A method for the construction of subterranean partitions or diaphragm walls in concrete, of the type in which a trench is excavated in the ground by known means so that when the casting concrete is effected, the walls of the trench assume directly the function of moulding boxes. Prior to pouring the concrete, a set of metal stressing members, such as high tensile strength steel, is inserted into the trench according to a predetermined profile. After the concrete has set, the said stressing members are subjected to a traction force to induce a prestress adapted to give the wall pre-inflection in a selected direction and amount. Since the concrete is in the trench and in intimate contact with the walls thereof, the traction force applied is of such a degree that, if the same force were applied to a similar wall element outside the earth, such a wall element would fail and crack.

7 Claims, 6 Drawing Figures
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**Fig. 3a**

**Fig. 3b**

\[ M_0 + M_1 = M_1 \]

**Fig. 3c**

\[ M_1 + M_1'' = M_2 \]

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BUILDING OF UNDERGROUND PARTITION WALLS
This application is a continuation-in-part of application Ser. No. 850,101 filed Aug. 14, 1969 now abandoned.

BACKGROUND OF THE INVENTION - FIELD OF INVENTION
Current use is now being made of structures called diaphragms or bulkheads — constructed in the subsoil by means of casting concrete or other material in trenches which are more or less deep and vary in width, excavated in the presence of bentonite muds — the main functions of which are those of supporting the earth, interrupting subterranean water courses and foundation.

DESCRIPTION OF THE PRIOR ART
It is known that, for the purpose of obtaining the required resistance to stresses, more especially the high stresses caused by the pressures of the ground and/or water and/or possible toploads, the designer of diaphragms or bulkheads can, in accordance with the present-day technique, have recourse to:
the adoption of reinforced casts; the metal reinforcement can be in ordinary iron or in steel of improved strength, arranged according to traditional schemes for work in reinforced concrete;
the use of various thicknesses of the diaphragms; the thickness is determined on the basis of the rigidity required, so as not to exceed the limits of the internal tensions which are permitted by the concrete;
the use of props or tie-rods (tie-beams); in the case of severe external thrusts, to narrow the spans and to reduce the bending moment; — the adoption of special sections; transverse sections are selected which have high moments of inertia, which sections are suitably in the form of a "T," "H" and the like;
the adoption of diaphragms with a curvilinear plane section; this configuration tends to form a collaboration between the elements which constitute the diaphragm, so as to obtain an accurate effect, and circular or elliptical diaphragms are a typical example.

In these types of constructions, cases are still found in which — for reasons of bulk, both in regard to performance and economy — the schemes previously disclosed do not allow the practical attainment of a bulkhead or diaphragm whose characteristics of resistance completely fulfill the static requirements demanded.

SUMMARY OF THE INVENTION
The object of the present invention is a method of constructing a subterranean diaphragm or bulkhead or wall which eliminates the aforesaid difficulties of the known techniques and satisfies more fully the present demands. Some advantages of the present invention are:
the possibility of extending the field of application of the diaphragms to works the performance of which has hitherto proved to be very difficult, or uneconomic, or impossible in practice;
the possibility of reducing the dimensions of the resistant sections;
the possibility of facilitating excavations of soil, for the protection of which the diaphragms are provided, reducing the internal props to a minimum;
the possibility of reducing the unitary tensions in the concrete of the diaphragms;
the possibility of eliminating tensions caused by traction in the concrete, particularly noticeable in the diaphragms having the function of hydraulic sealing;
the possibility of facilitating the installation of metal reinforcements, often heavy and bulky, reducing their weight;
the possibility of deriving economic advantages by reducing the quantities of concrete and iron employed, in comparison with the traditional diaphragms.

According to the present invention, the method of constructing subterranean bulkheads or diaphragms in concrete is of the type in which, in conformity with the known technique, a reinforcement of metal is first inserted into a trench excavated in the ground, for example in the presence of bentonite muds and the casting of concrete is then effected, the walls of the trench acting directly as a moulding box. Such a method is essentially characterized by the insertion into the trench of a set of special stressing members, according to an accurate profile and, when the concrete has set, by subjecting the said members to a traction appropriate to give the bulkhead or diaphragm a pre-inflection in the direction and of the value as may be desired.

The method according to the present invention is based namely on the fundamental idea of subjecting the diaphragm to a preliminary flexure, so as to summon at least part of the pressure of the earth even before this occurs naturally during the actual progress of the excavations for the protection of which the diaphragm is provided. The force applied is of such a degree that if the same force were applied to a similar wall element outside the earth, e.g., without the soil counterforce, it would have cracked the wall element.

The surprising observation has in fact been made that the internal tensions of the concrete, when the diaphragm is in the stage of preliminary flexure, are actually lower than those which in theory correspond to the applied flexure force; this is due to the intervention of the reaction of the soil, which resists the deformation of the diaphragm just when this would be likely to occur. In other words, it has been possible to ascertain that — with a diaphragm or bulkhead of the type indicated above, in which the walls of the trench form a moulding box and are consequently strictly adherent to the surfaces of the diaphragm — at the moment when this pre-inflection is being made, the horizontal pressure proceeding from it immediately summons a pressure from the soil substantially equal and of contrary degree, which avoids the arising of internal tensions of traction in the concrete. These internal unitary tensions therefore result, at any instant of the pre-inflection, determined by the algebraic sum of the action artificially provoked and of the counteraction of the soil reacting. As indicated earlier the traction forces are beyond the normal traction forces applied to such members outside the earth, so much that if the same forces were applied to a wall element outside the earth and hence in the absence of the reaction force of the earth the concrete would fail.

It could be said in the main that, at the various depths of the diaphragm, in the stage of pre-inflection, the concrete accumulates internal tensions which can be later restored when the ground pressure actually occurs
in the stage of digging out and levelling, the complete concrete section being kept in a constant state of firm compression.

Since the diaphragm, when actually being pre-inflected, is still completely submerged in the ground, it is also possible to effect the said pre-inflection in such a manner as will summon the ground reaction from either side; this permits to obtain at the various depths of the diaphragm point by point, such internal tensions as may be pre-determined and such that, when added to those derived from the external pressure in the stage of excavation and digging out are contained within pre-determined values which are particularly within the safety limits of the concrete even though the force applied to the traction member acting by itself would have resulted in a stress greater than a wall of the same thickness and/or reinforcement could have withstood in the absence of the counterforce due to said ground reaction.

Finally, with the pre-inflection of the diaphragm, internal tensions are definitely pre-disposed in the concrete of opposed degree to those which will afterwards be caused by the active pressure appearing in the stage of excavation which, in the various stages, allows the concrete section to remain compressed and thus be completely reactive.

In order to obtain a diaphragm pre-inflected according to the present invention, it is necessary to arrive at a realisable idea which is based on the possibility of employing materials more distinguished for resistance by means of a method different from that which has hitherto been in use for diaphragms.

The study of a pre-inflected diaphragm according to the invention introduces the use, for the first time in the field of cast in situ concrete diaphragms, of steel of extreme strength, such as for example harmonic steel or other types of steel of special quality.

The reinforcement of traditional type are abolished and replaced by cables or rods of harmonic steel surrounded by protective sheaths.

These special steels in the form of rods or cables are inserted into the concrete with the employment of protective sheaths.

According to a first arrangement, these rods or cables are submerged in the concrete for a certain extent of their lower end portion only, so as to effect a firm attachment of their end in the concrete, which allows them to be subjected to traction starting from the upper portion of the diaphragm.

This arrangement can be effected either by inserting the cables or rods at the same time as the relevant sheaths before effecting the casting of concrete, or by inserting only the sheaths before the casting and then inserting the cables or rods inside the sheaths or casings after the concrete has set. In this second instance the lower ends of the cables or rods will be able to be fixed with cement injections or with suitable mechanical means, of a type known 'per se'.

On the other hand, a second arrangement envisages, at the base of the diaphragm, return means connected to the said protective casings, which allows the use of a length of cable in the shape of a loop, the two ends of which are taken to the top of the diaphragm and simultaneously subjected to traction.

This solution permits the cables to be recovered when they have ceased to be of use by unthreading them from the respective casings. This opportunity of recovery is, however, also obtainable by using the above-mentioned mechanical means of attachment, assuming that the latter are provided with suitable means of release.

These cables are arranged in the concrete in a particular shape, dictated by the conditions of pre-inflection which it is desired from time to time to obtain in the diaphragm; this arrangement is effected by means of special supports which allow the cables to be made to follow curved lines more or less sinuous, in order to meet the conditions of restraint of the diaphragms in the various stages of use.

These supports can be in the form of simple guide cages, very light, to which the said casings are attached according to the profile envisaged; these cages will be able to be formed in accordance with any known technique. Such supports can, however, be effected in the shape of proper metal reinforcements, to which also the said casings are fastened; this solution is especially preferred in the case when — as mentioned above — at least a partial recovery of the cables is envisaged, since in such instance this reinforcement is charged with the main function of support in static conditions of completed work.

The upper end portions of the cables or rod in harmonic steel are not only simply submerged in the concrete forming the diaphragm, as with the reinforcements at present in use, but are attached by special supports — for example collection heads or plates for the cables or rods — which allow at will their re-attachment with devices (hydraulic or of other types) for their tensioning; this operation can in its turn be carried out and varied at will following schemes dictated by the working conditions of the diaphragm.

According to the present invention it is actually possible to make gradual alterations in the flexures which are caused in the diaphragm, for which the method according to the invention can be regarded as providing an important versatility of operation in the various stages of digging out, and levelling in various conditions, during the time; this is precisely due to the power of resuming and altering the tensions in the cables.

In the final working conditions, when the structure which has been made commences its normal function, the rods or cables in harmonic steel of extreme strength can be permanently connected to the mass of concrete forming the diaphragm, by means of injections of mixtures of cement or of some other kind inside the said casings, thus achieving, on the one hand, the protection of the metal structures, and, on the other hand, the permanent static conditions for the functioning of the diaphragm. Or, as mentioned above, there will be opportunity for providing for the complete or partial unthreading of the cables.

BRIEF DESCRIPTION OF THE DRAWING

In the attached drawings a diaphragm according to the present invention is illustrated by way of example and not restrictively, together with the diagrammatic arrangement of a reinforcement in harmonic steel for the purpose of obtaining the pre-inflection:

FIG. 1 is a vertical diagrammatic section of the diaphragm;

FIGS. 2a and 2b are horizontal sections of the diaphragm, according to two different embodiments;

FIGS. 3a, 3b and 3c show some comparative diagrams of the unitary tensions in the concrete, in the various stages of stressing of the diaphragm.
DESCRIPTION OF THE PREFERRED EMBODIMENT

As mentioned, FIG. 1 shows in profile one possible form of diaphragm or wall, inserted vertically into the ground, starting from an elevation $Q$ and adapted to resist the horizontal soil pressure (direction $T$) at the moment when a digging out to the excavation elevation $S$ is effected. The concrete structure of the diaphragm $1$ incorporates a metal reinforcement formed substantially of a cage or support $2$, and of a series of traction cables $3$, arranged according to an appropriately studied shape. The cables $3$ are each contained inside a sheath or casing $4$ which allows them to slide even after the concrete has set; all the casings $4$ are attached to the cage $2$ in such a manner as to keep the cables $3$ following the course envisaged in the drawing office.

Through the lower attachments $5$, the cables $3$ are fixed to the bottom of the diaphragm; at the top, on the other hand, the cables $3$ are fastened by means of adjustable attachments $6$ which comprise means for gripping the ends of the cables $3$ and bringing them to traction, and means for locking the cables in a position corresponding to a specific value of the said traction.

The attachments $5$ can be realized, as mentioned above, according to various methods, for example with injections of cement, with mechanical blocking means, or with return means (see for example the return element $5'$ shown by the hatched line in FIG. 1).

The result of a traction exerted on a series of cables $3$ arranged as in FIG. 1 is a pre-inflection of the diaphragm expressed in a pressure in the direction of the arrow $P$ which — when the digging out and levelling of the bank on one side is concluded — co-operates in counter-balancing the thrust $T$.

FIG. 2a shows a sectional view of the diaphragm structure according to FIG. 1, in which the longitudinal spacing between the cables $3$ can be seen.

FIG. 2b shows the section of a different embodiment of the diaphragm, wherein successive T-sections are used; in this case, the cables $3$ are preferably arranged in the leg of the "T," so that a greater arm is available.

FIG. 3a shows a partial diagrammatic section of a diaphragm constructed according to the known technique, and this is flanked by diagram of the internal tensions which act on the structure at the conclusion of the digging out of the bank.

As illustrated, the neutral axis $7$ separates the portion of the concrete which is compressed and works correctly, from the portion of the concrete subjected to traction and in which the metal reinforcement $8$ consequently works alone.

In the case of the pre-inflected diaphragm according to the present invention, on the other hand, it can be arranged that the diagram of the internal tensions caused solely by the forces imposed through the cables $3$ is as indicated in $M_0$ (see FIG. 3b). $M'$ represents, on the other hand, the diagram of the tensions caused by that part of the soil pressure summoned by the flexure of the diaphragm. The combination of $M_0$ and $M'$ gives a diagram which clearly indicates that solely forces of compression are present in the structure.

At the instant when the excavation of the bank is completed, the full thrust of the ground occurs, which — in so far as being partially absorbed in the preceding stage — causes a pressure upon the structure, represented by the diagram $M''$. The combination of $M''$ with $M_0$ gives diagram $M_1$ which is inverted with regard to $M_0$, but which still shows the forces of compression along are present in the structure.

The combination of the diagrams $M'$ and $M''$ represents, on the contrary, the effect of the ground pressure in its entirety.

To reiterate, diagram $M_1$ is the actual diagram of stresses present in the concrete as soon as prestressing is applied, prior to any excavation, and it is the resultant of diagram $M_0$ (showing the stresses that would develop in the concrete if the prestressing was done above the ground, see page 10, line 16 "solely by the forces imposed through cables $3'$") and diagram $M'$ (showing the reaction of the earth due to the prestressing). Since building codes establish the allowable stresses to be used in the design of reinforced concrete, the bottom line of diagram $M_1$ shows the maximum allowable stresses used for design, the bottom line of diagram $M_0$ exceeds this limit by the bottom line of diagram $M'$. Thus, even though the force applied to the traction member acting by itself would have resulted in a stress in the wall greater than the same wall could have withstood in the absence of force due to the reaction of the earth. The earth, serving as a molding box, permits this force to be applied.

As soon as the excavation is carried out, diagram $M_1$ is modified by diagram $M''$ (due to the lateral pressure of the remaining earth volume, e.g., the one to be supported by the wall) and the resulting diagram is diagram $M_2$, in which the upper line shows, as in diagram $M_1$, the maximum allowable stresses in the concrete.

It is obvious that the scope of the present invention includes alterations in the thickness of the diaphragm, the interaxis or the type of the cables, the use of various resistant sections, but always incorporating the idea of pre-inflection; in fact, these alterations, which are connected with the static needs arising from various problems which face the designer, do not in any way exceed the range of variety which the invention permits.

In comparison with the traditional diaphragms, the method of construction of pre-inflected diaphragms according to the invention offers advantages:

- the resisting moment can be more than doubled without increasing the thickness of the diaphragm;
- the depth of excavation or digging out can be increased by more than 50 percent, still without increasing the thickness of the diaphragm;
- the diaphragm with special sections allow possibilities of strength and depth of excavation which are noticeably greater still;
- the possibility of increasing the maximum limits of excavation hitherto attained, given the greater rigidity of pre-inflected diaphragms;
- the elimination, with equality of depth of the excavation of internal or anchoring struts, thereby achieving easier builder's yard conditions;
- the reduction in the number of intermediate supports (props, tie rods and the like);
- the achievement of guaranteed impermeability of the concrete with the elimination of cracks, in so far as the traction stresses in the concrete itself are avoided; this results in an effective protection in aggressive surroundings;
- case of putting the reinforcements to work, given the reduced weight and their flexibility and manageability;
the possibility of inserting, into the excavation, reinforcements without a break in continuity, even for diaphragms of great depth, by using flexible cables which can be continuously inserted by unwinding them from rolls; this permits, furthermore, working in spaces which are small in height (for example working in cellars or generally in covered spaces) without particular difficulty;

the possibility of recovery and re-utilization of the pre-flexing cables.

What is claimed is:

1. A method for the construction of a concrete wall of a given thickness in a trench, said trench constituting a molding box for said wall and having two side faces which delimit two earth volumes, one of which will later be removed so that the wall will support the remaining earth volume, comprising the steps of:

- inserting a stressing member and a concrete admixture into said trench;
- allowing said concrete admixture to set and form said concrete wall of a given thickness;
- applying a force to said stressing member in a direction and magnitude so as to inflect said wall in the direction of one said side faces of said trench which force creates a counterforce of said one of said side faces against said concrete wall which counterforce permits a pre-stress to be induced in said wall to support said remaining volume of earth when one of said volumes of earth is removed while the force on said stressing member acting by itself would have resulted in a stress greater than a wall of said given thickness could have withstood in the absence of said counterforce.

2. The method of claim 1 including constructing a metal cage structured to serve as a permanent reinforcement for said concrete wall after said concrete has set, said stressing member being an elongated member having a diameter which is narrow compared to its length, positioning said stressing member on said cage so that it contacts said cage at specific points and does not contact said cage at other specific points so that said elongated stressing member assumes a predetermined curved profile shape and a concavity facing the earthen wall constituting the remaining earthen volume,

and the step of inserting a stressing member is constituted by inserting said cage and said stressing member in said trench so that one elongate end of the stressing member is located substantially at the bottom of the trench and the other elongate end of said stressing member is located substantially at the top of said trench to receive the force applied to said stressing member.

3. The method of claim 2 wherein said stressing member comprises a protective sheath for a cable having return means for said cable located near the bottom of said trench and wherein said cable is inserted in said protective sheath including said return means so that it is in the shape of a loop, the two ends of which are situated at the top of said sheath and the rounded portion of which is situated in said return means, whereby said cable can be unthreaded from said wall when its use in said wall is no longer required.

4. The method of claim 2 further including the step of digging an excavation adjacent to said wall to a predetermined depth after said stress has been introduced to said concrete wall and thereafter applying another force to said stressing member to introduce a different stress to said concrete wall.

5. In a method for constructing at least a portion of a horizontally elongated concrete wall in a fluid slurry filled trench having two opposing earthen side faces, each earthen face delimiting a lateral earth volume, a first earth volume being later removed so that said concrete wall will support the remaining second earth volume, comprising the steps of inserting a concrete mixture into the trench to displace said fluid slurry and to form said concrete wall in situ, said two side faces of the trench forming at least part of a molding box for said concrete so that the exterior surfaces of said concrete wall are in intimate contact with said earthen side faces, allowing said concrete to set, and removing said first earth volume so that said concrete wall will support the remaining earth volume, the improvement comprising the additional steps of:

- inserting a wall flexing means in said trench after excavation of said trench and prior to inserting said concrete mixture,
- applying a force to said wall flexing means in order to inflect said concrete wall against said second earth volume, said inflection causing said concrete wall to bear against a side face of the trench with a force creating a counterforce of said second earth volume against said concrete wall, the resultant of said force and counterforce producing a pre-stress in said concrete wall which can be withstood by said wall without failing only in the presence of said counterforce, said pre-stress and the force of said remaining earth volume on said wall resulting in a stress in the concrete which is substantially completely compressive when said first earth volume is removed.

6. In a relatively thin concrete retaining wall situated at a selected relatively large depth below the level of the ground and against one earthen side wall of an excavation for the purpose of supporting said earthen side wall of the excavation on removal of the earthen side wall parallel and opposite to said one earthen side wall, said concrete wall being comprised of a concrete body member cast in situ in said excavation prior to removal of said earthen side wall parallel to said one earthen side wall having located therein a metal reinforcement cage elongated along the length of said wall, the improvement comprising,

- a set of high tensile strength steel stressing members, each member comprised of an elongated cable housed in an elongated protective sheath or casing said sheath contacting said cage at specific points and not contacting said cage at other specific points, said sheath and said cable having a predetermined curved profile determined by the location of said specific points on said cage, said stressing members having a tensile force applied to them which results in a pre-inflection of said concrete body member in the direction of said one earthen side wall such that the concrete wall will have an initial internal stress which, in the absence of said earthen side walls, would be sufficient to cause said concrete wall to fail, and on the removal of said earthen side wall parallel and opposite to said one earthen side wall the tensile stresses in said concrete are substantially zero.
7. The invention defined in claim 6 wherein said concrete retaining wall includes a concrete section extending transversely to said wall and having a high moment of inertia, and wherein at least a portion of said stressing members are arranged in said transversely extending section so that a greater moment arm is available to apply a greater pre-inflecting force to said stressing members.