar block (T), a widened extension (C) which extends transversely so as to cover, at least partially, the ends of the primary (P) and secondary (S) columnar blocks which surround the tertiary columnar block.

9. A method according to Claim 8, wherein step c) includes the step of
   forming, at each end of a tertiary columnar block (T), a corresponding widened extension (C) which extends transversely so as to cover, at least partially, the ends of the primary (P) and secondary (S) columnar blocks which surround this tertiary columnar block.

10. A method according to Claim 8 or 9, wherein the widened extension (C) of a given tertiary columnar block (T) has a transverse dimension such that it is tangential to a similar widened extension (C) of another tertiary columnar block positioned close to the said given tertiary block.

11. A method according to Claim 8 or 9, wherein the widened extension (C) of a given tertiary columnar block (T) has a transverse dimension such that it is securely joined to similar widened extensions (C) of other neighbouring tertiary columnar blocks, so as to form a continuous monolithic layer or slab of conglomerate which covers the structure lying above and/or below, comprising the primary (P) and secondary (S) columnar blocks.

12. A method according to any one of Claims 8 to 11, wherein the widened extensions (C) are formed by increasing the pressure or the flow rate of the cement mixture used to form the tertiary columnar blocks beyond the upper and/or lower ends of these blocks.

13. A method according to any one of Claims 8 to 12, wherein the widened extensions (C) are formed by retarding the vertical movement of cement mixture injection means with respect to the vertical speed at which the said injection means move to form the tertiary columnar blocks.

Fig.1

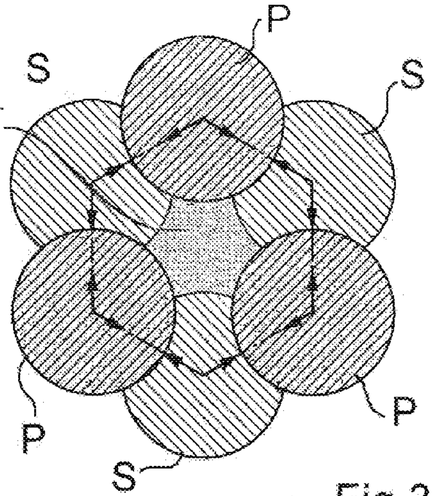


Fig.2

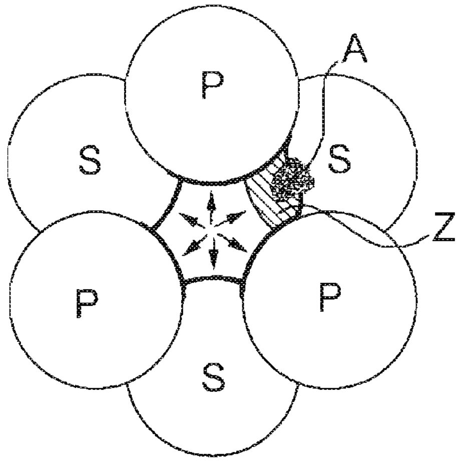


Fig.3

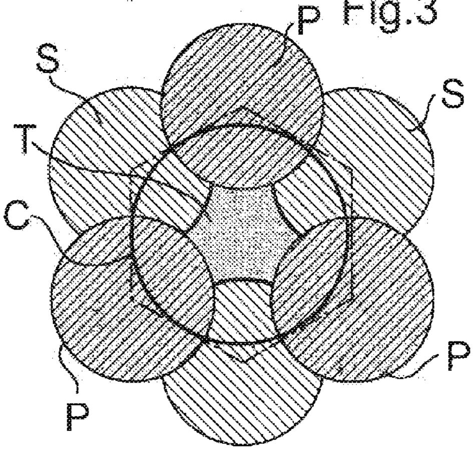


Fig.4

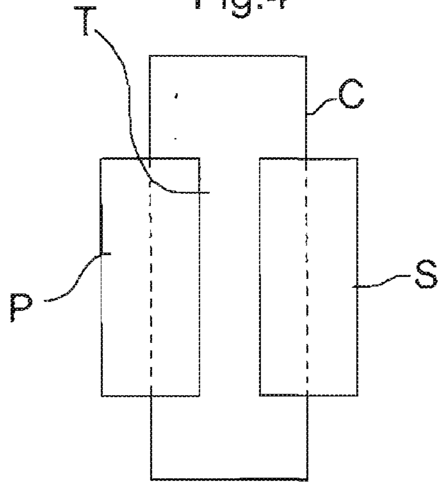


Fig.5

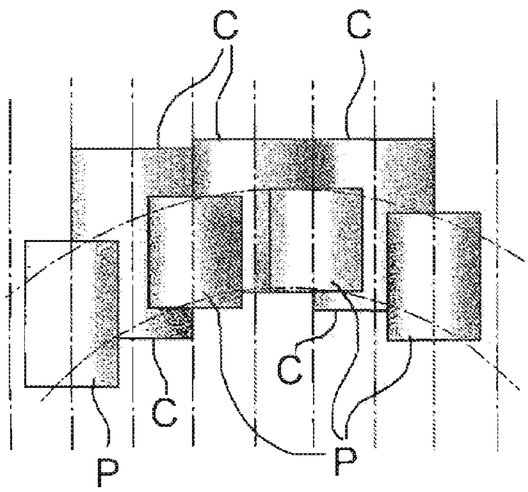
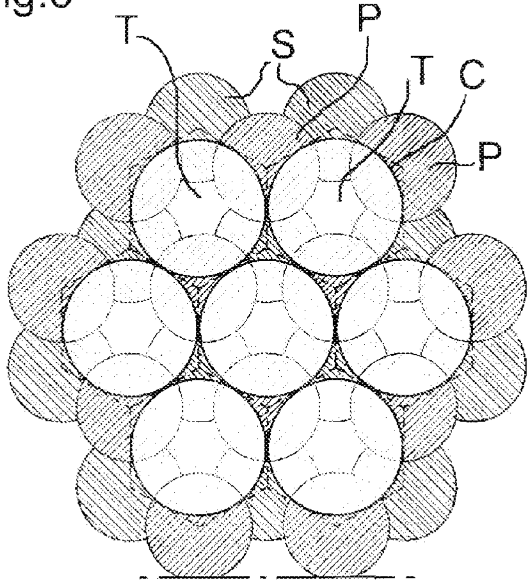


Fig.6



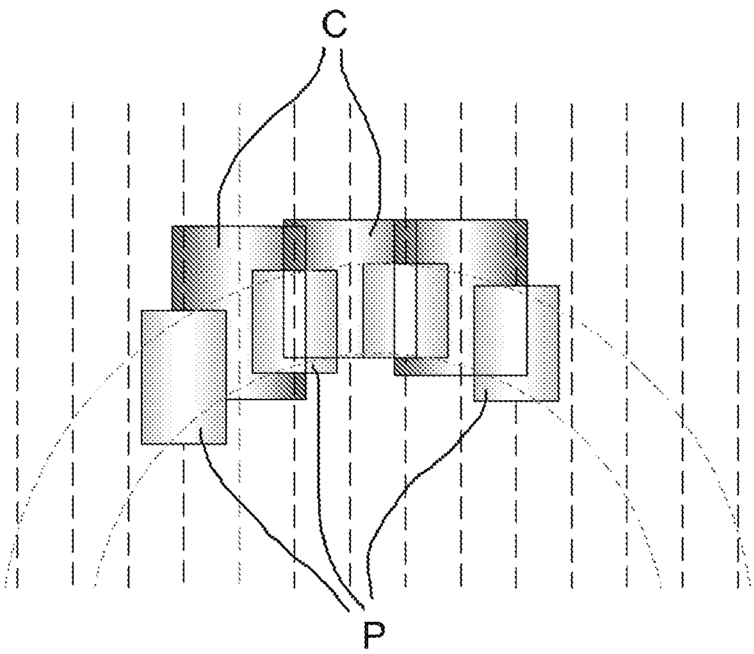


FIG.7

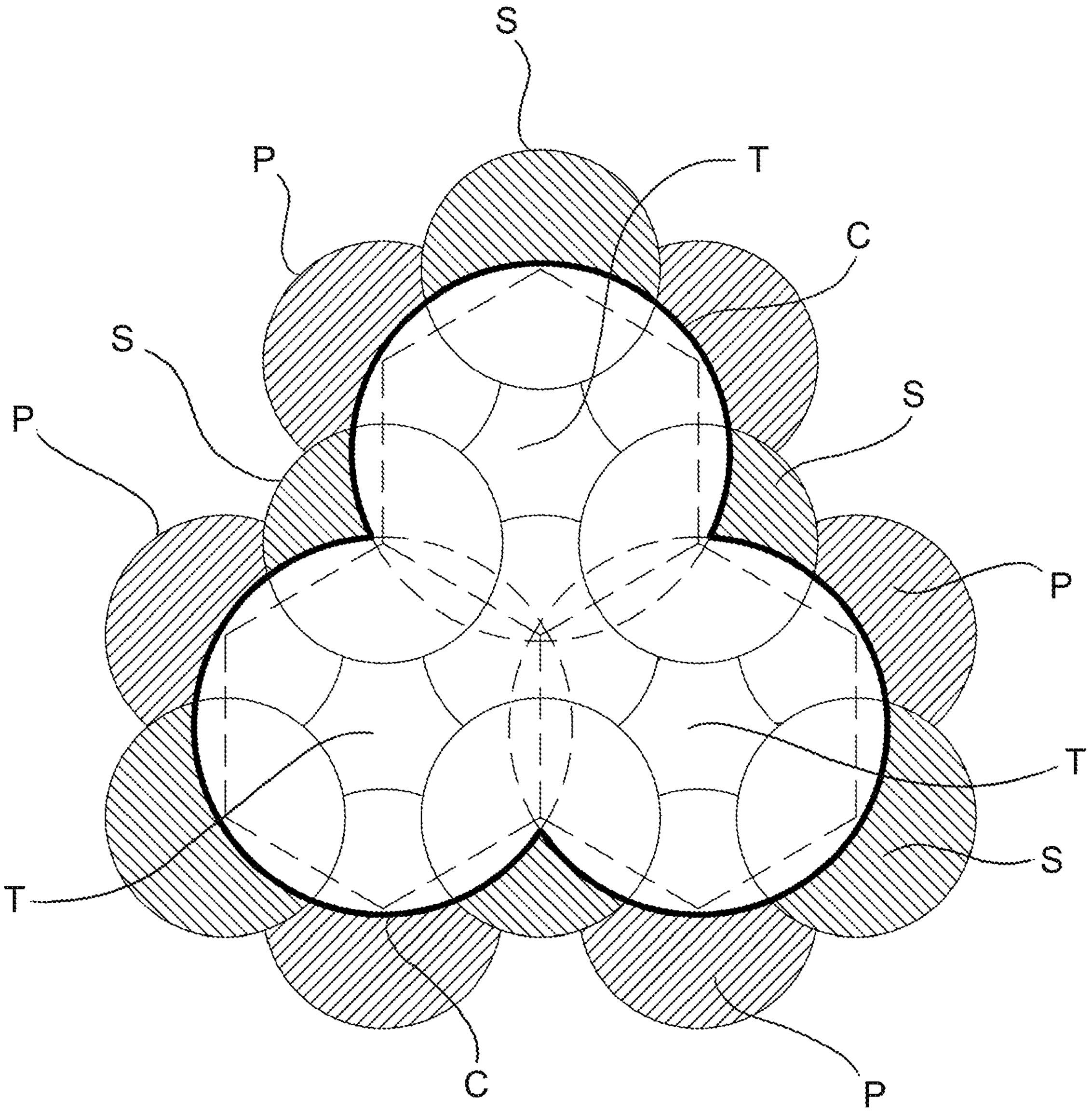


FIG.8