

METHOD OF MANUFACTURING AN UNDERGROUND STORAGE TANK AND CORRESPONDING TANK

FIELD OF THE INVENTION

5 The present invention relates to the construction of buried structures, more particularly to buried storage tanks designed to contain a fluid, notably a liquid, for example water.

10 BACKGROUND OF THE INVENTION

 There already exist tanks partially or totally buried in the ground, intended for storing a fluid such as water.

 Such tanks typically comprise an outer wall buried
15 in the ground and forming a ground support system defining a first volume to be excavated, a raft, and an inner lining coating the outer wall and joined in a fluid-tight manner to the bottom slab, for sealing a storage space for the fluid. Such inner lining is
20 traditionally made of steel or of reinforced concrete cast directly against the outer wall and integral with the raft.

 The outer wall and the inner lining must cope with major tensile and compressive forces due to ground and
25 groundwater pressures and to internal fluid pressure. In particular, the inner lining needs a significant amount of reinforcement to withstand shrinkage of the concrete constituting it, thermal stresses while concrete is setting, and high hoop tension stresses, which may lead
30 to cracking.

 To comply with recent standards for water storage structures, it is necessary to further limit the maximum width of cracks in structures. With present construction methods, this leads to increasing the dimensions of the
35 lining for a steel liner or to using more reinforcing steel for a concrete liner. However, the additional cost can be significant due to the quantities of steel

required. Also, with a concrete liner, the packing density of steel bars can be so tight as to make it difficult to place and compact the concrete properly. Finally, the fluid tightness of the structures and their durability can depend heavily on workmanship and on inspection during construction of the liner.

An object of the present invention is to provide a method of fabricating a buried storage tank, notably a buried tank for storing a fluid, in particular a liquid, having improved and durable resistance to cracking, which is easy to implement, economical, and does not require a large quantity of materials.

Another object of the present invention is to provide such a buried storage tank that has improved and durable resistance to cracking.

SUMMARY OF THE INVENTION

A method of fabricating a buried storage tank comprises at least the following steps:

- forming below ground a structure comprising an outer wall forming a first enclosed periphery defining a first volume, a raft, and an inner wall forming a second enclosed periphery defining a fluid-tight storage space for a fluid inside the first volume; and
- applying a prestressing force on the inner wall directed towards the inside of the storage space, whereby the inner wall is subjected to compressive hoop stress.

The inner wall forms an inner lining defining, inside the first volume, a fluid-tight storage space for a fluid to be stored. According to the present invention, the inner wall may be subjected to a radial prestressing force directed towards the inside of the storage space, before a fluid is introduced into the space for storing.

The inner wall is deformed towards the inside of the storage space, and is subjected to compressive hoop stress.

For a structure of circular section extending around an axis, a radial direction is defined as a direction perpendicular to the axis of the structure and passing via said axis.

5 In this example, the hoop stress applied to said structure is orthoradial, i.e. perpendicular to such a radial direction and to the axis of the structure.

When the storage space is then filled with the stored fluid, the stored fluid exerts a radial inside
10 pressure on the inner wall, whereby the inner wall tends to recover its initial position.

The hoop stress due to prestressing compensates a part of the tensile hoop stress in the inner wall induced by said inside pressure, so that resulting tensile
15 stresses in the inner wall are maintained at levels low enough not to require large amounts of reinforcement, or even to avoid the use of reinforcement completely. The inner wall is subjected to limited traction, and crack formation is limited or even avoided.

20 In an implementation, the outer wall and the inner wall are formed so as to be spaced apart from each other, whereby a gap is formed between them.

In an example, during the prestressing step, the gap is filled with at least one prestressing fluid, so that
25 the prestressing fluid exerts the radial prestressing force on the inner wall.

As is known, concrete walls usually shrink while the concrete is setting. With conventional construction methods where the inner wall is cast directly against the
30 outer wall, a gap created between the two walls by the shrinkage allows the inner wall to expand outwardly upon the storage space being filled with the stored fluid. The inner wall must therefore be even more reinforced in order to limit cracking.

35 With the method of the invention, the compressive hoop stress created in the inner wall due to the prestressing blocks any relative movement between the

inner and outer walls so that tension created in the inner wall is limited and, consequently, the widths of the cracks created therein are limited. Inner wall reinforcing means can thus be much more limited or even
5 omitted.

The prestressing fluid is advantageously a liquid material, for example water. Under such circumstances, the prestressing force exerted on the inner wall is due to the hydrostatic pressure of the liquid material poured
10 into the gap. In certain embodiments, the liquid material may remain in its liquid state over time.

However, the prestressing fluid may also be a hardening material, more particularly a self-hardening material. For example, the prestressing fluid may
15 comprise concrete, in particular slow-setting concrete.

When the fluid introduced into the gap is a hardening material, for example concrete, the rheology of the fluid and also its pouring sequence are advantageously selected so as to adjust the pressure that
20 is applied to the inner wall.

For example, when the fluid is concrete, its rheology may be adjusted (for example by using adjuvants, retarders) so that it starts to set (harden) (notably at the bottom of the gap) only once the gap has been
25 entirely filled, thus ensuring that the force exerted at the bottom of the inner wall is at the target value.

The method of the invention may also comprise monitoring the rate of introduction of the prestressing fluid into the gap. In particular, when the prestressing
30 fluid is a hardening material such as concrete, the fluid may be introduced into the gap step by step, i.e. a second volume of concrete may be introduced into the gap only once a first volume of concrete has already set (hardened) inside the gap. The maximum pressure measured
35 in the concrete can thus be limited.

The method may also comprise monitoring at least one pressure inside the gap.

In an implementation, limit values are set for the minimum and maximum pressures of the prestressing fluid inside the gap prior to starting pouring.

5 In an implementation, prior to the prestressing step, limit values are predetermined for compression of the inner wall during filling of the gap.

10 In an implementation, the top of the gap is sealed, the sealed gap remaining connected to supply means for supplying a filling substance under pressure, and the filling substance is introduced in the gap via said supply means so as to increase the prestressing force applied on the inner wall. It should be observed that the filling substance is generally a fluid, which fluid may be the prestressing fluid or a different fluid, and 15 when different it may be added after introduction of the prestressing fluid, e.g. in order to adjust the prestressing pressure or to increase said pressure over the lifetime of the structure, should said pressure decrease.

20 To obtain the final target compression at all locations of the liner, the prestressing of the inner wall may also be obtained by using conventional methods (in addition to or as an alternative to the above-described method). For example, the inner wall may be 25 prestressed using prestressing reinforcement, notably reinforcement installed horizontally around the inner wall. The reinforcement may be cables or bars for example.

30 The present invention also provides a buried storage tank, notably a tank for storing a fluid such as water, which tank may be obtained by the above-mentioned fabrication method.

35 The buried storage tank of the invention comprises an underground structure including an outer wall forming a first enclosed periphery defining a first volume, a raft, and an inner wall forming a second enclosed periphery defining a fluid-tight storage space for a

fluid inside the first volume, the tank being adapted to be in a filled state where a fluid is stored in the storage space or in an empty state where the storage space is empty, the tank comprising prestressing means adapted for applying a prestressing force on the inner wall directed towards the inside of the storage space in at least one configuration, whereby, in the empty state of the tank, the inner wall is subjected to compressive hoop stress.

10 In an embodiment, the outer wall and the inner wall are separated from each other by an intermediate layer, the intermediate layer comprising prestressing means.

In an embodiment, the layer comprises a hardening material that has set (hardened), for example concrete, which, in its fluid state, is provided to apply a radial prestressing force on the inner wall.

In another embodiment, the layer comprises a material in the liquid state, said material exerting a prestressing force on the inner wall towards the inside of the storage space.

The inner wall may be a concrete wall, in particular a reinforced concrete wall, or it may be made of steel.

The peripheral underground structure may have a circular or an oval shape.

25 In an embodiment, the intermediate layer may extend continuously around the entire periphery of the inner wall.

Except when obviously incompatible and unless otherwise stated, features of any one embodiment or example described herein can be applied to other embodiments or examples described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be better understood on reading the following description of the embodiments of the invention given as non-limiting examples, with reference to the accompanying drawings, in which:

- Figure 1 is a perspective view of a buried storage tank according to the present invention;

- Figures 2 to 5 are a schematic section views along II-II of Figure 1, showing the different steps of fabricating the buried storage tank of Figure 1 according to an embodiment of the present invention;

- Figures 6a) to 6c) illustrate a second embodiment in which prestressing fluid is introduced in the gap in a step-by-step process;

- Figure 7 illustrates a third embodiment in which the gap is sealed before introducing the prestressing fluid therein;

- Figure 8 illustrates a fourth embodiment in which prestressing of the inner wall is also obtained with horizontal prestressing reinforcement;

- Figures 9, 9A and 9B illustrate a fifth embodiment in which the inner wall is also compressed by using vertical prestressing reinforcement.

In the drawings, like reference signs generally refer to the same parts throughout the different views.

DETAILED DESCRIPTION

Figures 1 to 5 illustrate a buried storage tank in an embodiment of the present invention, particularly provided for the storage of fluids, and particularly liquids such as water. By way of example, such a tank has an outside diameter lying in the range 10 meters (m) to 60 m, and a total height lying in the range 10 m to 100 m.

The tank 100, illustrated in Figure 1, comprises an underground structure including an outer wall 20 forming a first enclosed periphery defining a first volume V1, a raft 10, and an inner wall 30 forming a second enclosed periphery defining, inside the first volume V1, a fluid-tight storage space S for a stored fluid W.

In the present description, unless otherwise stated, low and high portions of a structure are defined along a

vertical axis, a low portion referring to the bottom portion of the structure, directed to the deepest ground.

In the illustrated example, the tank 100 is opened at its top end 100a. However, although not shown, it is
5 also possible for the tank to be provided with a covering structure.

In the present description, a filled state of the tank 100 is defined as a state in which a fluid is stored in the storage space S. In contrast, a state where the
10 storage space S is empty (i.e. no fluid is stored therein) is defined as an empty state of the tank 100.

As can be seen from the description below, in the Figure 1 example, the tank comprises prestressing means adapted, in at least one configuration, to apply on the
15 inner wall 30 a radial prestressing force directed towards the inside of the storage space and to apply at the same time a radial prestressing force on the outer wall 20 directed towards the outside of the storage space. Due to said means, in the empty state of the
20 tank, the inner wall 30 is subjected to compressive hoop stress.

When the tank 100 is filled with a stored fluid as shown in Figure 1, an inside pressure due to the stored fluid is exerted on the inner wall 30, inducing tensile
25 hoop stress in said wall. This stress is balanced by the already existing compressive stress in the inner wall 30, consequently preventing cracks forming in the inner wall 30.

The structure of such a tank can be better
30 understood in light of the steps for fabricating it as described below with reference to Figures 2 to 5.

Typically, the outer wall 20 is first formed in the ground G and subsequently the earth contained in the first volume V1 defined thereby is excavated. Then, the
35 raft 10 is formed. The outer wall 20 and the raft 10 thus form the base structure of the tank shown in

Figure 2, which defines an excavation of corresponding shape in the ground.

As shown for example in Figures 1 and 2, the outer wall 20 forms a thick vertical supporting wall having its outer surface 20c in contact with the ground G. In the illustrated example, the outer wall 20 has a generally cylindrical shape extending around a main vertical axis X1. In the example, when seen in projection on a horizontal plane, the outer wall 20 has a circular shape. However, in other embodiments, the outer wall 20 may have any other suitable shape, in particular an oval shape.

The outer wall 20 is typically made of reinforced concrete. It may for example be achieved by the diaphragm wall technique, in particular by making a plurality of individual diaphragm panels, either in succession or in alternation. This example is not limiting however, and the outer wall may be made also by the technique known as Berlin walls or by systems of sheet piles or any other appropriate technique for making deep foundations. Since the above-mentioned techniques are well known to the person skilled in the art, they are not described here in more detail.

The raft 10 is connected to the outer wall 20, preferably in a fluid-tight manner. The raft 10 extends horizontally from the bottom portion of the outer wall 20, and is generally made of reinforced concrete.

As shown in Figure 3, the inner wall 30 is then formed to define a fluid-tight storage space S for the stored fluid W, inside the first volume.

The inner wall 30 lines the outer wall on the inside and is linked to the bottom concrete slab 10 in a fluid-tight manner. Advantageously, watertight gaskets (not shown) may be provided at the junction of the inner wall 30 with the slab 10.

The inner wall 30 may be made of concrete, notably of fiber reinforced concrete. It may for example be constructed using slipform techniques.

In the illustrated embodiment, the inner wall 30 has a cylindrical shape centered on axis X1 and thus extends in parallel with the outer wall 20. The inner wall 30 is spaced apart from the outer wall 20 in a radial direction (i.e. a direction orthogonal to the axis X1), around its entire circumference. An annulus or gap 40 is thus formed between the inner and outer walls 30, 20.

In the present embodiment, the above-mentioned compressive hoop stress in the inner wall 30 is obtained by introducing a prestressing fluid into the gap 40, in a step illustrated in Figure 4.

In the example, the prestressing fluid is concrete (referenced C in the drawings), which may be discharged directly in the gap 40 via one or more hoppers 42.

When the concrete C contained in the gap is in its fluid state, due to the hydrostatic pressure of the concrete C, the inner wall 30 is subjected to a deformation towards the inside of the storage space, resulting in compressive hoop stress. Dotted lines D1 in Figure 4 show the deformation of the inner wall 30 in an exaggerated manner.

Advantageously, limits for the minimum and maximum pressure of the concrete C inside the gap are set before starting pouring, and, during the pouring of the concrete C into the gap 40, means are used for monitoring pressure inside the gap 40.

Such means may comprise sensors 50 as illustrated in Figure 4, such as pressure cells connected to the surface in order to provide real time results to operators.

Advantageously, the concrete C may be chosen to be slow-setting, so that it starts to set at the bottom of the gap 40 only once the gap 40 has been entirely filled, thus ensuring that the pressure force F1 exerted by the poured concrete C at the bottom end of the inner wall 30 is maximized.

As shown in Figures 1 and 5, the annulus formed between the inner and outer wall 20, 30 forms an

intermediate layer 70 of concrete. The intermediate layer forms a structure that is clearly distinct from the outer and inner walls, first and second junction surface being clearly visible respectively between the
5 intermediate layer 70 and the outer wall 20 and the intermediate layer 70 and the inner wall 30. However, the intermediate layer 70 molded between the outer and inner walls forms a unitary construction with said walls, preventing any voids being formed between them.

10 Figure 5 shows the tank once the concrete C has cured and the storage space S has been filled with stored fluid, notably water W.

The inside pressure exerted by the stored fluid W on the inner wall 30 is represented by arrows F3 in
15 Figure 5.

The reaction of said inner wall 30, prestressed by the prestressing fluid C, is represented by arrow F2.

As a consequence of the stored fluid pressure F3, the inner wall 30 tends to expand outwardly (that is,
20 towards the outside of the storage space), inducing tensile hoop stress in the inner wall.

The compressive hoop stress of the inner wall 30, due to the prestressing, balances this tension resulting from the stored fluid pressure, so that tensile stresses
25 of the inner wall stay at acceptable levels. The inner wall is subjected to limited traction, and crack formation is limited or even avoided.

The resulting deformation of the inner wall 30 is represented in an exaggerated manner by dotted line D2,
30 in Figure 5.

In some circumstances, it is desired that the maximum pressure in the gap does not exceed a predetermined value.

Further, limit values may be set for compression of
35 the inner wall 30 during filling of the gap 40 and means (not shown) may be provided to monitor the deformation of

the inner wall 30 during prestressing, for example strain gauges.

In an implementation shown in Figures 6a) to 6c), in order to avoid exceeding such limit values, the method
5 may include monitoring the rate at which concrete is introduced into the gap.

In particular, the concrete C may be introduced into the gap 40 step by step.

As shown in Figure 6a), a first volume of concrete
10 C1 is introduced into the gap 40 to fill a portion (here the bottom third) of the gap 40.

After the first volume of concrete has set completely, and as shown in Figure 6b), a second volume C2 of concrete is introduced into the gap, filling a
15 second portion (here a second third) of the gap 40.

Thereafter, once the second volume C2 has set, a third volume of concrete C3 is introduced into the gap, above the first and second volumes C1, C2 (Figure 6c)).

Since the maximum pressure in the concrete increases
20 with increasing depth of liquid concrete, it can easily be understood that in this step-by-step process, the maximum pressure measured in the concrete is limited in comparison with the embodiment described with reference to Figure 4. As a direct consequence, the prestressing
25 force applied to the inner wall is also limited.

In contrast, in other cases, the pressure obtained in the gap under atmospheric pressure may not be sufficient.

In such circumstances, the top of the gap may be
30 sealed by a cap 62 as shown in Figure 7, and additional pressure may be applied.

The sealed gap may be connected to supply means 60 configured to supply a filling substance to the gap, the filling substance being the same or different from the
35 prestressing material, and the filling substance may be introduced in the gap under pressure, via the supply means 60. The additional pressure may be applied from

the top of the gap, though a hole 64 formed in the cap 62, or through holes 66 placed at any location in the inner wall 30, as a function of the target compression at each location.

5 The prestressing force applied on the inner wall is thus increased.

Another solution for obtaining the final desired compression at all locations of the liner is provided by the embodiment of Figure 8.

10 As shown, the prestressing of the inner wall is further enhanced here by prestressing reinforcement 80 disposed horizontally inside the gap 40 and surrounding the inner wall 30. These cables may be installed in the gap 40 before introducing the prestressing fluid therein.

15 In yet another embodiment shown in Figures 9, 9A, and 9B, the inner wall may further be prestressed using vertical prestressing reinforcement 82, e.g. anchored in the concrete raft 10 and fastened to the top end of the inner wall 30. As shown in Figure 9A, which is a section
20 view on line IXA-IXA of Figure 9, a plurality of cables 82 may be distributed in the circumferential direction, preferably in regular manner.

Nevertheless, the above-described embodiments are not limiting on the present invention.

25 As an example, the prestressing fluid need not be a hardening material such as concrete. The prestressing fluid may for example be water or any other fluid that remains in a liquid state.

Under such circumstances, the intermediate layer 70
30 is constituted by a liquid, the liquid exerting a force on the inner wall 30 towards the inside of the storage space 10 throughout the life of the tank.

Further, under such circumstances, inlets such as holes 64, 66 described with reference to Figure 7 may
35 advantageously be kept accessible so that prestressing fluid or any other filling substance can be added in the

gap so as to maintain the appropriate pressure on the inner wall 30 for the entire life of the tank 100.

CLAIMS

1. A method of fabricating a buried storage tank (100) comprising at least the following steps:
 - forming below ground a structure comprising an
5 outer wall (20) forming a first enclosed periphery defining a first volume (V1), a raft (10), and an inner wall (30) forming a second enclosed periphery defining a fluid-tight storage space (S) for a fluid inside the first volume (V1); and
 - 10 · applying a prestressing force on the inner wall (30) directed towards the inside of the storage space (S), whereby the inner wall is subjected to compressive hoop stress.
- 15 2. A method according to claim 1, wherein the outer wall (20) and the inner wall (30) are formed so as to be spaced apart from each other, whereby a gap (40) is formed between them, and the prestressing step comprises filling the gap (40) with at least one prestressing fluid
20 (C), so that the prestressing fluid (C) exerts the prestressing force on the inner wall (30).
3. A method according to claim 2, wherein the prestressing fluid (C) is a hardening material.
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4. A method according to claim 2 or claim 3, wherein the prestressing fluid (C) comprises concrete, in particular slow-setting concrete.
- 30 5. A method according to any one of claims 2 to 4, further comprising monitoring the rate of introduction of the prestressing fluid (C) into the gap (40).
6. A method according to any one of claims 2 to 5,
35 further comprising monitoring at least one pressure inside the gap (40).

7. A method according to any one of claims 2 to 6,
further comprising sealing the top of the gap (40), the
sealed gap remaining connected to supply means (60) for
supplying a filling substance, and introducing the
5 filling substance in the gap via said supply means (60)
so as to increase the prestressing force applied on the
inner wall (30).

8. A method according to any one of claims 1 to 7,
10 wherein the inner wall (30) is formed after the outer
wall (20) has been formed and the earth inside the first
volume (V1) has been removed.

9. A method according to any one of claims 1 to 8,
15 wherein the inner wall (30) is prestressed using
prestressing reinforcement (80, 82).

10. A buried storage tank (100) comprising an underground
structure including an outer wall (20) forming a first
20 enclosed periphery defining a first volume (V1), a raft,
and an inner wall (30) forming a second enclosed
periphery defining a fluid-tight storage space (S) for a
fluid inside the first volume, the tank being adapted to
be in a filled state where a fluid is stored in the
25 storage space or in an empty state where the storage
space is empty, wherein the tank comprises prestressing
means adapted for applying a prestressing force on the
inner wall (30) directed towards the inside of the
storage space (S) in at least one configuration, whereby,
30 in the empty state of the tank, the inner wall (20) is
subjected to compressive hoop stress.

11. A buried storage tank (100) according to claim 10,
wherein the outer wall (20) and the inner wall (30) are
35 separated from each other by an intermediate layer (70),
and the intermediate layer comprises the prestressing
means.

12. A buried storage tank (100) according to claim 11, wherein the intermediate layer (70) comprises a hardening material that has set, notably concrete.

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13. A buried storage tank (100) according to claim 11, wherein the intermediate layer (70) is made of a material in the liquid state, said material exerting a force on the inner wall (30) directed towards the inside of the storage space (S).

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14. A buried storage tank (100) according to any one of claims 11 to 13, wherein the intermediate layer (70) extends continuously around the entire periphery of the inner wall (30).

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15. A buried storage tank (100) according to any one of claims 10 to 14, wherein the inner wall (30) is a concrete wall.

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16. A buried storage tank (100) according to any one of claims 10 to 14, wherein the inner wall (30) is made of steel.