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(54) **A PREFABRICATED MODULAR ENERGY SEGMENT, A TUNNEL LINING MADE WITH A PLURALITY OF SUCH SEGMENTS AND A METHOD FOR EXCHANGING HEAT IN A TUNNEL BY MAKING A LINING WITH A PLURALITY OF SUCH SEGMENTS**

VORGEFERTIGTES MODULARES ENERGIESEGMENT, TUNNELAUSKLEIDUNG MIT MEHREREN SOLCHEN SEGMENTEN UND VERFAHREN ZUM WÄRMEAUSTAUSCH IN EINEM TUNNEL DURCH HERSTELLUNG EINER AUSKLEIDUNG MIT MEHREREN SOLCHEN SEGMENTEN

SEGMENT D'ÉNERGIE MODULAIRE PRÉFABRIQUÉ, CHEMISAGE DE TUNNEL CONSTITUÉ D'UNE PLURALITÉ DE TELS SEGMENTS ET PROCÉDÉ D'ÉCHANGE DE CHALEUR DANS UN TUNNEL PAR LA FABRICATION D'UN CHEMISAGE AVEC UNE PLURALITÉ DE TELS SEGMENTS

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Description

TECHNICAL FIELD

[0001] The present invention relates to the field of energy geostructures, to their application to tunnels, and, more generally, to civil engineering works.

[0002] More precisely the present invention relates to a prefabricated modular energy segment, that can be used for lining a tunnel to exchange heat with ground and/or with internal environment of the tunnel itself; in particular the prefabricated modular energy segment according to the present invention can take many configurations different from each other as regards number of networks of pipes and their positioning.

[0003] The present invention relates also to a tunnel lining made with a plurality of such prefabricated modular energy segments, radially joined with each other.

[0004] The invention relates also to a method for exchanging heat in a tunnel by making a lining with a plurality of such prefabricated modular energy segments.

[0005] The prefabricated modular energy segment according to the present invention can be advantageously used in the transport field, specifically in newly constructed urban tunnels for underground railway lines, for networks of water systems/sewer systems and for similar applications, as well as extra-urban tunnels, bored with a mechanized method by the Tunnel Boring Machine (TBM).

[0006] More in general, the prefabricated modular energy segment according to the present invention finds an advantageous application in winter heating and summer conditioning for buildings, allowing a tunnel, which has been made for different reasons (for example for road, motorway, railway transport needs, for making water systems, sewer systems, cable ducts or telecommunications networks), to be used also for heat exchange with the ground by a sustainable and renewable energy system.

PRIOR ART

[0007] Energy geostructures are an interesting topic in national and international research (see quotations from [1] to [8]); the same Inventors of the present invention have published the results of their studies about energy geostructures, including application to tunnels, and/or more generally to thermo-mechanical behavior of soils (see quotations from [9] to [19]).

[0008] The use of underground structures as sources of geothermal energy began in Austria about in 1985 and then it extended in other European countries such as Swiss, German, Great Britain, France and Russia.

[0009] It is known that, in principle, any underground structure (foundation piles and slabs, diaphragm walls, tunnel linings, ties) can be equipped such to become a heat exchanger (see quotations [2], [4], [5], [14], [15], [16] and [17]); the development of such application in Europe, however, has not been homogeneous and it interferes with national rules about thermal efficiency in buildings and infrastructures.

[0010] Underground structures can be thermally activated by installing a network of pipes, generally made of plastic material, inside the structural part made of concrete; a fluid that flows in the pipes is the medium for transferring heat from the ground to the buildings and vice versa, and heat is extracted from the heat transfer fluid by heat pumps.

[0011] In the current technological field, most of practical applications is about foundations (so called "energy piles") or containment structures, while documented examples for applications in tunnels are very few (see quotations [1], [3], [6] and [7]).

[0012] As regards tunnels, the thermal activation of the lining can occur mainly in two manners: for cast in-situ linings, by means of pipes of high density cross-linked polyethylene (PE-Xa) fastened to the geotextile placed between the preliminary lining and the final lining (see quotation [7]); for linings made of segments, by prefabrication in factory with already included pipes (see quotations [8], [9], [10], [11], [12], [13], [18] and [19]).

[0013] An example of a prefabricated modular segment is described in the European patent application n. EP 1 905 947 (quotation [20]); such segment comprises a concrete unit provided with a rigid or flexible pipe with a supply opening and a discharge opening for transporting a hot or cold heat transfer fluid, wherein the pipe is placed in a barycentric manner with respect to the thickness of the segment, and it develops substantially in a direction parallel to the longitudinal axis of the tunnel; connections between segments are made by external connections that occur by said openings from a central position.

[0014] Another example of a prefabricated modular segment is described in the European

[0015] Patent application n. EP 2 489 831 A2 (quotation [21]); this segment comprises a pipe equipped with a heat collector having a specific arrangement of fluid conduits, with the shape of pipe coil, with an inlet and an outlet; the coil is arranged such that the linear portions of the coil are parallel to the smallest development direction of the segment and the curves of the coil are parallel to the greatest development direction of the segment; the fluid conduits of the coil are placed at the extrados of the segment. Connections between the segments are made by openings from side position.

[0016] However the technical solutions described in the two patent applications mentioned above have the drawbacks of high head losses of the overall plant and a reduced efficiency of the heat exchange system for applications where the direction of the interstitial water flow in the ground is perpendicular to the axis of the tunnel.

[0017] Therefore none of prior art technical solutions mentioned above and commented herein solves the problem of providing a prefabricated modular segment, to be used for energy geostructures, configured such to decrease head losses and to increase heat exchange efficiency.

[0018] Therefore there is the unsatisfied need of providing a prefabricated modular segment for energy geostructures allowing head losses to decrease and heat exchange efficiency to be improved.

[0019] Moreover there is the unsatisfied need of providing a lining for tunnels made with a plurality of prefabricated modular segments, of a method for exchanging heat in a tunnel by making a lining with a plurality of prefabricated modular energy segments.

OBJECTS AND SUMMARY OF THE INVENTION

[0020] It is the object of the present invention to overcome prior art drawbacks in the field of energy geostructures, their application to tunnels and more generally to civil engineering works.

[0021] In particular the present invention intends to provide a prefabricated modular segment to be used for energy tunnels that, by an innovative arrangement of geothermal probes, allows head losses to decrease and heat exchange efficiency to be improved.

[0022] Moreover the object of the present invention is to provide a prefabricated modular energy segment that can be used for cooling the tunnel internal environment.

[0023] Moreover the object of the present invention is to provide a prefabricated modular energy segment easy to be manufactured and to be maintained, cheap, reliable and adaptable according to specific needs.

[0024] Moreover the object of the present invention is to provide a tunnel lining made with a plurality of prefabricated modular segments as specified above.

[0025] Moreover the object of the present invention is to provide a method for exchanging heat in a tunnel by making a lining with a plurality of prefabricated modular energy segments.

[0026] The above and other objects and advantages of the invention, as will be clear from the following description, are achieved by a prefabricated modular energy segment as the one according to claim 1.

[0027] Moreover the above and other objects and advantages of the invention are achieved by a tunnel lining made with a plurality of prefabricated modular segments as the one according to claim 6.

[0028] Moreover said and other objects and advantages of the invention are achieved by a method for exchanging heat in a tunnel by making a lining with a plurality of prefabricated modular energy segments as the one of claim 8.

[0029] Preferred embodiments and variants of the segment, the lining and of methods of the present invention are the subject matter of the dependent claims; in particular in one embodiment the segment, the lining and the method according to the invention provide the geothermal probes to be placed in proximity of the outer extrados of the segment to allow for heat exchange with the ground.

[0030] In another embodiment the segment, the lining and the method according to the invention provide the geothermal probes to be placed in proximity of the inner intrados of the segment to allow for heat exchange with the tunnel internal environment.

[0031] In another embodiment the segment, the lining and the method according to the invention provide the geothermal probes to be placed both in proximity of the outer extrados and of the inner intrados of the segment to promote heat exchange both with the ground and with the tunnel internal environment.

[0032] Variants of the several embodiments of the present invention further provide a different number and spacing of geothermal probes.

[0033] It is understood that all the annexed claims are an integral part of the present description and each one of the technical characteristics claimed therein is possibly independent and autonomously usable from the other aspects of the invention.

[0034] It is immediately clear that many changes can be made to what described (for example as regards shape, dimensions, arrangements and parts with equivalent functions) without departing from the scope of protection of the invention as claimed in the annexed claims.

[0035] Advantageously the technical solution according to the present invention that provides a prefabricated modular segment with an innovative arrangement of the geothermal probes allows for:

- winter heating and summer conditioning of buildings by a sustainable and renewable energy system;
- compensation for environmental damages generated by making underground works, by combining the construction of necessary infrastructures with a renewable energy supply system;
- decrease of head losses of the overall plant due to the smaller length thereof inside the tunnel and the smaller amount of elbows of the pipe composing the geothermal probe inside the prefabricated segment;
- a higher efficiency of the heat exchange system for applications where the direction of interstitial water flow in the ground is perpendicular to the axis of the tunnel;
- limiting inner overheating of the tunnel caused by operating traffic and reducing forced ventilation, by removing heat from inside the tunnel and by controlling its temperature;
- flexibility of use due to modularity and to the simple sectional behavior of prefabricated segments with which many configurations are easily made; and
- easiness and cheapness of the process manufacturing the prefabricated segments.

[0036] Further advantageous characteristics will be more clear from the following description of preferred but not exclusive embodiments, provided by way of example and not as a limitation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] The invention will be described below with reference to some preferred embodiments, provided by way of example and not as a limitation, with reference to the annexed drawings. These drawings show different aspects and examples of the present invention and, where appropriate, like structures, components, materials and/or elements in different figures are denoted by like reference numerals.

FIG. 1 is a top plan view of a prefabricated modular segment according to the present invention;
FIG. 2A is a perspective view of a segmental lining according to known prior art;
FIG. 2B is a perspective view of a segmental lining according to the present invention;
FIG. 3A is an external developed view of a first embodiment of a prefabricated modular segment according to the present invention;
FIG. 3B is cross-sectional view of FIG. 3A;
FIG. 3C is an inner developed view of FIG. 3A;
FIG. 4A is an external developed view of a second embodiment of a prefabricated modular segment according to the present invention;
FIG. 4B is a cross-sectional view of FIG. 4A;
FIG. 4C is an inner developed view of FIG. 4A;
FIG. 5A is an external developed view of a third embodiment of a prefabricated modular segment according to the present invention;
FIG. 5B is a cross-sectional view of FIG. 5A;
FIG. 5C is an inner developed view of FIG. 5A;
FIG. 6 is a cross-sectional view of a lining made with prefabricated segments for a tunnel with two tracks for underground railway transport;
FIG. 7 is a perspective view of a multiple lining made with segments according to the present invention; and
FIG. 8 is a flow diagram showing the steps of the method for exchanging heat in a tunnel by making a lining with a plurality of prefabricated modular energy segments according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0038] While the invention is susceptible of various modifications and alternative constructions, some preferred embodiments are shown in the drawings and will be described in details herein below.

[0039] It should be understood, however, that there is no intention to limit the invention to the specific disclosed embodiments but, on the contrary, the invention intends to cover all the modifications, alternative constructions and equivalents that fall within the scope of the invention as defined in the claims.

[0040] Therefore in the description below the use of "for example", "etc.", "or", "otherwise" denotes non-exclusive alternatives without limitation, unless otherwise noted; the use of "also" means "among which, but not limited to", unless otherwise noted; the use of "includes/comprises" means "includes/comprises, but not limited to", unless otherwise noted.

[0041] The segment, the lining and the method of the present invention are based on the concept of providing an innovative installation geometry of geothermal probes.

[0042] The main characteristic of such segments, lining and method is the fact that, by said innovative installation geometry of geothermal probes, important advantages are achieved as regards heat exchange efficiency, head losses of the plant and effectiveness thereof.

[0043] An important characteristic of said segment, lining and method is then the possibility of removing heat from the inside of a tunnel and controlling its temperature, thus reducing the need of forced ventilation.

[0044] Another important characteristic of said segment, lining and method is the modularity and sectional behavior, that meet the need of arranging only one product adaptable to many uses and functions.

[0045] In the present description the term "outer" means the portion of the prefabricated modular segment or of the lining made with prefabricated modular energy segments facing the ground; more precisely such term means the outer extrados.

[0046] In the present description the term "inner" means the portion of the prefabricated modular segment or of the lining made with prefabricated modular energy segments facing the inside of the tunnel; more precisely such term means the inner intrados.

[0047] With reference to FIG. 1, it shows the prefabricated modular energy segment according to the present invention; with reference to FIG. 3A-3C, 4A-4C and 5A-5C, they show, in details, a first, a second and a third embodiment of the prefabricated modular energy segment respectively according to the present invention.

[0048] With reference to FIG.1, the prefabricated modular energy segment 1 comprises:

- a structural element 2 having a main development direction 20 and comprising an outer extrados 4 and an inner intrados 6, and
- at least one pipe network 3 comprising a plurality of linear portions 5, a plurality of curvilinear junctions 7 for connecting two consecutive linear portions 5, a first 9a and a second 9b end.

[0049] As said above, the prefabricated modular segment 1 is characterized by having an innovative geometry of the pipe network 3, and specifically, in that the linear portions 5 of the pipe network 3 are directed in the main development direction 20 of the structural element 2 and in that the curvilinear junctions 7 are arranged perpendicularly to the main development direction 20 of the structural element 2.

[0050] The prefabricated modular segment 1 has a thickness ranging from 30 to 50 cm, and generally this is structural design information that depends on geotechnical conditions of the ground and on geometrical characteristics of the tunnel; the prefabricated modular segment 1 inside it has one or two pipe networks 3 able to convey a heat transfer fluid (preferably and particularly when used in tunnels, the heat transfer fluid is propylene glycol mixed with water and it is able to work also at temperatures lower than -20°C; however other heat transfer fluids can be used, depending on specific needs and applications, such as for example liquid water, glycol water, air, diathermic oil.

[0051] The structural element 2 is preferably made of reinforced concrete; however it can be made of metal material or any other material having mechanical properties suitable for the aim and suitable to maximize heat exchange.

[0052] The pipe network 3 comprises a number of linear portions 5 ranging from three to seven, preferably equal to five, and a number of curvilinear junctions 7 ranging from two to six, preferably equal to four.

[0053] The pipe network 3 and particularly its linear portions 5 and its curvilinear junctions 7, is preferably made of high density cross-linked polyethylene (Pe-Xa); however it is possible to use any other material able to carry out the same function and having chemical-physical and mechanical characteristics suitable for the aim.

[0054] More precisely the walls of the pipe network 3 and particularly of its linear portions 5 and of its curvilinear junctions 7 are composed of three concentric layers: a first layer in contact with the heat transfer fluid is composed of high density polyethylene, a second intermediate layer is made of polymer material and a third layer in contact with the material of the structural element is an oxygen-proof layer and it is composed of ethylene vinyl alcohol (EVOH) copolymers; in particular the pipe network 3 is able to withstand high pressures and temperatures as well as corrosion.

[0055] The pipe network 3 and particularly its linear portions 5 and its curvilinear junctions 7 is placed at a distance ranging between 5 cm and 15 cm, preferably at a distance of 10 cm, from the surface of the outer extrados 4, or from the surface of the inner intrados 6.

[0056] The linear portions 5 of the pipe network 3 are mutually spaced by an interval ranging between 20 and 40 cm, preferably an interval of 30 cm.

[0057] The linear portions 5 and the curvilinear junctions 7 of the pipe network 3 have an outer diameter ranging between 15 mm and 35 mm, preferably equal to 25 mm, and a thickness ranging from 1.5 mm to 3 mm, preferably equal to 2.3 mm.

[0058] Due to the innovative installation geometry of the pipe network described above, it is possible to achieve considerable improvements as regards efficiency for applications when the direction of the interstitial water flow in the ground is perpendicular to the axis of the tunnel, and to reduce head losses in the system.

[0059] In fact, by comparing the segment according to the present invention with a segment according to prior art (for example with the segment according to the already mentioned document EP 1 905 947 A1) an increase of heat that can be exchanged with the ground is found ranging from 5 to 10% with respect to the segment according to prior art, the material used being equal and in the case the tunnel is made with the axis perpendicular to the lines of water flow present underground. Such increase in efficiency allows an annual saving on heat producing equivalent costs, considering 1 km of activated tunnel, ranging from 40% to 50% more with respect to the use of the segment according to prior art.

[0060] Moreover, still by comparing the segment of the present invention with a segment according to prior art (for example the segment according to the document EP 1 905 947 A1 already mentioned above) a decrease in head losses has been found ranging from 20 to 30% of each individual lining ring, other conditions being equal such as geometry, diameter and depth of the tunnel, due to the fact that the inner curves of the segment of the pipe network according to the invention are only four versus seven curves of the segment according to the document EP 1 905 947 A1.

[0061] With reference to FIG. 3A-3C they show the first embodiment of the prefabricated modular energy segment 1 according to the invention, wherein such segment inside it has a pipe network 3 and wherein the pipe network 3 is positioned near the outer extrados 4 (visible in FIG.3A); for clarity reasons it is specified that near the inner intrados 6 there is no element able to exchange heat (such as shown in FIG 3C).

[0062] According to such first embodiment of the prefabricated modular energy segment 1 according to the invention, it is possible to accomplish a heat exchange between the segment and the ground with which such segment is in contact, such as shown in FIG.3B.

[0063] Characteristics of the individual elements of each prefabricated modular energy segment according to the first embodiment of the invention are completely similar to those described above with reference to the general embodiment shown in FIG.1, and therefore, for brevity reasons, they will not be disclosed again.

[0064] The first embodiment of the invention is particularly advantageous since, as mentioned above, it allows efficiency of heat exchange to be considerably improved between segment and ground with which is it in contact with respect to known solutions (for applications where the direction of interstitial water flow in the ground is perpendicular to the axis of the tunnel or of the involved civil engineering work) as well as it allows head losses to be considerably reduced.

[0065] With reference to FIG. 4A-4C they show the second embodiment of the prefabricated modular energy segment 1 according to the invention, wherein such segment has inside it a pipe network 3 and wherein the pipe network 3 is positioned near the inner intrados 6 (visible in FIG. 4C); for clarity reasons, it is specified that near the outer extrados 4 there are no elements able to exchange heat (such as shown in fig. 4A).

[0066] According to such embodiment of the prefabricated modular energy segment 1 according to the invention, it is possible to accomplish a heat exchange between segment and environment air with which such segment is in contact, such as shown in FIG.4B.

[0067] Characteristics of the individual elements of each prefabricated modular energy segment according to the second embodiment of the invention are completely similar to those described above with reference to the general embodiment shown in FIG.1, and therefore, for brevity reasons, they will not be disclosed again.

[0068] The second embodiment of the invention is particularly advantageous since it accomplishes the heat exchange between segment and environment air; in particular, when applied in a tunnel, such second embodiment mitigates the inner overheating of the tunnel caused by operating traffic since it allows heat to be removed from the tunnel and allows its temperature to be controlled, consequently reducing the need of forced ventilation.

[0069] With reference to FIG. 5A-5C they show the third embodiment of the prefabricated modular energy segment 1 according to the invention, wherein such segment has inside it two pipe networks 3a and 3b and wherein the first pipe network 3a is positioned near the outer extrados 4 (visible in FIG. 5C) while the second pipe network 3b is positioned near the inner intrados 6 (visible in FIG5C).

[0070] According to such third embodiment of the prefabricated modular energy segment 1 according to the invention, it is possible to accomplish a heat exchange both between segment and ground with which such segment is in contact and between segment and environment air with which such segment is in contact, such as shown in FIG.5B.

[0071] It is considered useful to specify that the first pipe network 3a is placed at a distance ranging from 5 cm to 15 cm, preferably at a distance of 10 cm, from the surface of the outer extrados 4, and the second pipe network 3b is placed at a distance ranging from 5 cm to 15 cm, preferably at a distance of 10 cm, from the surface of the inner intrados 6.

[0072] Other characteristics of the individual elements of each prefabricated modular energy segment according to the third embodiment of the invention are completely similar to those described above with reference to the general embodiment shown in FIG.1, and therefore, for brevity reasons, they will not be disclosed again.

[0073] The third embodiment of the invention, by combining the advantages of the first and second embodiments, achieve the result of allowing heat to be exchanged both with ground and with the tunnel internal environment by means of two separated and independent systems and plants.

[0074] With reference again to FIG.1 it shows that the pipe network 3 (and likewise each one of the two networks 3a and 3b of the third embodiment of the invention described above) comprises a first 9a and a second 9b ends; such first 9a and second 9b ends are provided to allow the pipe networks to be connected between a segment and an adjacent one and also to be connected to delivery and return lines visible in FIG.7; the connection generally takes place after installation, by means of sleeves that are easy to be inspected.

[0075] An aspect independent and usable autonomously from the other aspects of the present invention is about a tunnel lining 10 made with a plurality of prefabricated modular segments 1; such lining is shown in FIGG. 2B, 6 and 7. By way of comparison, FIG.2A shows a tunnel lining 10' according to the known technical solution of EP 1 905 947 A1 disclosed above; such lining comprises a plurality of prefabricated modular segments 1' wherein the pipes are arranged in a direction parallel to the axis of the tunnel.

[0076] The tunnel lining, or ring 10, according to the present invention visible in FIG2B, comprises a plurality of prefabricated modular energy segments 1, each segment comprising:

- a structural element 2 having a main development direction 20 and comprising an outer extrados 4 and an inner intrados 6, and
- at least one pipe network 3 comprising a plurality of linear portions 5, a plurality of curvilinear junctions 7 for connecting two consecutive linear portions 5, a first 9a and a second 9b end,
- the linear portions 5 of the pipe network 3 being directed in the main development direction 20 of the structural element 2, and the curvilinear junctions 7 being arranged perpendicularly to the main development direction 20 of the structural element 2.

[0077] Each segment 1 is radially joined to an adjacent segment 1 by connecting the first end 9a of the pipe network 3 of each segment 2 to the second end 9b of the pipe network 3 of the adjacent segment 1.

[0078] With reference to FIG.7 is shows that each ring 10 is joined to a consecutive ring 10 by the connection between a second end 9b of the segment 1 of the ring 10 and a first end 9a of a segment 1 of the consecutive ring 10, thus forming a multiple lining or a circuit of rings in series; preferably the circuit comprises a number of rings in series ranging from three to seven; more preferably the circuit comprises a number of rings in series equal to five, such as shown in Fig.7.

[0079] Characteristics of the individual elements of the prefabricated modular energy segments 1 are completely similar to those described above and thefore for brevity reaosns, thay will not be disclosed again.

[0080] The tunnel lining 10 has a number of segments ranging from five to seven.

[0081] The tunnel lining 10 is useful for exhanging heat with the ground placed in contact with the outer extradoses 4 of the plurality of segments 1 or with the enviroment inside the tunnel placed in contact with the inner intradoses 6 of the plurality of segments 1 or both with the ground and with the tunnel internal environment.

[0082] With reference to FIG.6 it shows an example of a lining ring made with prefabricated segments for a two-track tunnel for underground railway transport; in such example the number of segments is equal to six segments plus a keystone segment.

[0083] The lining shown herein merely by way of example and not as a limitation comprises:

- six prefabricated modular energy segments 1 and
- one keystone segment 8.

[0084] In particular the six prefabricated modular energy segments 1 are placed such to compose a continuous ring, while the keystone segment 8 is placed between two segments 1, in the space left empty such to complete the lining ring, to accomplish the function of guaranteeing a suitable contact between the segments.

[0085] In order to guarantee an easy inspection during the service life of the structure, the main delivery 12 and return 13 lines can be arranged under the safety floor 14 placed at the sides of the tunnel.

[0086] An aspect independent and usable autonomously from the other aspects of the present invention is about a method for exchanging heat in a tunnel by making a lining with a plurality of prefabricated modular energy segments shown in fig.8; the method comprises the following steps:

- providing at least one pipe network 3 formed by a plurality of linear portions 5, a plurality of curvilinear junctions 7 for connecting two consecutive linear portions, a first 9a and a second 9b end (step 101);
- providing a prefabricated modular energy segment 1 by positioning said at least one pipe network 3 in a structural element 2 having a main development direction 20, so that the linear portions 5 of the pipe network 3 are directed in the main development direction of the structural element 2 and the curvilinear junctions 7 are arranged perpendicularly to the main development direction of the structural element 2 (step 102);
- repeating the previous steps 101 and 102 for providing a plurality of prefabricated modular energy segments 1 (step 103);
- setting-up said plurality of prefabricated modular energy segments 1 by means of a segment erector of a Tunnel Boring Machine (TBM), thus realizing a first lining ring (step 104);
- hydraulically connecting each segment 1 to an adjacent segment 1 of said first lining ring by joining the first end 9a of the pipe network 3 of each segment 1 to the second end 9b of the pipe network 3 of the adjacent segment 1 (step 105);
- repeating the previous steps 104 and 105 for obtaining a plurality of lining rings and for hydraulically connecting with each other the prefabricated modular energy segments 1 of each lining ring (step 106);
- hydraulically connecting each lining ring to an adjacent lining ring to form a circuit of rings in series (step 107); and
- hydraulically connecting the circuit of rings in series with a main delivery line and with a main return line (step 108).

[0087] The method can further comprise the following steps:

- hydraulically connecting the system realized in step 108 to one or more heat pumps (step 109); and
- carrying out pressure testing and commissioning (step 110).

[0088] Preferably the method provides that the circuit formed in step 107 comprises a number of rings in series ranging from three to seven.

[0089] In a first embodiment, the method provides the geothermal probes to be positioned near the outer extrados of the segment.

[0090] As an alternative, in a second embodiment, the method according to the invention provides the geothermal probes to be positioned near the inner intrados of the segment.

[0091] As an alternative, in a third embodiment, the method according to the invention provides the geothermal probes to be arranged both near the outer extrados and near the inner intrados of the segment.

[0092] The segment, lining and the method according to the present invention have many areas of applications, that result directly from the innovative characteristics and from the advantages disclosed above; in particular the present invention can be advantageously used in the transport field, specifically in newly constructed urban tunnels for underground railway lines, for networks of water systems/sewer systems and for similar applications, as well as extra-urban tunnels, bored with a mechanized method by the Tunnel Boring Machine (TBM); more in general the present invention has an advantageous application in winter heating and summer conditioning of buildings, allowing a tunnel, which has been made for different reasons, to be used also for heat exchange with the ground by a sustainable and renewable energy system.

[0093] As deduced from the above, the innovative technical solution described herein has the following advantageous characteristics:

- meeting heating and conditioning needs of buildings by using a renewable and local energy source;
- mitigating environmental damages produced by making underground works and reducing costs for making heating/conditioning plants; by the use of structural works made for other reasons, an environmental compensation is achieved related to the reduction of pollution produced for heating and conditioning buildings served by the system according to the invention, and contemporaneously reducing

costs necessary for making heating/conditioning plants;

- reducing head losses of the plant since in the system according to the invention the curves inside the segment of the piping network intended to transport the heat transfer fluid are a lower number;
- increasing the heat exchange efficiency by means of a different arrangement of the pipes in the segment wherein the heat transfer fluid flows that allows, the used material being the same, heat exchange ability to be increased;
- reducing the need of forced ventilation inside the tunnel for cooling it by means of the inner piping network; and
- simple manufacturing and maintenance, cheapness and lightness, reliability and adaptability depending on specific needs.

[0094] From the above description it is clear therefore how the described segment, lining and method allow the above mentioned objects to be achieved.

Citations

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Claims

1. A prefabricated modular energy segment (1) comprising:

   - a structural element (2) having a main development direction (20) and comprising an outer extrados (4) and an inner intrados (6), and
   - at least one pipe network (3) comprising a plurality of linear portions (5), a plurality of curvilinear junctions (7) for connecting two consecutive linear portions (5), a first (9a) and a second (9b) end,

   characterized in that said linear portions (5) of said pipe network (3) are directed in the main development direction (20) of said structural element (2), and **in that** said curvilinear junctions (7) are arranged perpendicularly to the main development direction (20) of said structural element (2).

2. A prefabricated modular energy segment (1) according to claim 1, wherein said at least one pipe network (3) is positioned near said outer extrados (4).

3. A prefabricated modular energy segment (1) according to claim 1, wherein said at least one pipe network (3) is positioned near said inner intrados (6).

4. A prefabricated modular energy segment (1) according to claim 1, comprising a first (3a) and a second (3b) pipe network, wherein the first pipe network (3a) is positioned near said outer extrados (4) and the second pipe network (3b) is positioned near said inner intrados (6).

5. A prefabricated modular energy segment (1) according to any of the preceding claims, wherein said at least one pipe network (3) comprises a number of linear portions (5) ranging between three and seven, preferably equal to five, and a number of curvilinear junctions (7) ranging between two and six, preferably equal to four; and wherein said at least one pipe network (3) is positioned at a distance ranging between 5 cm and 15 cm, preferably at a distance of 10 cm, from the surface of said outer extrados (4) and/or of said inner intrados (6); and wherein said linear portions (5) of said pipe network (3) are mutually spaced by an interval ranging between 20 cm and 40 cm, preferably by an interval of 30 cm.

6. A tunnel lining (10) made with a plurality of prefabricated modular energy segments (1) according to any of the preceding claims, wherein each segment (1) is radially joined to an adjacent segment (1) by connecting the first end (9a) of the pipe network (3) of each segment (1) to the second end (9b) of the pipe network (3) of the adjacent segment (1).

7. A tunnel lining (10) according to claim 6, suitable to exchange heat with the ground placed in contact with the outer extrados (4) of the plurality of segments (1) and/or with the tunnel internal environment placed in contact with the inner intrados (6) of the plurality of segments (1).

8. A method for exchanging heat in a tunnel by making a lining with a plurality of prefabricated modular energy segments (1) comprising the following steps:

   - providing at least one pipe network (3) formed by a plurality of linear portions (5), a plurality of curvilinear junctions (7) for connecting two consecutive linear portions, a first (9a) and a second (9b) end (step 101);
   - providing a prefabricated modular energy segment (1) by positioning said at least one pipe network (3) in a structural element (2) having a main development direction (20), so that the linear portions (5) of the pipe network (3) are directed in the main development direction of the structural element (2) and the curvilinear junctions (7) are arranged perpendicularly to the main development direction of the structural element (2) (step 102);
   - repeating the previous steps 101 and 102 for providing a plurality of prefabricated modular energy segments (1) (step 103);
   - setting-up said plurality of prefabricated modular energy segments (1) by means of a segment erector of a Tunnel Boring Machine (TBM), thus realizing a first lining ring (step 104);
   - hydraulically connecting each segment (1) to an adjacent segment (1) of said first lining ring by joining the first end (9a) of the pipe network (3) of each segment (1) to the second end (9b) of the pipe network (3) of the adjacent segment (1) (step 105);
   - repeating the previous steps 104 and 105 for obtaining a plurality of lining rings and for hydraulically connecting with each other the prefabricated modular energy segments (1) of each lining ring (step 106);
   - hydraulically connecting each lining ring to an adjacent lining ring to form a circuit of rings in series (step 107); and
   - hydraulically connecting the circuit of rings in series with a main delivery line and with a main return line (step 108).

9. A method according to claim 8, further comprising the following steps:

   - hydraulically connecting the system realized in step 108 to one or more heat pumps (step 109); and
   - carrying out pressure testing and commission-

ing (step 110).

10. A method according to claim 8 or 9, wherein the circuit formed in step 107 comprises a number of rings in series ranging between three and seven.

Patentansprüche

1. Vorgefertigtes modulares Energiesegment (1) mit:

- ein Strukturelement (2) mit einer Hauptentwicklungsrichtung (20) und mit einer äußeren Oberseite (4) und einer inneren Unterseite (6)/und
- mindestens ein Rohrnetz (3) mit mehreren linearen Abschnitten (5), mehreren krummlinigen Verbindungen (7) zum Verbinden zweier aufeinanderfolgender linearer Abschnitte (5), einem ersten (9a) und einem zweiten (9b) Ende,

dadurch gekennzeichnet, dass die linearen Abschnitte (5) des Rohrnetzes (3) in die Hauptentwicklungsrichtung (20) des Strukturelements (2) gerichtet sind und dass die krummlinigen Verbindungen (7) senkrecht zu der Hauptrichtung (20) des Strukturelements (2) angeordnet sind.

2. Vorgefertigtes modulares Energiesegment (1) nach Anspruch 1, wobei das mindestens eine Rohrnetz (3) nahe der äußeren Oberseite (4) positioniert ist.

3. Vorgefertigtes modulares Energiesegment (1) nach Anspruch 1, wobei das mindestens eine Rohrnetz (3) nahe der inneren Unterseite (6) positioniert ist.

4. Vorgefertigtes modulares Energiesegment (1) nach Anspruch 1, umfassend ein erstes (3a) und ein zweites (3b) Rohrnetz, wobei das erste Rohrnetz (3a) in der Nähe der äußeren Oberseite (4) und das zweite Rohrnetz (3b) in der Nähe der inneren Unterseite (6) positioniert sind.

5. Vorgefertigtes modulares Energiesegment (1) nach einem der vorhergehenden Ansprüche, wobei das mindestens eine Rohrnetz (3) eine bestimmte Anzahl zwischen drei und sieben, vorzugsweise fünf, von linearen Abschnitten (5) aufweist, und eine Anzahl zwischen zwei und sechs, vorzugsweise vier, von krummlinigen Verbindungen (7), aufweist; und wobei das mindestens eine Rohrnetz (3) in einem Abstand zwischen 5 cm und 15 cm, vorzugsweise in einem Abstand von 10 cm, von der Oberfläche der äußeren Oberseite (4) und/oder der inneren Unterseite (6) angeordnet ist; und wobei die linearen Abschnitte (5) des Rohrnetzes (3) voneinander in einem Abstand zwischen 20 cm und 40 cm, vorzugsweise in einem Abstand von 30 cm, beabstandet sind.

6. Tunnelauskleidung (10) hergestellt mit mehreren vorgefertigten modularen Energiesegmenten (1) nach einem der vorhergehenden Ansprüche, wobei jedes Segment (1) radial mit einem benachbarten Segment (1) verbunden ist, um das erste Ende (9a) des Rohrnetzes (3) jedes Segments (1) am zweiten Ende (9b) des Rohrnetzes (3) des benachbarten Segments (1) zu verbinden.

7. Tunnelauskleidung (10) nach Anspruch 6, die in der Lage ist, Wärme mit dem Boden auszutauschen, der in Kontakt mit der äußeren Oberseite (4) der Vielzahl von Segmenten (1) und/oder mit der inneren Umgebung des Tunnels in Kontakt mit den inneren Unterseite (6) der Mehrzahl von Segmenten (1) gebracht wird.

8. Verfahren zum Wärmeaustausch in einem Tunnel durch Herstellen einer Auskleidung mit mehreren vorgefertigten modularen Energiesegmenten (1), umfassend die folgenden Schritte:

- Bereitstellen mindestens eines Rohrnetzes (3), das aus mehreren linearen Abschnitten (5), mehreren krummlinigen Verbindungen (7) zum Verbinden zweier aufeinanderfolgender linearer Abschnitte, einem ersten Ende (9a) und einem zweiten Ende (9b) besteht (Schritt 101) ;
- Bereitstellen eines vorgefertigten modularen Energiesegments (1) durch Positionieren des mindestens einen Rohrnetzes (3) in einem Strukturelement (2) mit einer Hauptentwicklungsrichtung (20), so dass die linearen Abschnitte (5) des Rohrnetzes (3) in der Hauptentwicklungsrichtung des Strukturelementes (2) gerichtet sind und die krummlinigen Verbindungen (7) senkrecht zur Hauptentwicklungsrichtung des Strukturelementes (2) angeordnet sind (Schritt 102);
- Wiederholen der vorherigen Schritte 101 und 102, um mehrere vorgefertigte modulare Energiesegmente (1) bereitzustellen (Schritt 103);
- Positionieren der Mehrzahl von vorgefertigten modularen Energiesegmenten (1) mittels einer Positionierung der Segmente einer Tunnel Boring Machine (TBM), wodurch ein erster Auskleidungsring erzeugt wird (Schritt 104);
- hydraulisches Verbinden jedes Segments (1) mit einem benachbarten Segment (1) des ersten Auskleidungsrings durch Verbinden des ersten Endes (9a) des Rohrnetzes (3) jedes Segments (1) mit dem zweiten Ende (9b) des Rohrnetzes (3) des benachbarten Segments (1) (Schritt 105) ;
- Wiederholen der vorhergehenden Schritte 104 und 105, um mehrere Auskleidungsringe zu er-

halten und um die vorgefertigten modularen Energiesegmente (1) jedes Auskleidungsrings hydraulisch miteinander zu verbinden (Schritt 106);
- hydraulisches Verbinden jedes Auskleidungsrings mit einem benachbarten Auskleidungsring, um einen Ringkreis in Reihe zu bilden (Schritt 107); und
- hydraulisches Verbinden des Ringkreises in Reihe mit einer Hauptversorgungsleitung und einer Hauptrückführungsleitung (Schritt 108).

9. Verfahren nach Anspruch 8, ferner umfassend die folgenden Schritte:

- hydraulisches Verbinden des in Schritt 108 hergestellten Systems mit einer oder mehreren Wärmepumpen (Schritt 109); und
- Drucktests und Inbetriebnahme durchführen (Schritt 110) .

10. Verfahren nach Anspruch 8 oder 9, wobei der in Schritt 107 gebildete Kreis eine Anzahl, zwischen drei und sieben, von Ringen in Reihe umfasst.

Revendications

1. Segment d'énergie modulaire préfabriqué (1) comprenant:

- un élément structurel (2) ayant une direction de développement principale (20) et comprenant un extrados extérieur (4) et un intrados intérieur (6), et
- au moins un réseau de canalisations (3) comprenant une pluralité de portions linéaires (5), une pluralité de jonctions linéaires (7) pour relier deux portions linéaires consécutives (5), une première (9a) et une deuxième (9b) extrémité,

caractérisé en ce que lesdites parties linéaires (5) dudit réseau de canalisations (3) sont dirigées dans la direction principale de développement (20) dudit élément structurel (2), et **en ce que** lesdites jonctions curvilignes (7) sont disposées perpendiculairement à la direction de développement principale (20) dudit élément structurel (2).

2. Segment d'énergie modulaire préfabriqué (1) selon la revendication 1, dans lequel ledit au moins un réseau de canalisations (3) est positionné à proximité dudit extrados extérieur (4).

3. Segment d'énergie modulaire préfabriqué (1) selon la revendication 1, dans lequel ledit au moins un réseau de canalisations (3) est positionné à proximité dudit intrados intérieur (6).

4. Segment d'énergie modulaire préfabriqué (1) selon la revendication 1, comprenant un premier (3a) et un deuxième (3b) réseau de canalisations, dans lequel le premier réseau de canalisations (3a) est positionné à proximité dudit extrados extérieur (4) et le deuxième réseau de canalisations (3b) est positionné à proximité dudit intrados intérieur (6).

5. Segment d'énergie modulaire préfabriqué (1) selon l'une quelconque des revendications précédentes, dans lequel ledit au moins un réseau de canalisations (3) comprend un certain nombre de portions linéaires (5) comprises entre trois et sept, de préférence égales à cinq, et un nombre de jonctions curvilignes (7) comprises entre deux et six, de préférence égales à quatre; et dans lequel ledit au moins un réseau de canalisations (3) est positionné à une distance comprise entre 5 cm et 15 cm, de préférence à une distance de 10 cm, de la surface dudit extrados extérieur (4) et/ou dudit intrados intérieur (6); et dans lequel lesdites parties linéaires (5) dudit réseau de canalisations (3) sont mutuellement espacées d'un intervalle compris entre 20 cm et 40 cm, de préférence d'un intervalle de 30 cm.

6. Revêtement de tunnel (10) réalisé avec une pluralité de segments d'énergie modulaires préfabriqués (1) selon l'une quelconque des revendications précédentes, dans lequel chaque segment (1) est joint radialement à un segment adjacent (1) en reliant la première extrémité (9a) du réseau de canalisations (3) de chaque segment (1) à la deuxième extrémité (9b) du réseau de canalisations (3) du segment adjacent (1).

7. Revêtement de tunnel (10) selon la revendication 6, apte à échanger de la chaleur avec le sol placé en contact avec l'extrados extérieur (4) de la pluralité de segments (1) et/ou avec l'environnement intérieur du tunnel mis en contact avec l'intrados intérieur (6) de la pluralité de segments (1).

8. Procédé d'échange de chaleur dans un tunnel en réalisant un revêtement avec une pluralité de segments d'énergie modulaires préfabriqués (1) comprenant les étapes suivantes:

- prévoir au moins un réseau de canalisations (3) formé par une pluralité de parties linéaires (5), une pluralité de jonctions curvilignes (7) pour relier deux parties linéaires consécutives, une première (9a) et une deuxième (9b) extrémité (étape 101);
- fournir un segment d'énergie modulaire préfabriqué (1) en positionnant ledit au moins un réseau de canalisations (3) dans un élément structurel (2) ayant une direction de développement principale (20), de sorte que les parties linéaires

(5) du réseau de canalisations (3) sont dirigés dans la direction principale de développement de l'élément structurel (2) et les jonctions curvilignes (7) sont disposées perpendiculairement à la direction principale de développement de l'élément structurel (2) (étape 102);

- répéter les étapes précédentes 101 et 102 pour fournir une pluralité de segments d'énergie modulaires préfabriqués (1) (étape 103);
- mise en place de ladite pluralité de segments d'énergie modulaires préfabriqués (1) au moyen d'un érecteur de segments d'une Tunnel Boring Machine (TBM), réalisant ainsi un premier anneau de revêtement (étape 104) ;
- relier hydrauliquement chaque segment (1) à un segment adjacent (1) dudit premier anneau de revêtement en joignant la première extrémité (9a) du réseau de canalisations (3) de chaque segment (1) à la deuxième extrémité (9b) du réseau de canalisations (3) du segment adjacent (1) (étape 105);
- répéter les étapes précédentes 104 et 105 pour obtenir une pluralité d'anneaux de revêtement et pour relier hydrauliquement les uns aux autres les segments d'énergie modulaires préfabriqués (1) de chaque anneau de revêtement (étape 106);
- connecter hydrauliquement chaque anneau de revêtement à un anneau de revêtement adjacent pour former un circuit d'anneaux en série (étape 107); et
- relier hydrauliquement le circuit d'anneaux en série avec une conduite principale d'alimentation et une conduite principale de retour (étape 108).

9. Procédé selon la revendication 8, comprenant en outre les étapes suivantes:

- connecter hydrauliquement le système réalisé à l'étape 108 à une ou plusieurs pompes à chaleur (étape 109); et
- effectuer des tests de pression et la mise en service (étape 110).

10. Procédé selon la revendication 8 ou 9, dans lequel le circuit formé à l'étape 107 comprend un nombre d'anneaux en série compris entre trois et sept.

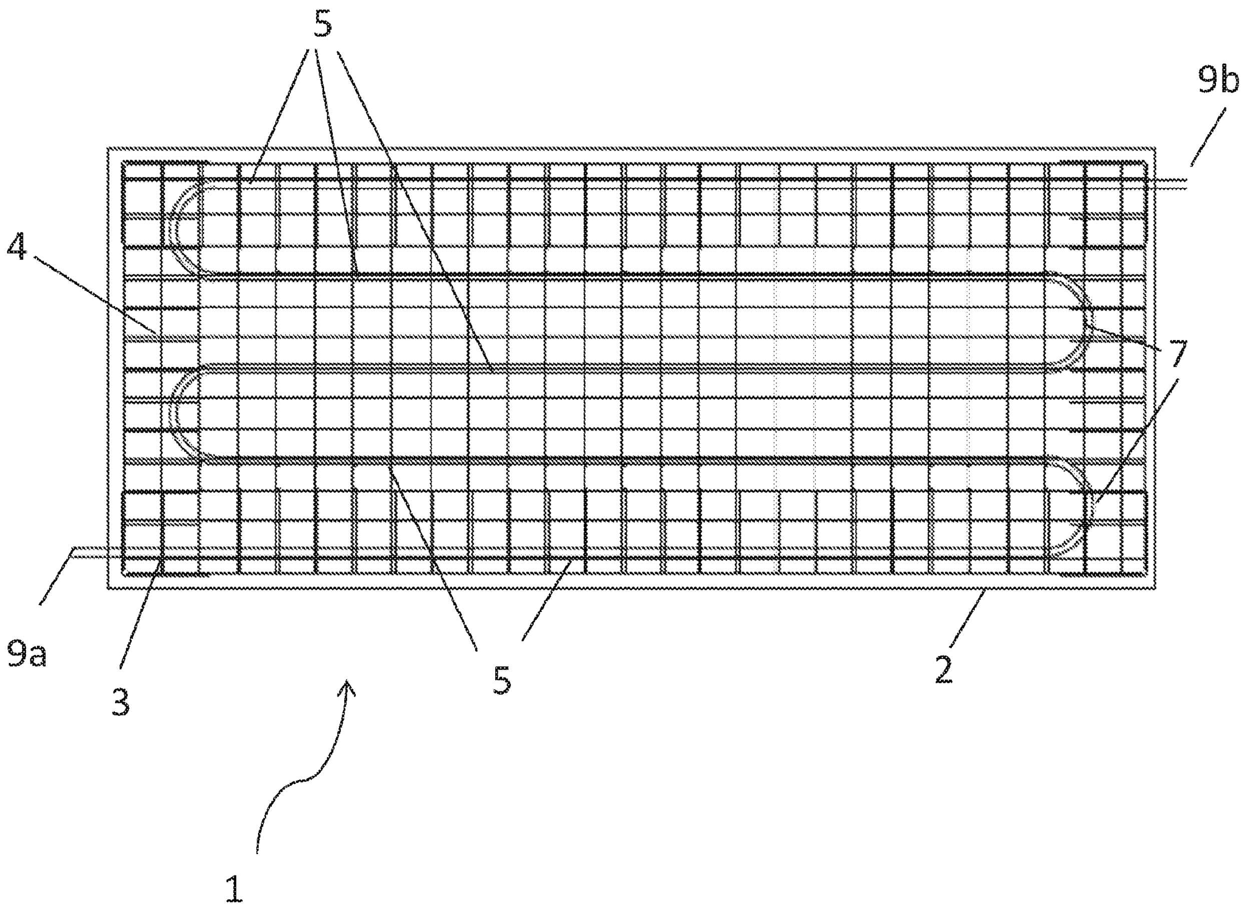

Fig. 1

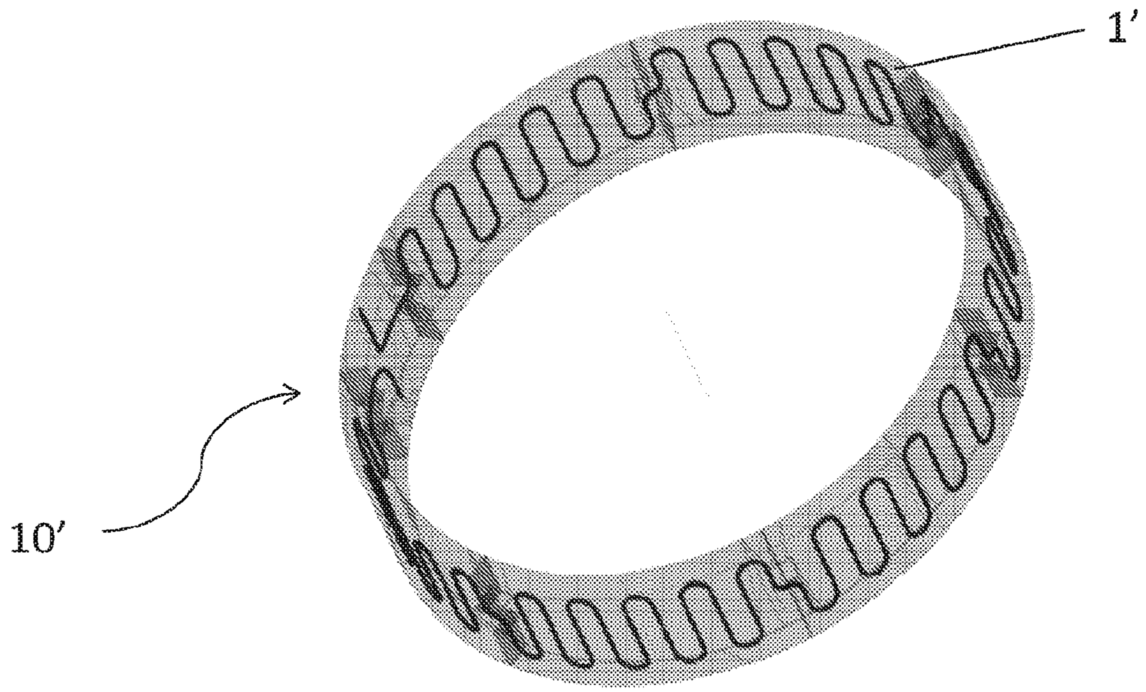

Fig. 2A - PRIOR ART

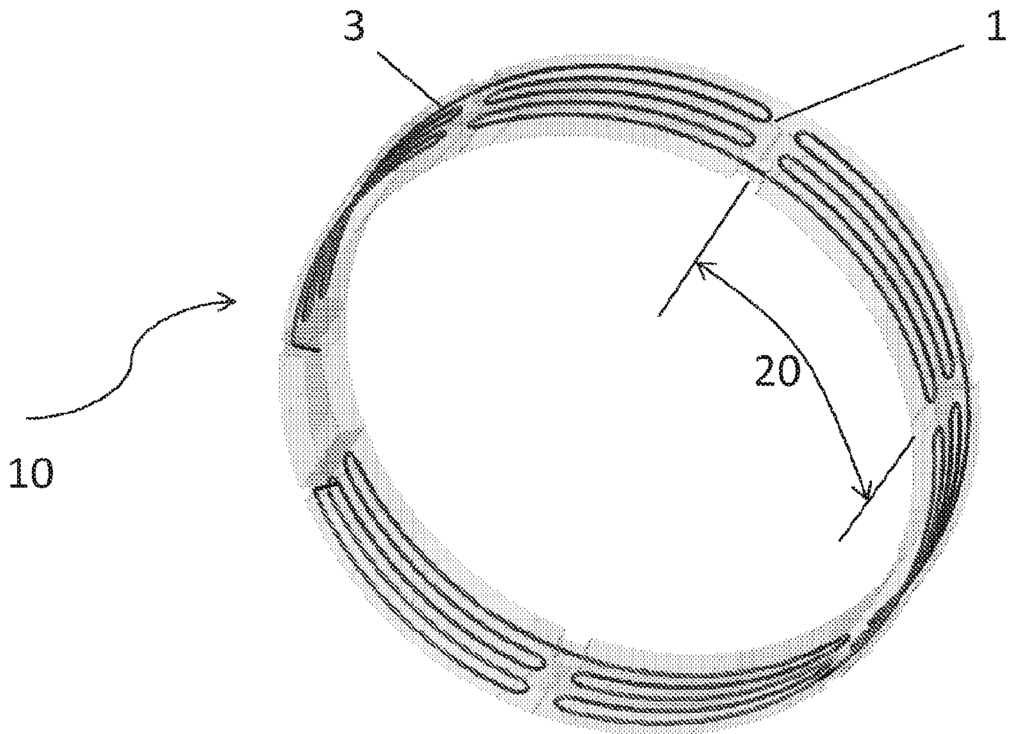

Fig. 2B

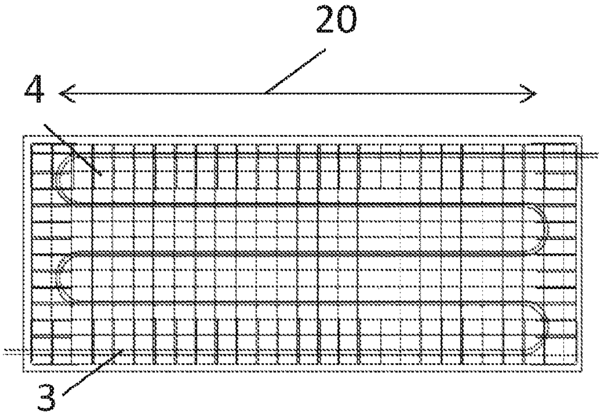

Fig. 3A

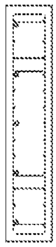

Fig. 3B

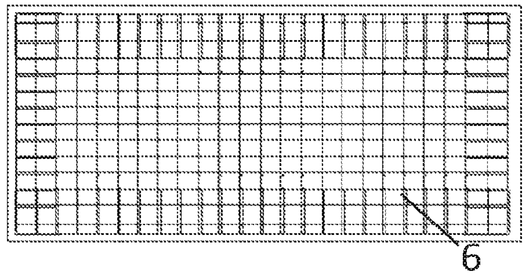

Fig. 3C

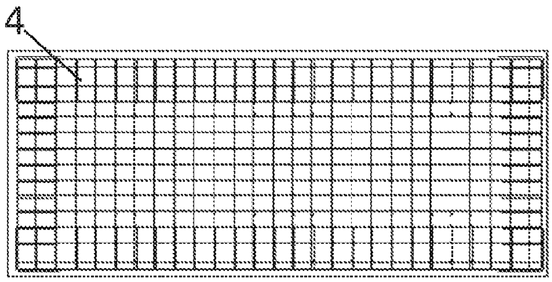

Fig. 4A

Fig. 4B

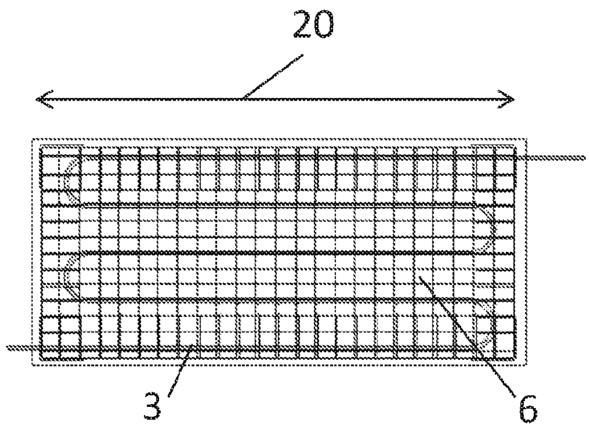

Fig. 4C

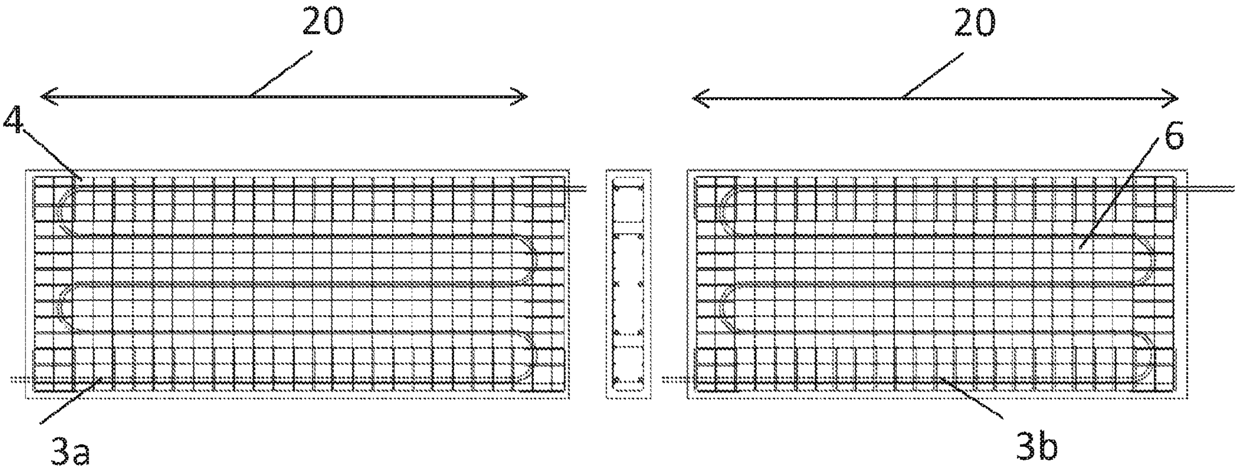

Fig. 5A Fig. 5B Fig. 5C

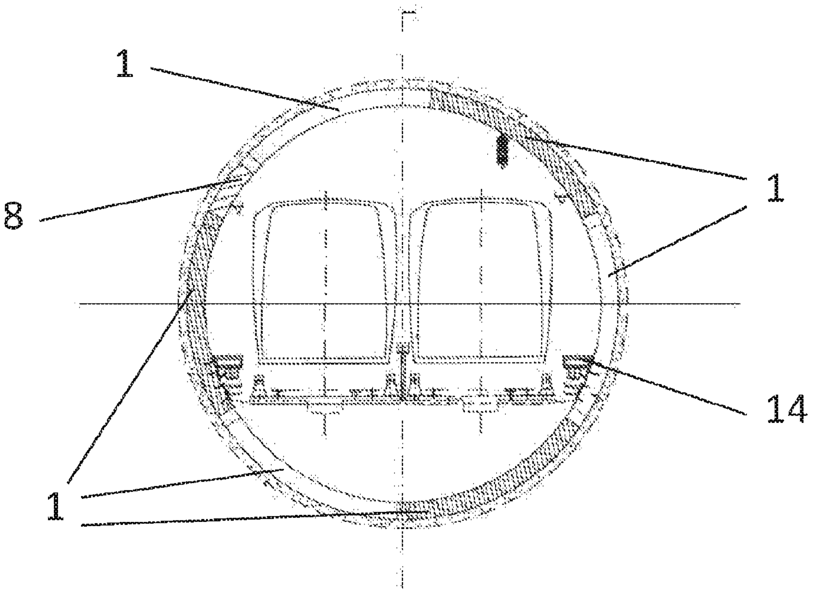

Fig. 6

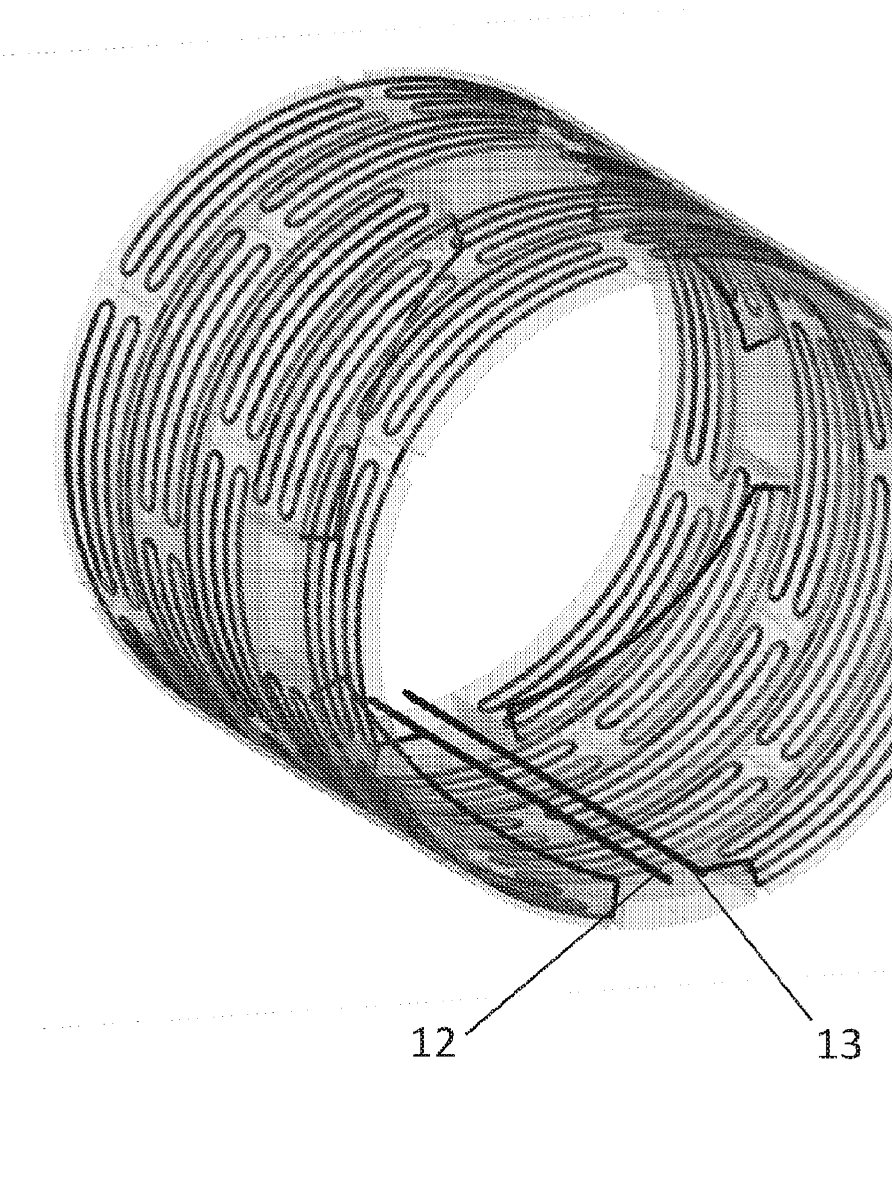

Fig. 7

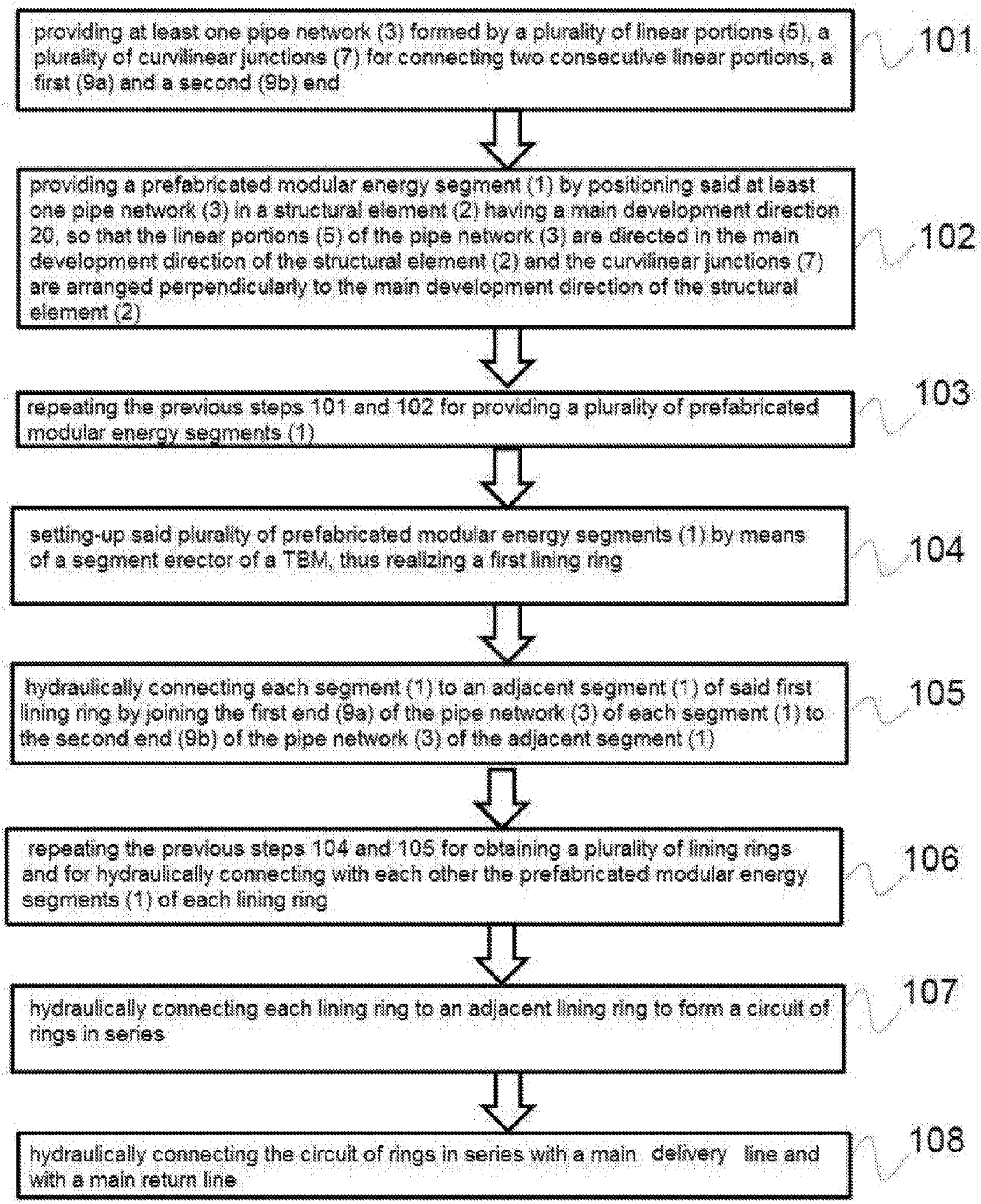
providing at least one pipe network (3) formed by a plurality of linear portions (5), a plurality of curvilinear junctions (7) for connecting two consecutive linear portions, a first (9a) and a second (9b) end
101
providing a prefabricated modular energy segment (1) by positioning said at least one pipe network (3) in a structural element (2) having a main development direction 20, so that the linear portions (5) of the pipe network (3) are directed in the main development direction of the structural element (2) and the curvilinear junctions (7) are arranged perpendicularly to the main development direction of the structural element (2)
102
repeating the previous steps 101 and 102 for providing a plurality of prefabricated modular energy segments (1)
103
setting-up said plurality of prefabricated modular energy segments (1) by means of a segment erector of a TBM, thus realizing a first lining ring
104
hydraulically connecting each segment (1) to an adjacent segment (1) of said first lining ring by joining the first end (9a) of the pipe network (3) of each segment (1) to the second end (9b) of the pipe network (3) of the adjacent segment (1)
105
repeating the previous steps 104 and 105 for obtaining a plurality of lining rings and for hydraulically connecting with each other the prefabricated modular energy segments (1) of each lining ring
106
hydraulically connecting each lining ring to an adjacent lining ring to form a circuit of rings in series
107
hydraulically connecting the circuit of rings in series with a main delivery line and with a main return line
108

Fig. 8

REFERENCES CITED IN THE DESCRIPTION

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