July 24, 1956 E. FREYSSINET 2,755,630

BURIED RESERVOIRS OF PRE-STRESSED CONCRETE

Filed Sept. 22, 1952 2 Sheets-Sheet 1

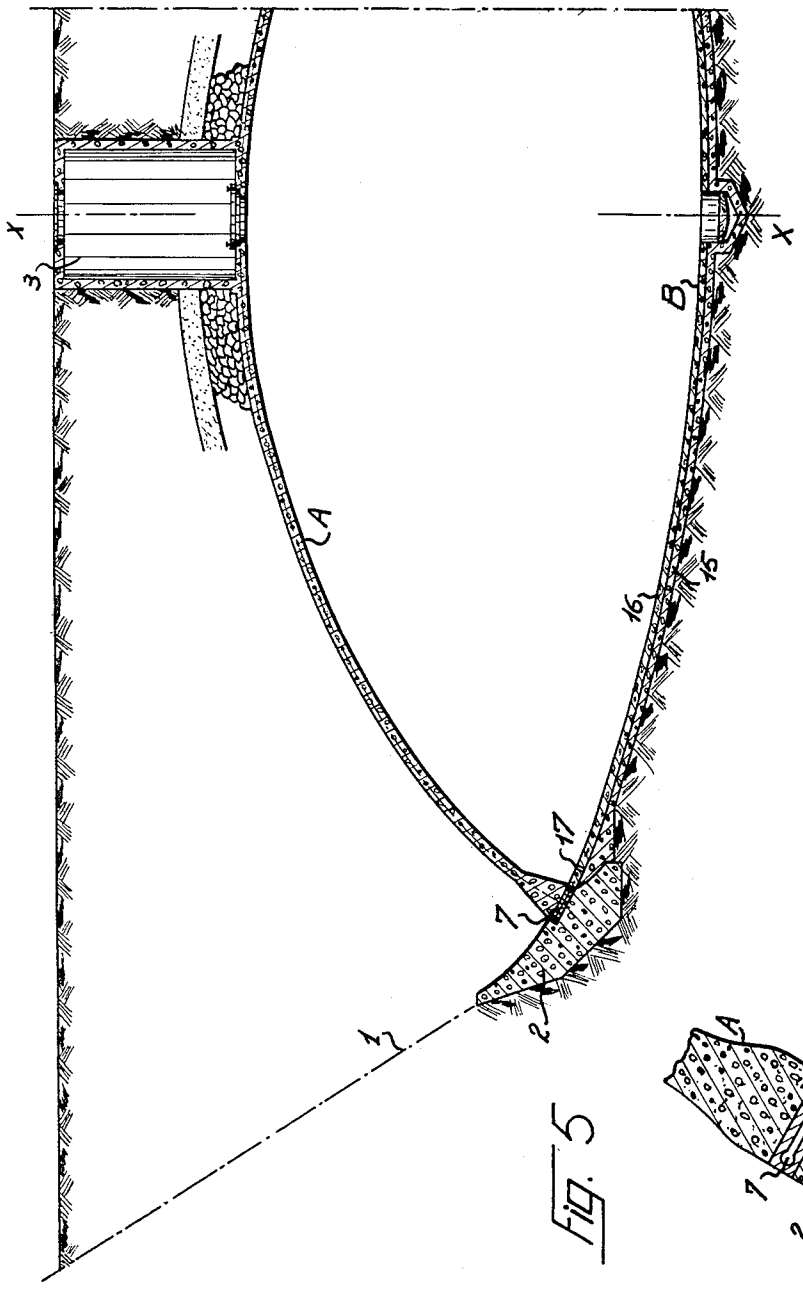


Fig. 1

Fig. 5

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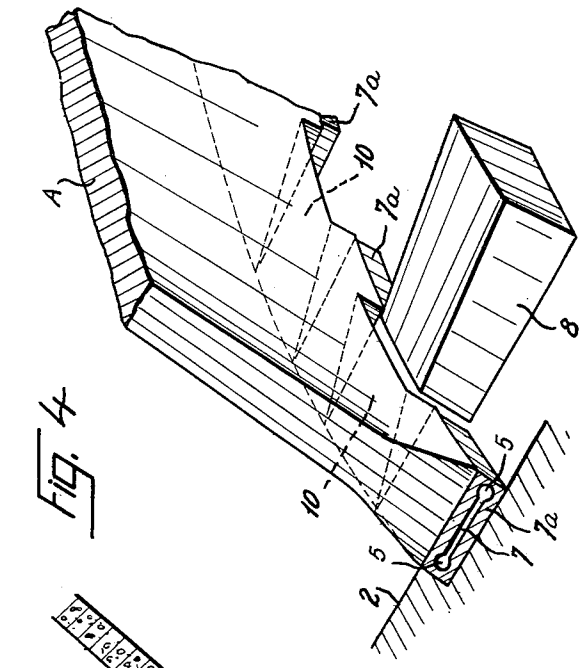


Fig. 4

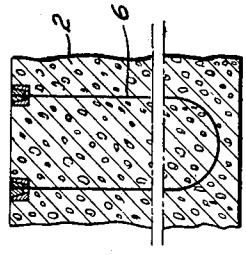


Fig. 3

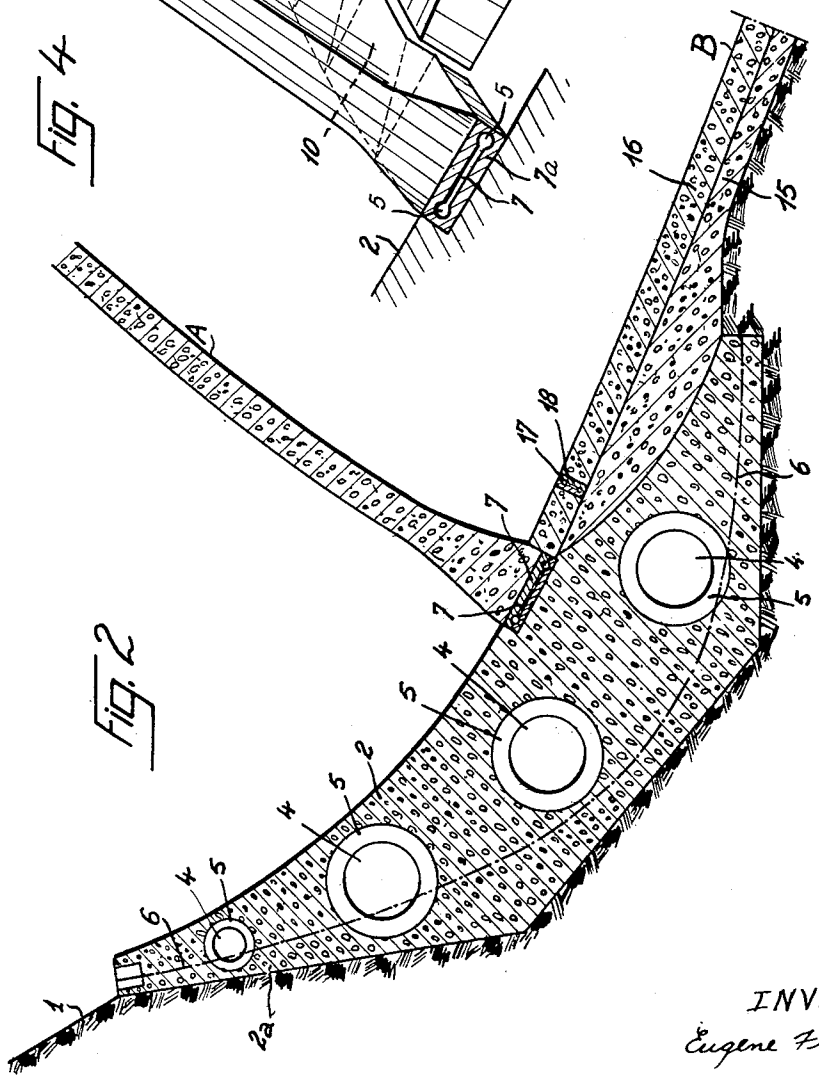


Fig. 2

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2,755,630

Patented July 24, 1956

2,755,630

BURIED RESERVOIRS OF PRE-STRESSED CONCRETE

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Application September 22, 1952, Serial No. 310,893

Claims priority, application France October 4, 1951

10 Claims. (Cl. 61—.5)

The present invention has for its object a buried reservoir of pre-stressed concrete, in which the pre-stressing is obtained by utilizing the weight of the masses of movable earth under which the reservoir is buried.

It covers the method of building this reservoir and the apparatus intended for carrying out this method in practice.

The reservoir is composed of two superposed parts, joined on a common horizontal plane.

The upper part which supports the earth covering the reservoir is formed by a cupola, preferably of revolution shape, made of relatively thin concrete and having advantageously a constant thickness along sections through horizontal planes, which in the case of a cupola of revolution are parallels. This concrete may be reinforced with a simple very light check-pattern reinforcement.

The shape of this upper part is defined in such a way that, at every point, the compressions due to the load of earth create, in the concrete, unitary compression stresses of the same order in all directions. In the case of a cupola of revolution, in particular, it is known that if P is the pressure on the cupola (the difference between the internal and external pressures), the formula of Laplace gives the relation:

$$\frac{N_1}{R_1}+\frac{N_2}{R_2}=P$$

N_1 and N_2 being pressures per meter of length along the meridians and the parallels and R_1 and R_2 the main radii of curvature. Moreover, the necessary balance of loads and reactions supplies on each parallel a second equation $f(N_1, N_2, P)=0$. The local thicknesses e can always be so defined that the local pressures equal to

$$\frac{N_1}{e} \text{ and } \frac{N_2}{e}$$

have such a value as is desired.

The values of P, and therefore of the prestresses, thus determined are rather badly defined, unless very particular care is employed in the filling up or packing with earth.

In the method according to the invention, after properly packing with earth which is preferably hydraulically tamped and which may comprise sand or gravel towards the bottom, one avails himself, in order to load the concrete in the upper part, of all the weight of the earth covering the reservoir together with the frictions between this earth and the neighbouring ground and, furthermore, an accurately predetermined value is given to this load.

To this end there is arranged, between the upper part and a sufficiently resistant and preferably pre-stressed foundation a joint comprising jacks, advantageously of the flat type, composed of inflatable metallic bags of the type described by the applicant in his U. S. Letters Patent No. 2,226,201 then, after completion of the upper part and construction of the packing, a pressure is exerted between the foundation and the springing of the upper part along a suitable direction chosen in order to effect a

shortening by compression of the perimeter of the base of the said upper part and a raising of this part covered by its packing, the result being to load in a definite manner the said part not only with the whole weight of the said packing but also with the friction of this packing against the neighbouring ground.

The effect of the pre-stressing thus obtained is made permanent in the reservoir finally constructed, by immobilising the upper part after raising, for example by means of wedges introduced into the joint between the jacks as the raising takes place, the jacks being adapted to be then withdrawn, or by blocking the jacks, which is effected by injecting a hardening liquid to operate them.

The invention is illustrated by way of example in the accompanying drawings, wherein:

Fig. 1 is a diagrammatic view in partial vertical section, of one manner of constructing a reservoir according to the invention.

Fig. 2 is a view, similar to Fig. 1 but on a larger scale, showing the detail of the joint between the upper spherical vault and the pre-stressed annular foundation.

Figs. 3, 4 and 5 show details.

In the embodiment shown in the drawings both the upper part A and the lower part B of the reservoir have shapes of revolution about a common vertical axis X—X. The sections in Figs. 1 and 2, which are only partial views, are therefore taken along a meridian plane. The two parts have the forms of spherical caps, but this form is not limitative. The lower part B rests on the soil of the bottom of the excavation of which the slope is indicated at 1, as well as on an annular foundation 2. The springs of the upper spherical vault A provided with the shaft 3 for access rest on this foundation by means of a joint of which the details will be given hereinafter.

The foundation 2 may be of prestressed concrete. An annular prestress can be conveniently effected with the help of jacks (preferably of the so-called flat type according to the aforesaid patents of the applicant) disposed in 2, 3 or 4 radial joints.

Fig. 2 assumes that one of these joints is arranged in the plane of the drawing and comprises four flat jacks 4 each comprising two parallel circular plates connected by a toric flange 5. The foundation is furthermore prestressed transversely by looped cables 6. These cables, covered by a lubricant and by lapping to avoid adherence to the concrete, are stretched after the grip by the concrete and enclosed at their ends, for example by wedge anchorings as described in the United States Patents Nos. 2,270,240; 2,618,147 and 2,686,963.

The detail of the loops which each of them forms is shown in Fig. 3, which represents a part of the foundation 2 developed. If the soil is bad the foundation can be enlarged or reinforced by light piles of sand, wood or concrete. The spherical vault A is constructed on the annular foundation 2 or more exactly on an annular bed of flat jacks 7 separated by keys 8, which bed lies on the foundation. Each jack is composed in the example illustrated of two circular parallel steel plates connected at their edges by a toric flange 5 provided with an injection appendage. Each jack is preferably enclosed in a prismatic mass 7a of concrete. The keys 8 placed in the spaces between the jacks have a cuniform vertical section so as to form wedges which are buried, as will be hereinafter described, below the cupola in accordance with the inflation of the jacks, the surfaces 10 of which the slant corresponds to that of the said wedges being formed on the supporting surface of the spring of the spherical vault (see the diagrammatic part in perspective of Fig. 4) in order to co-operate with the wedges. Once the spherical vault is completed, the excavation is filled in and the spherical vault is loaded with the packing up to the prescribed height. After

formation and hydraulic tamping of the packing, the jacks 7 are inflated so as to exert a pressure between the foundation 2 and the spring of the vault. The surface of this foundation and the supporting surface of the springs of the vault are so directed that the action of the jacks produces a shortening of the perimeter of the base of the vault equal to the compression to be obtained in the concrete. For example, if on a spherical vault having a radius of two meters, it is desired to effect a shortening of $\frac{1}{10000}$ that is to say a reduction in radius of 5 mm., with a stroke of the jacks of one centimeter, it is necessary that the line of action of the latter should be inclined at ½.

Furthermore the jacks 7 can be arranged, not directly between the vault and the foundation 2, but between the vault and pivotal elements 11 (Fig. 5) supported by ball shaped projections 12 on the foundation 2 which renders the deformations of the base parallel of the vault independent of the stroke of the jacks.

The keys or wedges 8 are buried between the vault and the foundations as the jacks are inflated. In case of damage to a jack, this allows of releasing the pressure in this jack and of replacing it by another jack from the interior of the reservoir, by which the whole manipulation is effected.

The action of the jacks has for its effect not only to produce compressions in the concrete of the vault by shortening its base perimeter as has been described, but also to raise the vault covered by its packing earths which thus load this vault in a sure and uniform way. Furthermore the mass of earth raised at the same time by the vault makes friction with the adjacent ground. The vault is finally loaded not only with the total weight of the earth surmounting it, but with a large addition due to the friction which has been described, the whole furthermore limited to the measurable action of the jacks. In order to illustrate the operation, an example is given; a packing having a height of three meters above the centre voussoir of a cap, a diameter of 25 meters and a rise of about 6 meters suffices to cause prestressings of the order of 60 kgs./sq. cm. in a shell of 12 cms. thickness, even if the piezometric level of the liquid in the reservoir shall rise several meters above the top of the latter.

The lower part B may be formed in such a manner as desired. But in a reservoir more or less deeply buried, it often arises that there is the necessity of resisting sub-pressures. They can however be limited by surrounding the said lower part by a drainage, for example by a packing of stones comprising a discharge duct at a given level. Preferably the said lower part will be formed by a cap which can be spherical as shown in the drawings or of form calculated to give, in the zone of support of the upper vault, minimum horizontal reactions. This cap may have for example a radius decreasing from the centre to the periphery. Preferably it will rest against the base of the upper vault.

It is possible and advantageous to prestress this cap. It is necessary for this so to arrange things that its concrete can shorten itself elastically despite the support on the bottom of the excavation. Commencement may be made by sweeping-up according to the form chosen for the meridian of the cap, a concrete layer 15 for neatness which will cause all irregularity of form to disappear especially towards the foundation and which is packed with a plastic body such as bitumen. The layer of concrete 16, to be prestressed, is run onto the bitumen whilst arranging an annular joint 17 near the base of the upper vault. In this joint, extending along a parallel of the cap, there is inserted a bag jack formed by a tube of flattened sheet metal 18 well supported by mortar packings against the concrete on the two faces of the joint. This tube is inflated with a liquid (water or oil) so as to compress the concrete 16 forming the operative part of the lower cap, after which, for this

liquid a body is substituted which is capable of forming a connection: cement grout, synthetic resin which keeps the jack 18 inflated. The fluidtight jack thus formed is completed by a packing of the upper part of the remaining joint and an injection of the lower inaccessible part. The peripheral pressure created on the base of the vault by the action of the jack 18 will have for its effect to deflect the reaction of the vault on the foundation. Allowance will be made for the construction of the annular foundation 2. For example this foundation can be prolonged on the outer side as indicated at 2*a*, by a concrete covering of the earths before filling in the excavation and placing the vault under compression. By friction on the ground this extension 2*a* of the foundation will provide the necessary additional reaction.

The invention provides the means for forming prestressed reservoirs by a construction which is simple and very economical, the proportion of prestressing being the higher, the thinner the walls.

The type of reservoir may be adapted to all grounds and all dimensions. It can even be constructed as a subterranean at great depth by boring a well which will be enlarged at its base like an elephant's foot. Into the cavity thus formed, parts of the reservoir will be constructed as has been described, and in order to prestress the upper cap, between it and the wall of the cavity which overhangs it there can be interposed sandy-clay mud of a certain thickness intended to adjust the pressures. This mud will be compressed between the vault and the wall of the cavity when the vault is prestressed.

What I claim is:

1. In the construction of a buried reservoir having a concrete wall of generally arcuated shape, the convexity of which faces upward, and a foundation supporting said wall through at least a part of the base perimeter thereof a process of prestressing said concrete wall comprising the steps of packing earthlike material on top of said wall, exerting a pressure between said foundation and said part of the base perimeter of said wall so as to produce a shortening by compression of said perimeter and a raising of said wall covered with said material, and sealing the crack thus produced between said wall and said foundation.

2. Process as recited in claim 1, further comprising the step of holding in a substantially permanent manner said wall in spaced relationship with respect to said foundation, whereby said wall remains with its shortened perimeter and in its raised position, even upon release of said pressure.

3. Process as recited in claim 1, wherein said foundation is made of concrete, further comprising the step of prestressing said concrete foundation.

4. A buried reservoir comprising a prestressed concrete wall of generally arcuated shape, the convexity of which faces upward, a foundation supporting said wall through at least a part of the base perimeter thereof, earthlike material packed on top of said wall, pressure exerting means between said foundation and said part of the base perimeter of said wall, to hold said wall in a raised position wherein its perimeter is compressed and a crack is produced between said wall and said foundation, and means sealing said crack.

5. Reservoir as recited in claim 4, wherein the pressure exerting means comprises a hollow, inflatable jack inserted between said foundation and said part of the wall, and inflating material filling said jack.

6. Reservoir as recited in claim 4, wherein the pressure exerting means comprises a wedge-shaped member inserted between said foundation and said part of the wall.

7. A buried reservoir comprising a curved pre-stressed wall of general revolution shape about a generally vertical axis and of upwardly facing convexity, a generally annular foundation supporting said wall through the base perimeter thereof, earthlike material packed on top of said wall, a plurality of spaced, pressure exerting means between said

annular foundation and the base of said wall, acting along inwardly inclined directions to hold said wall in a raised position wherein its base perimeter is compressed and a crack is produced between said wall and said foundation, and means sealing said crack.

8. Reservoir as recited in claim 7, wherein the direction of action of said pressure exerting means lies in a general axial plane between vertically upward and horizontally inward.

9. Reservoir as recited in claim 8, wherein the pressure exerting means comprise a series of flat, hollow, inflatable jacks circularly distributed along said annular foundation, said jacks being inclined relatively to each other, and an inflating material filling said jacks.

10. Reservoir as recited in claim 8, wherein the pressure exerting means comprise a series of wedge-shaped members circularly distributed along said annular foundation, said members being inclined relatively to each other and inserted between said foundation and the base of said wall.

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